

Technical Report No. 245  
UPDATE OF US/IBP GRASSLAND BIOME  
LITERATURE: A KWIC INDEX AND ABSTRACTS\*

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GRASSLAND BIOME  
U.S. International Biological Program  
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\* A total of 479 articles are indexed herein while 168 articles are abstracted herein. The first 311 articles are abstracted in Technical Report No. 155.

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# ABSTRACT

A total of 479 articles originating from the efforts of the US/IBP Grassland Biome Program up to 1973 have been indexed in this report, and of these, the last 168 have been abstracted herein. This report must be used in conjunction with Technical Report No. 155 as the first 311 articles (up to 1971) are abstracted there. Indices include a KWIC index (Key Word In Context) and a SWIT index (Significant Word In Title). In all, 621 key words have been used. The key words were allotted to each article on the basis of its entire text. Instructions for the use of the indices are detailed in the report.

## INTRODUCTION

A significant amount of information has been generated by the US/IBP Grassland Biome Program since its inception in 1968. This information is scattered in the form of various kinds of reports like Progress Reports, Annual Reports, Technical Reports, publications in the Range Science Department Science Series, and Technical Journals. This makes the search for information on specific topics rather difficult. The desire was felt, therefore, to collect the abstracts of all the documents produced directly or indirectly through the efforts of this program under a single cover with a suitable index. This was done for the abstracts up to 1971 in Technical Report No. 155 and from 1971 to 1973 herein. All abstracts up to 1973 are indexed herein. This would not only facilitate the search for information by individual investigators participating in the program, but would also help in the synthesis and modeling efforts.

The following sources were selected for this purpose:

US/IBP Grassland Biome Technical Reports No. 1-235 (starts with Tech. Rep. No. 139 herein).  
Range Science Department Science Series No. 2, 3, 5, 6, 7, 10, 11, and 12 (starts with series no. 11 herein).  
Biome Proposal 1967 (in Tech. Rep. No. 155).  
Progress Reports and Continuation Proposals, 1969, 1970, 1971, 1973 (1973 only herein).  
Annual Reports prior to Technical Reports, 1969 (in Tech. Rep. No. 155).  
Open literature, up to 1973 (1971 to 1973 herein).

The existing abstracts of the documents were collected. Recent abstracts are reproduced in this report on p. 154.

In order to index the literature in a useful manner, it was decided to use certain key words which should be assigned to the article not only on the basis of its abstract, but on the basis of its entire text. It was also decided that the articles indexed under a particular key word should have one or more of the following items of information on the topic: Literature review, concept, parameters for state, and driving variables, or rate processes.

In evolving the list of key words, generous help was available from: David Coleman, James Ellis, John Marshall, Freeman Smith, David Swift, J. K. Lewis, George Innis, and George Van Dyne.

The list of key words used in this report is given on p. 2. The key words used for each article are included with the respective abstract. The KWIC Key Word In Context index thus evolved is presented on p. 7.

Another index (SWIT) based on Significant Word in Title only was also formulated and the same is Included on p. 101.

Computer programs for both indices were written by Robert D. Robinson. David Swift and Vicki Keith were responsible for updating the computerization of the indices, and Barbara Hendricks and Leila Menges coordinated the production of the manuscript.

### Instructions for Use of the Indexes:

1. Select the key word which best represents the subject you are interested in from the list of key words.
  2. Locate this key word in the left-hand column of the index. The key words are arranged alphabetically.
  3. See all the titles listed under this key word. Author's name and year of publication are also included along with each title.
  4. If the article(s) meets your requirement, note the reference from the right-hand column of the index.
- The symbols used in the reference are explained below:  
TR = US/IBP Grassland Biome Technical Report  
SS = Range Science Department Science Series  
BP = Biome Proposal (Tech. Rep. 155 only)  
PR = Progress Report and Continuation Proposal  
AR = Annual Reports prior to Technical Reports (Tech. Rep. 155 only)  
OL = Publications in open literature.

The Technical Reports (TR) are suffixed with No. 001 to 235. Technical Report 220 is followed by the page number of the chapter. The Science Series volumes (SS) are suffixed with their respective numbers, followed by the page numbers of the article. The supplement of Science Series No. 2 carries the code SS02S followed by the page numbers of the article. The Biome Proposal (BP) and the Progress Reports (PR) are suffixed with the year of publication, and in the latter case this is followed by the number or the volume and number (1973 Progress Report) of the pertinent section. The Annual Reports (AR) are suffixed with the year of publication (69), followed by the respective project number. Articles in the open literature (OL) are suffixed with simple numbers 001 to 092.

5. Once the reference for the selected article has been noted, turn to the section of abstracts and locate the abstract of the desired article with the help of this reference. The reference appears on the left-hand side of the citation for each abstract. One example is given below for each of the above categories included in this report:

| Key Word              | Article                                                                                   | Reference |
|-----------------------|-------------------------------------------------------------------------------------------|-----------|
| 1. Ecosystem model    | ELM: Version 1.0. (Anway, et al. 1972)                                                    | TR 156    |
| 2. Jackrabbit biomass | Diets and habitats of jackrabbits in northeastern Colorado. (Flinders and Hansen 1972)    | SS 12     |
| 3. Mammal checklist   | Mammals from southwestern North Dakota. (Genoways and Jones 1972)                         | OL051     |
| 4. Primary production | Analysis of structure, function, and utilization of grassland ecosystems. (Van Dyne 1973) | PR 73-II3 |

Abstracts for the above citations appear on pages 159, 186, 200, and 193, respectively.

The SWIT index also operates in a similar manner with the only exception that the left-hand column of this index contains significant words, pulled out of the title, instead of key words.

# LIST OF KEY WORDS

## Abiotic

|                          |                               |                                      |
|--------------------------|-------------------------------|--------------------------------------|
| Abiotic model            | Infiltration                  | Precipitation model                  |
| Air temperature          | Infiltration rate             | Profile development                  |
| Albedo                   | Instrumentation               | Reflectivity                         |
| Altitude                 | Interception                  | Runoff                               |
| Aridity index            | Irrigation                    | Snow                                 |
| Atmospheric water        | Latitude                      | Snow fence                           |
| Barometric pressure      | Light spectrum                | Soil aeration                        |
| Beta attenuation         | Lysimeter                     | Soil chemical characteristics        |
| Bulk density             | Mean particle size            | Soil depth                           |
| Climate                  | Meteorology                   | Soil heat flux                       |
| Cloud cover              | Microclimate                  | Soil movement                        |
| Compaction               | Microrelief                   | Soil nitrogen                        |
| CO <sub>2</sub> ambient  | Microwatersheds               | Soil physical characteristics        |
| CO <sub>2</sub> transfer | Mineralization                | Soil temperature                     |
| Energy balance           | Moisture index                | Soil types                           |
| Erosion                  | Moisture stress               | Soil water                           |
| Evaporation              | Net radiation                 | Soil water hierarchical diagram      |
| Evaporation model        | Nitrification                 | Solar radiation                      |
| Evapotranspiration       | Nitrogen                      | Solar radiation hierarchical diagram |
| Fertilization            | Nitrogen cycle                | Solum depth                          |
| Field capacity           | Nitrogen turnover             | Texture                              |
| Fire                     | Nutrient cycling              | Topography                           |
| Grassland climate        | Nutrient model                | Vapor pressure                       |
| Grassland soil           | Phosphorus model              | Water balance                        |
| Growing season           | Pond chemical characteristics | Water cycle                          |
| Heat balance             | Pond physical characteristics | Water potential                      |
| Heat model               | Ponds                         | Water storage                        |
| Heat transfer            | Potential evaporation         | Watershed                            |
| Hydrological cycle       | Potential evapotranspiration  | Wind                                 |
| Hydrology                | Precipitation                 |                                      |

## Producer

|                               |                               |                               |
|-------------------------------|-------------------------------|-------------------------------|
| Aboveground plant biomass     | Leaf area index               | Primary production            |
| Annual increment              | Leaf height                   | Producer hierarchical diagram |
| Anthesis                      | Leaf temperature              | Producer model                |
| Belowground plant biomass     | Litter                        | Remote sensing                |
| Biomass category relationship | Litter accumulation           | Respiration                   |
| Biomass family relationship   | Live dead root separation     | Respiration quotient          |
| Biomass mapping               | Longevity                     | Root annual increment         |
| Biomass meter                 | Mapping                       | Root respiration              |
| Blue grama                    | Needle leaf sedge             | Root soil separation          |
| Bluestem                      | Net photosynthesis            | Root turnover                 |
| Buffalo grass                 | Phenology                     | Scarlet globemallow           |
| C-3 pathway                   | Phenology model               | Seedling survival             |
| C-4 pathway                   | Photoproduct identification   | Shoot-root ratio              |
| Canopy resistance             | Photosynthesis                | Shortgrass                    |
| Carbon-14                     | Photosynthesis model          | Snakeweed                     |
| Carbon dioxide exchange       | Photosynthesis response curve | Species association           |
| Chlorophyll                   | Phytoplankton                 | Species diversity             |
| CO <sub>2</sub> compensation  | Phytoplankton checklist       | Spectroreflectance            |
| Community replacement         | Phytoplankton productivity    | Standing dead                 |
| Competition                   | Plant checklist               | Succession                    |
| Cool forb                     | Plant competition             | System transfer function      |
| Cool grass                    | Plant cover                   | Translocation                 |
| Cool shrub                    | Plant demography              | Transpiration                 |
| Cool succulent                | Plant diversity               | Vegetation mapping            |
| Cover                         | Plant energetics              | Vegetation structure          |
| Crown respiration             | Plant fragment identification | Vegetation types              |
| Dispersion                    | Plant growth                  | Warm forb                     |
| Ecotype                       | Plant growth model            | Warm grass                    |
| Efficiency energy capture     | Plant leachate                | Warm shrub                    |
| Energy flow                   | Plant live dead separation    | Warm succulent                |
| Grassland types               | Plant nutrients               | Water efficiency              |
| Grassland vegetation          | Plant nutrition               | Western wheatgrass            |
| Growth analysis               | Plant pattern                 | Wheat                         |
| Growth rate                   | Plant respiration             | Wheatgrass                    |
| Leaf area                     | Prickly pear                  | Yield                         |

# Consumer

Age structure  
Amphibian  
Amphibian checklist  
Amphibian ecology  
Amphibian population  
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## KWIC INDEX

### Key Word In Context

#### Instructions for Use of the Indexes

1. Select the key word which best represents the subject you are interested in from the list of key words.
2. Locate this key word in the left-hand column of the index. The key words are arranged alphabetically.
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5. Once the reference for the selected article has been noted, turn to the section of abstracts and locate the abstract of the desired article with the help of this reference. The reference appears on the left-hand side of the citation for each abstract.

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ABIOTIC-MODEL

ABOVEGROUND-PLANT-BIOMASS

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(LAUFROTH AND SIMS 1973)

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REMOTE SPECTRAL MEASUREMENTS AS A METHOD FOR DETERMINING PLANT COVER.  
(PEARSON AND MILLER 1972)

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SMALL MAMMAL STUDIES ON THE PANNEE SITE DURING THE 1971 FIELD SEASON. (GRANT 1972)

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PRIMARY PRODUCTIVITY OF THE FESCUE GRASSLAND IN WESTERN MONTANA.  
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SOIL NUTRIENT-PLANT NUTRIENT RELATIONSHIPS AT THE PANNEE SITE. (DITTBARNER 1971)

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## ARTICLE

## REFERENCE

- ABOVEGROUND-PLANT-BIOMASS  
 ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-2.6. (VAN DYNE 1971) PR71-2.6
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SMCUMHJMS -

SYSTEM-HYPOTHESES

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1300M-MODEL

CONCURRENCE MODE:

ECOSYSTEM-MODEL

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CO SYSTEM-MODEL

SYSTEM-MODEL

CO SYSTEM-MODEL

SYSTEM-MODEL  
SYSTEM-MODEL

SSJALS-WELSYOO

CONFIDENTIAL

100

## CO-SYSTEM-STRESS

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**FICIENCY-ENERGY.**

## FICIENCY-ENERGY

**EFFICIENCY-ENERGY**

## RESULTS

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## LIVE-DEAD-ROOT-SEPARATION

LIZARD

LIZARD-BIOMASS

LIZARD-DENSITY

LONGEVITY

LYSIMETER

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SNAKES AND LIZARDS OF THE PAWNEE SITE. (BAUERLE 1971)

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TR187

AR69-2562.3

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OL051

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KEY-WORD

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| POND-PHYSICAL-CHARACTERISTICS | A PRELIMINARY STUDY OF THREE LENTIC COMMUNITIES ON THE PAWNEE NATIONAL GRASSLANDS. (LAVELLE, ET. AL. 1969)                                             |               |

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| POND-PHYSICAL-CHARACTERISTICS | PHYSICAL AND CHEMICAL LIMNOLOGY OF COTTONWOOD POND AND SPRING POND (SEPT. 1969--DEC. 1970). (HERRMANN 1971)                   | TR071        |
| POND-PHYSICAL-CHARACTERISTICS | AQUATIC PRIMARY PRODUCTIVITY AND PHYSICAL-CHEMICAL LIMNOLOGY ON THE PANNEE SITE. (HERRMANN, ET. AL. 1970)                     | TR049        |
| PONDS                         | PHYSICAL AND CHEMICAL LIMNOLOGY OF COTTONWOOD POND AND SPRING POND (SEPT. 1969--DEC. 1970). (HERRMANN 1971)                   | TR071        |
| PONDUS                        | AQUATIC PRIMARY PRODUCTIVITY AND PHYSICAL-CHEMICAL LIMNOLOGY ON THE PANNEE SITE. (HERRMANN, ET. AL. 1970)                     | TR049        |
| PONDUS                        | A PRELIMINARY STUDY OF THREE LENTIC COMMUNITIES ON THE PANNEE NATIONAL GRASSLANDS. (LAVELLE, ET. AL. 1969)                    | SS02-308-315 |
| PONDUS                        | A PRELIMINARY STUDY OF LENTIC COMMUNITIES ON THE PANNEE NATIONAL GRASSLANDS. (LAVELLE, ET. AL. 1969)                          | AR69-2581-82 |
| POTENTIAL-EVAPORATION         | RESULTS OF WORKSHOP GROUPS. (WRIGHT AND VAN DYNE 1970)                                                                        | SS0611-1-69  |
| POTENTIAL-EVAPOTRANSPIRATION  | ABIOTIC FACTORS IN GRASSLAND ECOSYSTEM ANALYSIS AND FUNCTION. (RASMUSSEN 1971)                                                | SS10-11-34   |
| POTENTIAL-EVAPOTRANSPIRATION  | HYDROLOGY AND WATER-BALANCE OF SEMI-DESERT SOILS. (COOPER 1970)                                                               | SS061119-128 |
| POTENTIAL-EVAPOTRANSPIRATION  | HERBAGE DYNAMICS AND NET PRIMARY PRODUCTION IN CERTAIN UNGRAZED AND GRAZED GRASSLANDS IN NORTH AMERICA. (SIMS AND SINGH 1971) | SS10-59-124  |
| POTENTIAL-EVAPOTRANSPIRATION  | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1971)                                                | SS10-317-387 |
| POTENTIAL-EVAPOTRANSPIRATION  | METEOROLOGICAL CHARACTERISTICS OVER THE GRASSLAND BIOME'S PANNEE SITE. (NUNN 1973)                                            | TR216        |
| POTENTIAL-EVAPOTRANSPIRATION  | EFFECTS OF ENVIRONMENTAL STRESSES ON A SHORTGRASS PRAIRIE ECOSYSTEM, 1970 AND 1971. (LAUENKOTH AND SIMS 1973)                 | TR209        |
| PRECIPITATION                 | SURFACE ENERGY AND WATER BUDGET OVER THE GRASSLAND, 1970. (ALMEYDA AND RASMUSSEN 1972)                                        | TR202        |
| PRECIPITATION                 | VEGETATIONAL STUDIES ON THE ALE RESERVE, 1971. (RICKARD, ET AL. 1972)                                                         | TR191        |
| PRECIPITATION                 | BREEDING BIOLOGY OF THE MOUNTAIN-PLOVER (CHARADRIUS MONTANUS), 1969-1972. (GRAUL 1972)                                        | TR199        |
| PRECIPITATION                 | HYDROLOGIC DATA AT PANNEE SITE, 1971. (STRIFFLER 1972)                                                                        | TR196        |
| PRECIPITATION                 | HERBAGE DYNAMICS ON A MIXED PRAIRIE GRASSLAND, 1968-1970. (HULETT AND TOMANEK 1972)                                           | TR189        |
| PRECIPITATION                 | PRIMARY PRODUCERS, INVERTEBRATES, BIRDS, AND DECOMPOSERS ON THE JORNADA SITE, 1971. (PIEPER, ET AL. 1972)                     | TR200        |
| PRECIPITATION                 | HERBAGE DYNAMICS STUDIES AT THE PANTEX SITE, 1971. (FAGAN AND PETIT 1972)                                                     | TR193        |
| PRECIPITATION                 | SUPPLEMENTAL REPORT ON PRIMARY PRODUCTIVITY AND ABIOTIC STUDIES AT THE DICKINSON SITE : 1970 SEASON. (WHITMAN 1972)           | TR190        |
| PRECIPITATION                 | GRASSLAND BIOME STUDIES AT THE BRIDGER SITE, 1971. (COLLINS AND WEAVER 1972)                                                  | TR198        |
| PRECIPITATION                 | DEVELOPMENT OF A LARGE, UNDISTURBED WEIGHING LYSIMETER FOR EVAPOTRANSPIRATION STUDIES ON GRASSLAND. (ARMJO 1972)              | TR165        |
| PRECIPITATION                 | PREDICTABILITY OF PATTERNS AND VARIABILITY OF PRECIPITATION IN GRASSLANDS. (WIENS 1972)                                       | TR168        |
| PRECIPITATION                 | LEAF AREA DYNAMICS ON THE PANNEE GRASSLAND, 1970-1971. (KNIGHT 1972)                                                          | TR164        |
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| PRECIPITATION                 | GROWTH RESPONSE OF BLUE GRAMA TO THUNDERSTORM RAINFALL. (SMITH 1972)                                                          | TR157        |
| PRECIPITATION                 | PRELIMINARY PRODUCER DATA SYNTHESIS, 1970 COMPREHENSIVE SITES. (RISSEY 1972)                                                  | TR161        |
| PRECIPITATION                 | THE GRASSLAND HYDROLOGIC CYCLE. (STRIFFLER 1969)                                                                              | SS02-101-116 |
| PRECIPITATION                 | THE IMPACT OF DOMESTIC ANIMALS ON THE FUNCTION AND STRUCTURE OF GRASSLAND ECOSYSTEMS. (HYDER 1969)                            | SS02-243-260 |
| PRECIPITATION                 | MACROCLIMATE AND THE GRASSLAND ECOSYSTEM. (COLLINS 1969)                                                                      | SS02-29-39   |
| PRECIPITATION                 | METEOROLOGICAL DATA ANALYSIS, 1972. (NUNN AND BECKER 1973)                                                                    | TR226        |
| PRECIPITATION                 | DYNAMICS OF THE ATMOSPHERE IN THE GRASSLAND ECOSYSTEM. (POCHOP 1969)                                                          | SS02-89-100  |
| PRECIPITATION                 | HYDROLOGIC DATA, 1970, PANNEE GRASSLANDS. (STRIFFLER 1971)                                                                    | TR075        |
| PRECIPITATION                 | OSAGE SITE, 1970 REPORT, PRIMARY PRODUCTION. (RISSEY 1971)                                                                    | TR080        |
| PRECIPITATION                 | GROWING SEASON PRECIPITATION RECORDS, CENTRAL PLAINS EXPERIMENTAL RANGE A.R.S., NUNN, COLORADO. (SMITH 1971)                  | TR074        |
| PRECIPITATION                 | PRELIMINARY REPORT ON THE STUDY OF THE PRECIPITATION ON THE PANNEE NATIONAL GRASSLAND. (BERTOLIN AND RASMUSSEN 1969)          | TR017        |
| PRECIPITATION                 | ABIOTIC AND HERBAGE DYNAMICS STUDIES ON THE COTTONWOOD SITE, 1970. (LEWIS, ET. AL. 1971)                                      | TR111        |
| PRECIPITATION                 | PRIMARY PRODUCTIVITY AND ABIOTIC STUDIES AT THE DICKINSON SITE, 1970 SEASON. (WHITMAN 1971)                                   | TR116        |

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| PRECIPITATION       | GRASSLAND CLIMATOLOGY OF THE PANWEE GRASSLAND. (RASMUSSEN, ET. AL. 1971)                                                              | TR127         |
| PRECIPITATION       | PRIMARY PRODUCTIVITY OF THE FESCUE GRASSLAND IN WESTERN MONTANA. (MORRIS AND BRUNNER 1971)                                            | TR113         |
| PRECIPITATION       | HERBAGE DYNAMICS ON A MIXED PRAIRIE GRASSLAND NEAR HAYS, KANSAS. (HULETT AND TOMANEK 1971)                                            | TR108         |
| PRECIPITATION       | MULTIVARIATE NORMAL DATA GENERATOR. (BLEDSOE AND GUSTAFSON 1971)                                                                      | TR092         |
| PRECIPITATION       | AN ECOLOGICAL STUDY OF RODENTS IN A SHORTGRASS PRAIRIE OF NORTHEASTERN COLORADO. (FLAKE 1971)                                         | TR100         |
| PRECIPITATION       | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1971)                                                        | SS10,317-387  |
| PRECIPITATION       | AN ECOLOGICAL DESCRIPTION OF A SEMI-ARID EAST AFRICAN ECOSYSTEM. (HARRIS 1972)                                                        | SS11          |
| PRECIPITATION       | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-2.5. (VAN DYNE 1971)                    | PR71-2.5      |
| PRECIPITATION       | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-2.5. (VAN DYNE 1970)                                 | PR70-2.5      |
| PRECIPITATION       | HERBAGE DYNAMICS AND NET PRIMARY PRODUCTION IN CERTAIN UNGRAZED AND GRAZED GRASSLANDS IN NORTH AMERICA. (SIMS AND SINGH 1971)         | SS10,59-124   |
| PRECIPITATION       | SOME ASPECTS OF THE ECOLOGICAL CLIMATOLOGY OF THE JORNADA EXPERIMENTAL RANGE NEW-MEXICO. (BRYSON, ET. AL. 1970)                       | SS061,2-74    |
| PRECIPITATION       | A QUANTITATIVE ECOLOGY OF THE JORNADA EXPERIMENTAL RANGE. (HERBEL, ET. AL. 1970)                                                      | SS061,133-177 |
| PRECIPITATION       | RESULTS OF WORKSHOP GROUPS. (WRIGHT AND VAN DYNE 1970)                                                                                | SS061,1-69    |
| PRECIPITATION       | ABIOTIC FACTORS IN GRASSLAND ECOSYSTEM ANALYSIS AND FUNCTION. (RASMUSSEN 1971)                                                        | SS10,11-34    |
| PRECIPITATION       | LEAF AREA DYNAMICS OF A SHORTGRASS PRAIRIE IN COLORADO. (KNIGHT 1973)                                                                 | OL082         |
| PRECIPITATION       | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                             | PR73-112      |
| PRECIPITATION       | PRELIMINARY REPORT ON THE STUDY OF THE CLIMATOLOGY OF THE PANWEE NATIONAL GRASSLAND. (BERTOLIN AND RASMUSSEN 1969)                    | AR69-2532.1   |
| PRECIPITATION       | METEOROLOGICAL CHARACTERISTICS OF HEAVILY AND LIGHTLY GRAZED NATURAL GRASS RANGE LAND. (NUNN, ET. AL. 1971)                           | OL015         |
| PRECIPITATION-MODEL | SOME ASPECTS OF THE ECOLOGICAL CLIMATOLOGY OF THE JORNADA EXPERIMENTAL RANGE NEW-MEXICO. (BRYSON, ET. AL. 1970)                       | SS061,2-74    |
| PREDATION           | PATTERN AND PROCESS IN GRASSLAND BIRD COMMUNITIES. (WIENS 1971)                                                                       | SS10,147-212  |
| PREDATION           | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1971)                                                        | SS10,317-387  |
| PREDATION           | THE ROLE OF INVERTEBRATES IN THE GRASSLAND BIOME. (MCDANIEL 1971)                                                                     | SS10,267-315  |
| PREDATION           | ETHOLOGY OF ABALUTUS KUFOFIBIALIS ON THE PANWEE GRASSLANDS IBP SITE. (LAVIGNE 1972)                                                   | OL047         |
| PREDATION           | PATTERN AND PROCESS IN GRASSLAND BIRD COMMUNITIES. (WIENS, 1973)                                                                      | OL062         |
| PREDATION           | SUMMER ECOLOGY OF THE LARK-BUNTING IN NORTH-CENTRAL COLORADO. (CREIGHTON 1969)                                                        | AR69-2563.1   |
| PREDATION           | THE EFFECT OF INSECT PREDATORS AND PARASITES ON GRASS FEEDING INSECTS. (LAVIGNE 1969)                                                 | AR69-2564.3   |
| PREDATION           | DATA COLLECTED ON THE PANWEE SITE RELATING TO WESTERN HARVESTER ANT AND INSECT PREDATORS AND PARASITES, 1970. (LAVIGNE, ET. AL. 1971) | TR107         |
| PREDATION           | A PRELIMINARY MODEL FOR CONSUMER PREDATION. (HARRIS AND SWARTZMAN 1971)                                                               | TR119         |
| PREDATION           | SOME COMPARISONS OF FEEDING ECOLOGY OF FOUR SPECIES OF OWLS IN NORTH-CENTRAL COLORADO. (MARTI 1969)                                   | TR027         |
| PREDATION           | SUMMER ECOLOGY OF THE LARK-BUNTING, PANWEE SITE. (BALDWIN, ET. AL. 1969)                                                              | TR029         |
| PREDATION           | EFFECT OF INSECT PREDATORS AND PARASITES ON GRASS FEEDING INSECTS, PANWEE SITE. (LAVIGNE AND ROGERS 1970)                             | TR020         |
| PREDATION           | THE FUNCTION OF SOIL FAUNA IN GRASSLAND ECOSYSTEMS. (PARIS 1969)                                                                      | SS02,331-360  |
| PREDATION           | BREEDING BIOLOGY OF THE MOUNTAIN-PIPER (CHARADRIUS MONTANUS), 1969-1972. (GRAUL 1972)                                                 | TR199         |
| PREDATION           | FEEDING ECOLOGY AND NESTING BEHAVIOR OF GRASSLAND BIRDS AT THE PANWEE SITE, 1971. (BALDWIN AND CREIGHTON 1972)                        | TR185         |
| PREDATION           | THE ECOLOGY OF THE NESTING BIRDS OF PREY OF NORTHEASTERN COLORADO. (OLENDORFF 1973)                                                   | TR211         |
| PREDATION           | HERBAGE DYNAMICS STUDIES AT THE PANTEX SITE, 1971. (FAGAN AND PETTIT 1972)                                                            | TR193         |
| PRICKLY-PEAR        | LEAF AREA DYNAMICS ON THE PANWEE GRASSLAND, 1970-1971. (KNIGHT 1972)                                                                  | TR164         |
| PRICKLY-PEAR        | PRELIMINARY REPORT OF METHODOLOGY AND RESULTS FOR ANALYSIS OF PLANT PATTERN SUBPROJECT RESEARCH ON THE PANWEE SITE. (FISHER 1969)     | TR009         |

## KEY-WORD

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| PRICKLY-PEAR                  | SPATIAL DISTRIBUTION AND SUCCESSIONAL STATE OF GRASSLAND VEGETATION RELATED TO GRAZING INTENSITY TREATMENTS. (MITCHELL 1971)                                                                            | TR101         |
| PRICKLY-PEAR                  | HERBAGE DYNAMICS ON THE PAWNEE SITE: ABOVEGROUND AND BELOWGROUND HERBAGE DYNAMICS ON THE FOUR GRAZING INTENSITY TREATMENTS; AND PRELIMINARY SAMPLING ON THE ECOSYSTEM STRASS SITE. (SIMS, ET. AL. 1971) | TR099         |
| PRICKLY-PEAR                  | ANALYSIS OF PLANT PATTERN, DISTRIBUTION AND RELATIONSHIP TO ENVIRONMENTAL PROCESSES. (FISHER AND LESHER 1969)                                                                                           | AR69-2553.1   |
| PRICKLY-PEAR                  | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-2.5. (VAN DYNE 1971)                                                                                      | PR71-2.5      |
| PRICKLY-PEAR                  | OPUNTIA CLUMP SIZE VARIATION ON THE SHORTGRASS PLAINS, PAWNEE SITE, NUNN, COLORADO. (LESTER AND FISHER 1970)                                                                                            | OL014         |
| PRICKLY-PEAR                  | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-2.4. (VAN DYNE 1971)                                                                                      | PR71-2.4      |
| PRICKLY-PEAR                  | LEAF AREA DYNAMICS OF A SHORTGRASS PRAIRIE IN COLORADO. (KNIGHT 1973)                                                                                                                                   | OL082         |
| PRICKLY-PEAR                  | LEAF AREA DYNAMICS OF A SHORTGRASS PRAIRIE IN COLORADO. (KNIGHT 1973)                                                                                                                                   | OL082         |
| PRIMARY-PRODUCTION            | AN ECOLOGICAL DESCRIPTION OF A SEMI-ARID EAST AFRICAN ECOSYSTEM. (HARRIS 1972)                                                                                                                          | SS11          |
| PRIMARY-PRODUCTION            | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1971)                                                                                                                          | SS10.317-387  |
| PRIMARY-PRODUCTION            | HERBAGE DYNAMICS AND NET PRIMARY PRODUCTION IN CERTAIN UNGRAZED AND GRAZED GRASSLANDS IN NORTH AMERICA. (SIMS AND SINGH 1971)                                                                           | SS10.59-124   |
| PRIMARY-PRODUCTION            | SOME ASPECTS OF THE ECOLOGICAL CLIMATOLOGY OF THE JORNADA EXPERIMENTAL RANGE NEW-MEXICO. (BRYSON, ET. AL. 1970)                                                                                         | SS061.2-74    |
| PRIMARY-PRODUCTION            | MODELS OF SEASONAL PRIMARY PRODUCTIVITY IN EASTERN TENNESSEE FESTUCA AND ANDROPOGON ECOSYSTEMS. (KELLY, ET. AL. 1969)                                                                                   | OL028         |
| PRIMARY-PRODUCTION            | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | PR73-113      |
| PRIMARY-PRODUCTION            | ABIOTIC AND HERBAGE DYNAMICS STUDIES ON THE COTTONWOOD SITE, 1970. (LEWIS, ET. AL. 1971)                                                                                                                | TR111         |
| PRIMARY-PRODUCTION            | PRIMARY PRODUCTIVITY OF THE FESCUE GRASSLAND IN WESTERN MONTANA. (MORRIS AND BRUNNER 1971)                                                                                                              | TR113         |
| PRIMARY-PRODUCTION            | REPLACEMENT OF NATIVE PLANT COMMUNITIES WITH INTRODUCED COMMUNITIES AND ITS IMPACT ON ECOSYSTEM FUNCTION. (EVERSON 1969)                                                                                | SS025241.1-87 |
| PRIMARY-PRODUCTION            | PROBLEMS IN MEASURING GRASSLAND PRODUCTIVITY. (JAMESON 1970)                                                                                                                                            | SS02.261-267  |
| PRIMARY-PRODUCTION            | EFFECTS OF WATER AND NITROGEN STRESSES ON A SHORTGRASS PRAIRIE ECOSYSTEM. (LAUENROTH AND SIMS 1973)                                                                                                     | SS07.58       |
| PRIMARY-PRODUCTION            | LEAF AREA DYNAMICS ON THE PAWNEE GRASSLAND, 1970-1971. (KNIGHT 1972)                                                                                                                                    | TR232         |
| PRIMARY-PRODUCTION            | PRELIMINARY PRODUCER DATA SYNTHESIS, 1970 COMPREHENSIVE SITES. (HISSEY 1972)                                                                                                                            | TR164         |
| PRIMARY-PRODUCTION            | SUPPLEMENTAL REPORT ON PRIMARY PRODUCTIVITY AND ABIOTIC STUDIES AT THE DICKINSON SITE : 1970 SEASON. (WHITMAN 1972)                                                                                     | TR161         |
| PRIMARY-PRODUCTION            | GRASSLAND BIOME STUDIES AT THE BRIDGER SITE, 1971. (COLLINS AND WEAVER 1972)                                                                                                                            | TR190         |
| PRIMARY-PRODUCTION            | HERBAGE DYNAMICS ON A MIXED PRAIRIE GRASSLAND, 1968-1970. (HULETT AND TOMANEK 1972)                                                                                                                     | TR198         |
| PRIMARY-PRODUCTION            | VEGETATIONAL STUDIES ON THE ALE RESERVE, 1971. (RICKARD, ET AL. 1972)                                                                                                                                   | TR189         |
| PRINCIPAL-COMPONENT-ANALYSIS  | STATISTICAL ANALYSIS OF INTRASEASONAL HERBAGE DYNAMICS IN A VARIETY OF GRASSLAND COMMUNITIES. (FRANCIS AND CAMPION 1972)                                                                                | TR191         |
| PRINCIPAL-COMPONENT-ANALYSIS  | HERBAGE DYNAMICS AND NET PRIMARY PRODUCTION IN CERTAIN UNGRAZED AND GRAZED GRASSLANDS IN NORTH AMERICA. (SIMS AND SINGH 1971)                                                                           | TR141         |
| PRINCIPAL-COMPONENT-ANALYSIS  | THE ROLE OF INVERTEBRATES IN THE GRASSLAND BIOME. (MCDANIEL 1971)                                                                                                                                       | SS10.59-124   |
| PRINCIPAL-COMPONENT-ANALYSIS  | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1971)                                                                                                                          | SS10.267-315  |
| PRODUCER-HIERARCHICAL-DIAGRAM | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-2.4. (VAN DYNE 1970)                                                                                                   | SS10.317-387  |
| PRODUCER-MODEL                | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-8.51 (VAN DYNE 1969)                                                                                                   | PR70-2.4      |
| PRODUCER-MODEL                | EXAMPLES OF TROPHIC LEVEL AND TOTAL ECOSYSTEM MODELS. (VAN DYNE 1970)                                                                                                                                   | PR69-8.51     |
| PRODUCER-MODEL                | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | SS07.191-198  |
| PRODUCER-MODEL                | A COMPARTMENT MODEL SIMULATION OF SECONDARY SUCCESSION. (BLEDSOE AND VAN DYNE 1971)                                                                                                                     | PR73-113      |
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## REFERENCE

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| PRODUCERS           | THE FUNCTION OF SOIL FAUNA IN GRASSLAND ECOSYSTEMS. (PARIS 1969)                                                                                                                     | SS02,331-360  |
| REEDRUCK            | AN ECOLOGICAL DESCRIPTION OF A SEMI-ARID EAST AFRICAN ECOSYSTEM. (HARRIS 1972)                                                                                                       | SS11          |
| REFLECTIVITY        | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-2-5. (VAN DYNE 1971)                                                                   | PR71-2-5      |
| REFLECTIVITY        | PRODUCER FUNCTION ON THE INTENSIVE AND COMPREHENSIVE SITES. (WILLIAMS 1971)                                                                                                          | SS10,125-132  |
| REFLECTIVITY        | THE MEASUREMENT OF PERCENT OF FUNCTIONING VEGETATION IN GRASSLAND AREAS. (MILLER 1969)                                                                                               | AR69-2520     |
| REFLECTIVITY        | MEASUREMENT OF THE COMBINED-EFFECT OF GREEN BIOMASS, CHLOROPHYLL, AND LEAF WATER ON C ANOPY SPECTROREFLECTANCE OF THE SHORTGRASS PRAIRIE. (TUCKER, ET.AL. 1973)                      | OL066         |
| REFLECTIVITY        | AERIAL MAPPING PROGRAM OF THE IBP GRASSLAND BIOME: REMOTE SENSING OF THE PRODUCTIVITY OF THE SHORTGRASS PRAIRIE AS INPUT INTO BIOSYSTEM MODELS. (MILLER AND PEARSON 1971)            | OL079         |
| REFLECTIVITY        | DESIGN OF A FIELD SPECTROPHOTOMETER LAB. (PEARSON AND MILLER 1971)                                                                                                                   | OL016         |
| REFLECTIVITY        | REMOTE MAPPING OF STANDING CROP BIOMASS FOR ESTIMATION OF THE PRODUCTIVITY OF THE SHO RTGRASS PRAIRIE, PANNEE NATIONAL GRASSLANDS, COLORADO. (PEARSON AND MILLER 1972)               | OL048         |
| REFLECTIVITY        | SOME INFLUENCES OF VEGETATION STRUCTURE ON ENERGY-FLUX, WATER-FLUX, AND NUTRIENT-FLUX IN GRASSLAND ECOSYSTEMS. (KNIGHT 1969)                                                         | SS02,197-220  |
| REFLECTIVITY        | METEOROLOGICAL DATA ANALYSIS, 1972. (NUNN AND BECKER 1973)                                                                                                                           | TR226         |
| REFLECTIVITY        | A FIELD LIGHT-QUALITY LABORATORY--INITIAL EXPERIMENT: TBS MEASUREMENT OF PERCENT OF FUNCTIONING VEGETATION IN GRASSLAND AREAS BY REMOTE SENSING METHODOLOGY. (PEARSON, ET. AL. 1971) | TR090         |
| REFLECTIVITY        | REMOTE SPECTRAL MEASUREMENTS AS A METHOD FOR DETERMINING PLANT COVER. (PEARSON AND MILLER 1972)                                                                                      | TR167         |
| REFLECTIVITY        | DESIGN OF FIELD SPECTROPHOTOMETER LAB. (PEARSON AND MILLER 1971)                                                                                                                     | TR133         |
| REFLECTIVITY        | PSYCHROMETRY IN WATER RELATIONS RESEARCH: A REVIEW. (VAN HAVEREN 1971)                                                                                                               | TR132         |
| REFLECTIVITY        | MAPPING STANDING CROP BIOMASS BY COMPUTER PROCESSING OF AERIAL MULTISPECTRAL IMAGERY. (PEARSON AND MILLER 1973)                                                                      | TR214         |
| REMOTE-SENSING      | REMOTE MAPPING OF STANDING CROP BIOMASS FOR ESTIMATION OF THE PRODUCTIVITY OF THE SHO RTGRASS PRAIRIE, PANNEE NATIONAL GRASSLANDS, COLORADO. (PEARSON AND MILLER 1972)               | OL048         |
| REPRODUCTION        | RENESTING BY BARN OWLS AND GREAT HORNED OWLS. (MARTI 1969)                                                                                                                           | OL030         |
| REPRODUCTION        | PATTERN AND PROCESS IN GRASSLAND BIRD COMMUNITIES. (WIENS, 1973)                                                                                                                     | OL062         |
| REPRODUCTION        | MAMMALS FROM SOUTHWESTERN NORTH DAKOTA. (GENOWAYS AND JONES 1972)                                                                                                                    | OL051         |
| REPRODUCTION        | SUMMER ECOLOGY OF THE LARK-BUNTING IN NORTH-CENTRAL COLORADO. (CREIGHTON 1969)                                                                                                       | AK69-2563.1   |
| REPRODUCTION        | PATTERN AND PROCESS IN GRASSLAND BIRD COMMUNITIES. (WIENS 1971)                                                                                                                      | SS10,147-212  |
| REPRODUCTION        | AN ECOLOGICAL STUDY OF RODENTS IN A SHORTGRASS PRAIRIE OF NORTHEASTERN COLORADO. (FLAKE 1971)                                                                                        | TR100         |
| REPRODUCTION        | AVIAN PRODUCTIVITY ON THE PANNEE SITE IN NORTH-CENTRAL COLORADO. (STRONG AND RYDER 1971)                                                                                             | TR082         |
| REPTILE-BIOMASS     | SNAKES AND LIZARDS OF THE PANNEE SITE. (BAUERLE 1971)                                                                                                                                | TR120         |
| REPTILE-BIOMASS     | BIOLOGICAL PRODUCTIVITY OF SNAKES OF THE PANNEE SITE, 1970-1971. (BAUERLE 1972)                                                                                                      | TR207         |
| REPTILE-CHECKLIST   | COMPREHENSIVE NETWORK SITE DESCRIPTION, COTTONWOOD. (LEWIS 1970)                                                                                                                     | TR039         |
| REPTILE-CHECKLIST   | THE IMPORTANCE AND ROLE OF AMPHIBIANS AND REPTILES IN GRASSLAND ECOSYSTEMS. (THOMAS 1970)                                                                                            | SS02S307,1-23 |
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| SNAKE            | ENVIRONMENTAL POLLUTANTS IN TWO SPECIES OF SNAKES FROM THE PANNEE SITE.                                                       |             |
| SNAKE            | (BAUERLE AND SPENCER 1971)                                                                                                    |             |
| SNAKE            | BIOLOGICAL PRODUCTIVITY OF SNAKES OF THE PANNEE SITE, 1970-1971. (BAUERLE 1972)                                               |             |

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| Snake-Energy-Flow             | Biological productivity of snakes of the Pawnee site, 1970-1971. (Bauerle 1972)                                                              | TR207        |
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| Soil-Aeration                 | Physical properties of grassland soils and their influence on primary productivity. (Hemmlinger 1969)                                        | TR224        |
| Soil-ATP                      | Adenosine triphosphate (ATP) in grassland soil: its relationship to microbial biomass and activity. (Sparrow and Duxader 1973)               | SS10,133-146 |
| Soil-ATP                      | Decomposer and nitrogen cycling investigations in the grassland biome. (Duxader 1969)                                                        | SS07,107-108 |
| Soil-ATP                      | Biomass determinations of soil microorganisms. (Duxader 1970)                                                                                | AR69-2572.1  |
| Soil-ATP                      | Microbial biomass measurements at the Pawnee site, preliminary methodology and result S. (Duxader 1969)                                      | PR73-114     |
| Soil-ATP                      | Analysis of structure, function, and utilization of grassland ecosystems. (Van Dyne 1973)                                                    | OL005        |
| Soil-Biochemistry             | The microflora of grassland. (Clark and Paul 1970)                                                                                           | TR110        |
| Soil-Biochemistry             | Microbial decomposer activities at the Pawnee site: integration of experimental approaches with program modelling requirements. (Klein 1971) | TR122        |
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| Soil-Chemical-Characteristics | Soil microfungi investigations, Pawnee site. (Christensen, Scarborough 1969)                                                                 | SS02,71-88   |
| Soil-Chemical-Characteristics | Soil chemistry as a factor in the function of grassland ecosystems. (Kline 1969)                                                             | SS02,117-123 |
| Soil-Chemical-Characteristics | The role of abiotic factors in the structure and function of the grassland ecosystem. (Hurlaff 1969)                                         | TR213        |
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| Soil-Chemical-Characteristics | The ecological effects of the western harvester ant (Pogonomyrmex occidentalis) in the shortgrass plains ecosystem. (Rogers 1972)            | SS10,35-40   |
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| Soil-Chemical-Characteristics | An ecological description of a semi-arid east African ecosystem. (Harris 1972)                                                               | SS10,35-40   |
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| Soil-Fauna                    | Soil macroarthropod species and their distribution and abundance in the grassland biome. (Lloyd 1969)                                        | PR73-114     |
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| SOIL-WATER       | SOIL WATER STUDY OF A SHORTGRASS PRAIRIE ECOSYSTEM, PANNEE SITE. (GALBRAITH 1969)                                                  | TR086         |
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| SOIL-WATER       | PHYSICAL PROPERTIES OF GRASSLAND SOILS AND THEIR INFLUENCE ON PRIMARY PRODUCTIVITY. (TERWILLIGER 1969)                             | SS02,65-70    |
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| SPECIES-DIVERSITY     | AN ECOLOGICAL DESCRIPTION OF A SEMI-ARID EAST AFRICAN ECOSYSTEM. (HARRIS 1972)                                                                                  | SS11         |
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| SPECTROPHOTOMETER-LAB | THE ROLE OF INVERTEBRATES IN THE GRASSLAND BIOME. (MCDANIEL 1971)                                                                                               | SS10,267-315 |
| SPECTROPHOTOMETER-LAB | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1971)                                                                                  | SS10,317-387 |
| STANDING-DEAD         | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REP                                                                           | PR71-2.4     |
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| STANDING-DEAD         | PRELIMINARY PRODUCER DATA SYNTHESIS, 1970 COMPREHENSIVE SITES. (WISSER 1972)                                                                                    | TR084        |
| STANDING-DEAD         | HERBAGE DYNAMICS OF A TALLGRASS PRAIRIE, OSAGE, 1971. (WISSER AND KENNEDY 1972)                                                                                 | TH108        |
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| STANDING-DEAD         | HERBAGE DYNAMICS ON A MIXED PRAIRIE GRASSLAND NEAR HAYS, KANSAS. (HULETT AND TOPANEK 1971)                                                                      |              |
| STANDING-DEAD         | ABIOTIC AND HERBAGE DYNAMICS STUDIES ON THE COTTONWOOD SITE, 1970. (LEWIS, ET AL. 1971)                                                                         |              |
| STANDING-DEAD         | PRIMARY PRODUCTIVITY OF THE FESCUE GRASSLAND IN WESTERN MONTANA. (MORRIS AND BRUNNER 1971).                                                                     |              |

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| STANDING-DEAD          | PRIMARY PRODUCTIVITY AND ABIOTIC STUDIES AT THE DICKINSON SITE, 1970 SEASON.<br>(WHITMAN 1971)                                          | TR116         |
| STANDING-DEAD          | HERPETOLOGICAL STUDIES AT THE PANTEX SITE. (FAGAN AND PETTIT 1971)                                                                      | TR078         |
| STANDING-DEAD          | OSAGE SITE, 1970 REPORT, PRIMARY PRODUCTION. (KISSER 1971)                                                                              | TR080         |
| STANDING-DEAD          | PRELIMINARY METHODOLOGY AND RESULTS FOR ABOVEGROUND HERBAGE BIOMASS SAMPLING ON THE P<br>AWNEE SITE. (LUKESK AND SIMS 1969)             | TR033         |
| STEEP-METAROLISM       | FUNCTIONAL INTERACTION OF LARGE HERBIVORES ON GRASSLANDS. (RICE, ET. AL. 1971)                                                          | SS10,241-266  |
| STEEPS                 | FUNCTIONAL INTERACTION OF LARGE HERBIVORES ON GRASSLANDS. (RICE, ET. AL. 1971)                                                          | SS10,241-266  |
| STEEPS                 | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-2.5.<br>(VAN DYNE 1970)                                | PR70-2.5      |
| STEEPS                 | BOTANICAL SPECIES OF PLANTS EATEN AND INTAKE OF STEERS GRAZING LIGHT, MEDIUM AND HEAV<br>Y USE. (RICE AND VAVRA 1969)                   | AR69-2561.3   |
| STEEPS                 | METHODS OF ESTIMATING DRY WEIGHT COMPOSITION IN DIETS OF STEERS.                                                                        | OL011         |
| STEEPS                 | (FREE, ET. AL. 1971)                                                                                                                    | OL003         |
| STEEPS                 | ESTIMATING DRY WEIGHTS OF FOOD PLANTS IN FECES OF HERBIVORES. (FREE, ET. AL. 1970)                                                      | OL006         |
| STEEPS                 | PRECISION OF INDIRECT METHODS FOR ESTIMATING DIGESTIBILITY OF FORAGE CONSUMED BY GRAZ<br>ING CATTLE. (WALLACE AND VAN DYNE 1970)        | OL050         |
| STEEPS                 | SALIVARY CONTAMINATION OF FORAGE SELECTED BY ESOPHAGEAL FISTULATED STEERS GRAXING SAN<br>DILL GRASSLAND. (WALLACE, ET. AL. 1972)        | OL038         |
| STEEPS                 | PRECISION OF INDIRECT METHODS FOR ESTIMATING DIGESTIBILITY OF FORAGE CONSUMED BY GRAZ<br>ING CATTLE. (WALLACE AND VAN DYNE 1970)        | OL037         |
| STEEPS                 | ESOPHAGEAL VS. FECAL SAMPLING FOR THE BOTANICAL DETERMINATION OF STEER DIETS.                                                           | TR012         |
| STEEPS                 | (VAVRA, ET. AL. 1970)                                                                                                                   | SS02,243-260  |
| STEEPS                 | BOTANICAL SPECIES OF PLANTS EATEN AND INTAKE OF STEERS GRAZING LIGHT, MEDIUM, AND MEA<br>VY USE SHORTGRASS RANGE. (RICE AND VAVRA 1969) | SS10,267-315  |
| STEEPS                 | THE IMPACT OF DOMESTIC ANIMALS ON THE FUNCTION AND STRUCTURE OF GRASSLAND ECOSYSTEMS.<br>(HYDER 1969)                                   | SS061,133-177 |
| STINK-BUG              | THE ROLE OF INVERTEBRATES IN THE GRASSLAND BIOME. (MCDANIEL 1971)                                                                       | SS02,243-260  |
| STOCKING-RATE          | A QUANTITATIVE ECOLOGY OF THE JORNADA EXPERIMENTAL RANGE. (HERBEL, ET. AL. 1970)                                                        | TR039         |
| STOCKING-RATE          | THE IMPACT OF DOMESTIC ANIMALS ON THE FUNCTION AND STRUCTURE OF GRASSLAND ECOSYSTEMS.<br>(HYDER 1969)                                   | TR128         |
| STOCKING-RATE          | COMPREHENSIVE NETWORK SITE DESCRIPTION, COTTONWOOD. (LEWIS 1970)                                                                        | TR056         |
| STOCKING-RATE          | METABOLIC COMPONENTS OF CATTLE UNDER LIGHT AND HEAVY RATES OF STOCKING IN 1970.<br>(HYDER, ET. AL. 1971)                                | TR101         |
| STYLE-TECHNICAL-REPORT | STYLE AND FORMAT OF TECHNICAL REPORTS. (HENDRICKS 1970)                                                                                 | SS03,1-39     |
| SUCCESSION             | SPATIAL DISTRIBUTION AND SUCCESSIONAL STATE OF GRASSLAND VEGETATION RELATED TO GRAZIN<br>G INTENSITY TREATMENTS. (MITCHELL 1971)        | SS02S241,1-87 |
| SUCCESSION             | GRASSLANDS MANAGEMENT, RESEARCH, AND TRAINING VIEWED IN A SYSTEMS CONTEXT.<br>(VAN DYNE 1969)                                           | SS02,261-267  |
| SUCCESSION             | PRIMARY PRODUCERS IN GRASSLAND ECOSYSTEMS. (LEWIS 1970)                                                                                 | SS02,3-26     |
| SUCCESSION             | REPLACEMENT OF NATIVE PLANT COMMUNITIES WITH INTRODUCED COMMUNITIES AND ITS IMPACT ON<br>ECOSYSTEM FUNCTION. (EVERSON 1969)             | TR232         |
| SUCCESSION             | SOME MATHEMATICAL MODELS OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1969)                                                                       | SS061,191-197 |
| SUCCESSION             | EFFECTS OF WATER AND NITROGEN STRESSES ON A SHORTGRASS PRAIRIE ECOSYSTEM.<br>(LAUENROTH AND SIMS 1973)                                  | SS07,191-198  |
| SUCCESSION             | STOCHASTIC ABILITY AND SECONDARY SUCCESSION. (JAMESON 1970)                                                                             | OL010         |
| SUCCESSION             | EXAMPLES OF TROPHIC LEVEL AND TOTAL ECOSYSTEM MODELS. (VAN DYNE 1970)                                                                   | OL004         |
| SUCCESSION             | A COMPARTMENT MODEL SIMULATION OF SECONDARY SUCCESSION.<br>(BLEDSOE AND VAN DYNE 1971)                                                  | AR69-2552.2   |
| SUCCESSION             | VALUE OF BROOD SNAKEWEED AS A RANGE CONDITION INDICATOR. (JAMESON 1970)                                                                 | SS10,317-387  |
| SUCCESSION             | REPLACEMENT OF NATIVE COMMUNITIES WITH INTRODUCED COMMUNITIES AND ITS IMPACT ON ECOSY<br>STEM FUNCTION. (EVERSON 1969)                  | SS10,267-315  |
| SUCKING-ARTHROPODS     | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1971)                                                          | TR112         |
| SUCKING-ARTHROPODS     | THE ROLE OF INVERTEBRATES IN THE GRASSLAND BIOME. (MCDANIEL 1971)                                                                       | TR079         |
| SUCKING-ARTHROPODS     | STUDIES OF POPULATIONS OF ADULTS AND IMMATURE INSECTS AND MITES FROM TWO TREATMENTS A<br>T COTTONWOOD, SOUTH DAKOTA. (MCDANIEL 1971)    | TR026         |
| SUCKING-ARTHROPODS     | INSECT POPULATION STUDIES. (HUDDLESTON, ET. AL. 1971)                                                                                   |               |
| SWAINSONS-HAWK         | DJURNAL RAPTORS ON THE PAMNEE SITE. (HYDER 1969)                                                                                        |               |

## ARTICLE

| KEY-WORD                 | ARTICLE                                                                                                                                                                                       | REFERENCE     |
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| SWAINSONS-HAWK           | THE LARGE BIRDS OF PREY OF THE PANNEE NATIONAL GRASSLAND: NESTING HABITS AND PRODUCTIVITY, 1969-1971. (OLENDORFF 1972)                                                                        | TR151         |
| SWAINSONS-HAWK           | THE ECOLOGY OF THE NESTING BIRDS OF PREY OF NORTHEASTERN COLORADO. (OLENDORFF 1973)                                                                                                           | TR211         |
| SWIT-INDEX               | U.S. IBP GRASSLAND BIOME LITERATURE: A KWIC INDEX AND ABSTRACTS. (SINGH 1972)                                                                                                                 | TR155         |
| SYMPOSIUM-REPORT         | PROCESS STUDIES WORKSHOP REPORT. (JAMESON AND DYER 1973)                                                                                                                                      | TR220         |
| SYMPOSIUM-REPORT         | GRASSLAND BIOME GRADUATE STUDENT SYMPOSIUM -- A REVIEW. (WHIGHT AND SMITH 1970)                                                                                                               | TR059         |
| SYMPOSIUM-REPORT         | PSYCHOMETRY IN WATER RELATIONS RESEARCH: A REVIEW. (VAN HAVEREN 1971)                                                                                                                         | TR132         |
| SYMPOSIUM-REPORT         | INTRODUCTION. (DYER AND JAMESON 1973)                                                                                                                                                         | TR220,1-12    |
| SYMPOSIUM-REPORT         | PRAIRIE REBIRTH. (MOIR 1968)                                                                                                                                                                  | OL002         |
| SYNTHESIS                | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                     | PR73-16       |
| SYNTHESIS-INTERBIOME     | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                     | PR73-16       |
| SYNTHESIS-INTERBIOME     | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                     | PR73-16       |
| SYNTHESIS-INTERBIOME     | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                     | PR73-16       |
| SYSTEM-TRANSFER-FUNCTION | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1971)                                                                                                                | SS10,317-387  |
| SYSTEM-TRANSFER-FUNCTION | HERBAGE DYNAMICS AND NET PRIMARY PRODUCTION IN CERTAIN UNGRAZED AND GRAZED GRASSLANDS IN NORTH AMERICA. (SIMS AND SINGH 1971)                                                                 | SS10,59-124   |
| SYSTEMS-APPROACH         | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                     | PR73-117      |
| SYSTEMS-APPROACH         | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                     | PR73-111      |
| SYSTEMS-APPROACH         | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                     | SS11          |
| SYSTEMS-APPROACH         | AN ECOLOGICAL DESCRIPTION OF A SEMI-ARID EAST AFRICAN ECOSYSTEM. (HARRIS 1972)                                                                                                                | SS10,147-212  |
| TANZANIA                 | PATTERN AND PROCESS IN GRASSLAND BIRD COMMUNITIES. (WIENS 1971)                                                                                                                               | OL062         |
| TERRITORIALITY           | PATTERN AND PROCESS IN GRASSLAND BIRD COMMUNITIES. (WIENS, 1973)                                                                                                                              | TR063         |
| TERRITORIALITY           | AVIAN POPULATIONS AND PATTERNS OF HABITAT OCCUPANCY AT THE PANNEE SITE, 1968-1969. (WIENS 1970)                                                                                               | TR205         |
| TERRITORIALITY           | AVIAN POPULATIONS AT IBP GRASSLAND BIOME SITES: 1971. (WIENS, ET AL. 1972)                                                                                                                    | OL041         |
| TERRITORIALITY           | HABITAT HETEROGENEITY AND THE STRUCTURE OF AVIAN COMMUNITIES IN GRASSLANDS. (WEIN'S 1970)                                                                                                     | OL045         |
| TEXTURE                  | A METHOD FOR MEASURING SOIL EROSION AND DEPOSITION WITH BETA PARTICLE ATTENUATION. (CALLOREDGE AND WHICKER 1972)                                                                              | AR69-2542.2   |
| TEXTURE                  | MINERALOGY OF REPRESENTATIVE SOILS. (FRANKLIN 1969)                                                                                                                                           | TR175         |
| TEXTURE                  | SOIL MICROBIOLOGICAL STUDIES ON THE ALE RESERVE, 1971. (WILDUNG AND SCHMIDT 1972)                                                                                                             | TR165         |
| TEXTURE                  | DEVELOPMENT OF A LARGE, UNDISTURBED WEIGHING LYSIMETER FOR EVAPOTRANSPIRATION STUDIES ON GRASSLAND. (ARMILJO 1972)                                                                            | TR122         |
| TEXTURE                  | SOIL NUTRIENT-PLANT NUTRIENT RELATIONSHIPS AT THE PANNEE SITE. (DITTBERNER 1971)                                                                                                              | TR115         |
| TEXTURE                  | SOME HYDROLOGIC AND PHYSICAL PROPERTIES OF THE MAJOR SOIL TYPES ON THE PANNEE INTENSIVE SITE. (VAN HAVEREN, GALBRAITH 1971)                                                                   | TR113         |
| TEXTURE                  | PRIMARY PRODUCTIVITY OF THE FESCUE GRASSLAND IN WESTERN MONTANA. (MORRIS AND BRUNNER 1971)                                                                                                    | SS10,267-315  |
| TEXTURE                  | THE ROLE OF INVERTEBRATES IN THE GRASSLAND BIOME. (MCDANIEL 1971)                                                                                                                             | TR127         |
| TEXTURE                  | GRASSLAND CLIMATOLOGY OF THE PANNEE GRASSLAND. (RASMUSSEN, ET. AL. 1971)                                                                                                                      | TR091         |
| TEXTURE                  | CENTRAL BASIN HYDROLOGIC PROCESS STUDIES. (SMITH 1971)                                                                                                                                        | TR089         |
| TEXTURE                  | THE DESIGN OF A SPATIAL DATA FRAMEWORK, CENTRAL BASIN WATERSHED, PANNEE SITE. (OLIVER AND MILLER 1971)                                                                                        | TR086         |
| TEXTURE                  | PRELIMINARY RESULTS OF GROWTH CHARACTERISTICS OF BUFFALOGRASS, BLUE GRAMA, AND WESTERN WHEATGRASS. AND METHODOLOGY FOR TRANSLOCATION STUDIES USING 14C AS A TRACER. (KNIEVEL AND SCHMER 1971) | TR220,149-244 |
| TRANSLOCATION            | PRODUCER SUBSYSTEM. (JAMESON 1973)                                                                                                                                                            | TR160         |
| TRANSLOCATION            | CARBOHYDRATE TRANSLOCATION IN BLUE GRAMA, BUFFALO-GRASS, AND WESTERN WHEATGRASS AS INFLUENCED BY TEMPERATURE AND GROWTH STAGE. (SCHMER AND KNIEVEL 1972)                                      | PR73-113      |
| TRANSLOCATION            | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                     | PR69-8.53     |
| TRANSLOCATION            | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-8.53. (VAN DYNE 1969)                                                                                        |               |

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| TRANSPIRATION<br>TREE-HOPPER | HYDROLOGY AND WATER-BALANCE OF SEMI-DESERT SOILS. (COOPER 1970)<br>PLANT/INSECT INTERACTIONS OF SELECTED INSECTS AT THE PANNEE SITE.<br>(YOUNT AND THATCHER 1972)         | SS061,119-128<br>TR142 |
| TRIP-REPORT                  | SOME OBSERVATIONS ON FOREIGN GRASSLAND AND RELATED RESEARCH: APRIL-JULY, 1970 VAN DY<br>ME TRIP REPORT. (VAN DYNE 1970)                                                   | TR057                  |
| TROPICAL-GRASSLAND           | CALORIC VALUES OF IMPORTANT PLANT AND INSECT SPECIES OF A TROPICAL GRASSLAND AT KURUK<br>SHEWA, INDIA. (SINGH AND YADAVA 1972)                                            | OL083                  |
| WARM-DEVELOPMENT             | LAND USE AND THE FRONT-RANGE. (WRIGHT 1972)                                                                                                                               | OL089                  |
| WINE-OUTPUT                  | WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTITIONING BY CATTLE.<br>(HYDER 1969)                                                                          | AR69-2561.1            |
| WINE-OUTPUT                  | METABOLIC COMPONENTS OF CATTLE: WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER<br>AND PARTITIONING BY CATTLE. (HYDER, ET. AL. 1969)                                 | TR010                  |
| WINE-OUTPUT                  | METABOLIC COMPONENTS OF CATTLE UNDER LIGHT AND HEAVY RATES OF STOCKING IN 1970.<br>(HYDER, ET. AL. 1971)                                                                  | TR128                  |
| UTILIZATION-STUDIES          | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.<br>(VAN DYNE 1973)                                                                              | PR73-15                |
| VAPOR-PRESSURE               | SOME ASPECTS OF THE ECOLOGICAL CLIMATOLOGY OF THE JORNADA EXPERIMENTAL RANGE NEW-MEXI<br>CO. (BRYSON, ET. AL. 1970)                                                       | SS061,2-74             |
| VEGETATION-MAPPING           | MEASUREMENT OF THE COMBINED-EFFECT OF GREEN BIOMASS, CHLOROPHYLL, AND LEAF WATER ON C<br>ANOPY SPECTROREFLECTANCE OF THE SHORTGRASS PRAIRIE. (TUCKER, ET. AL. 1973)       | OL066                  |
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| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-2.6. (VAN DYNE 1970)                                                       | PR70-2.6     |

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| ECOSYSTEMS | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-4.4.                           | PR71-4.4      |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-9.                                          | PR69-9        |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-2.5.                           | PR71-2.5      |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-6.                            | PR71-6        |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-8.                                          | PR70-8        |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-2.5.                                        | PR70-2.5      |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.                                                    | PR73-11       |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, BIOME PROPOSAL 1967.                                             | BP67          |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-4.                                          | PR69-4.       |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.                                                    | PR73-12       |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-0.                                          | PR69-0        |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-8.52.                                       | PR69-8.52     |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.                                                    | PR73-13       |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-2.4.                                        | PR70-2.4      |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-8.4.                                        | PR69-8.4      |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.                                                    | PR73-14       |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-8.53.                                       | PR69-8.53     |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-6.                                          | PR69-6.       |
| ECOSYSTEMS | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.                                                    | PR73-15       |
| ECOSYSTEMS | RECIPROCAL INFLUENCES BETWEEN DOMESTIC ANIMALS AND OTHER COMPONENTS OF SEMI-DESERT ECOSYSTEMS. (HOUSTON 1970)                | SS061,178-190 |
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| ECOSYSTEMS | SOME MATHEMATICAL MODELS OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1969)                                                            | SS02,3-26     |
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| ECOSYSTEMS | THE NATURE AND SIGNIFICANCE OF ECO-GENETIC VARIATION IN ECOSYSTEMS. (WARD 1969)                                              | SS02,148-152  |
| ECOSYSTEMS | THE FUNCTION OF SOIL FAUNA IN GRASSLAND ECOSYSTEMS. (PARIS 1969)                                                             | SS02,331-360  |
| ECOSYSTEMS | THE IMPACT OF DOMESTIC ANIMALS ON THE FUNCTION AND STRUCTURE OF GRASSLAND ECOSYSTEMS. (HYDER 1969)                           | SS02,243-260  |
| ECOSYSTEMS | PRIMARY PRODUCERS IN GRASSLAND ECOSYSTEMS. (LEWIS 1970)                                                                      | SS02S241,1-87 |
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| ECOSYSTEMS    | ENERGY FIXATION AND THE ROLE OF PRIMARY PRODUCERS IN ENERGY-FLUX OF GRASSLAND ECOSYSTEMS. (MOIR 1969)                                                                      | SS02-125-147  |
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| FI ELECTRONIC | USE OF ELECTRONIC METER IN ESTIMATING BIOMASS. (JAMESON 1970)                                                                                                              | SS07-65       |
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| ENERGY-FLUX   | ENERGY FIXATION AND THE ROLE OF PRIMARY PRODUCERS IN ENERGY-FLUX OF GRASSLAND ECOSYSTEMS. (MOIR 1969)                                                                      | SS02-125-147  |
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| ENVIRONMENTAL | ANALYSIS OF PLANT PATTERN, DISTRIBUTION AND RELATIONSHIP TO ENVIRONMENTAL PROCESSES. (FASER AND LESHER 1969)                                                               | AR69-2553.1   |
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| ESOPHAGEAL    | SALIVARY CONTAMINATION OF FORAGE SELECTED BY ESOPHAGEAL FISTULATED STEERS GRADING SAN DILL GRASSLAND. (WALLACE, ET. AL. 1972)                                              | OL050         |
| ESOPHAGEAL    | A COMPARISON OF THE ESOPHAGEAL FISTULA WITH RUMEN SAMPLES FOR THE DETERMINATION OF THE BOTANICAL AND CHEMICAL COMPOSITION OF THE DIET OF HERBIVORES. (PRICE, ET. AL. 1969) | TR011         |
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| EVALUATION         | A SIMPLIFIED UNIT FOR EVALUATION OF SOIL CORE RESPIROMETRIC ACTIVITY. (KLEIN, ET AL. 1972)                                                                  | OL067        |
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| EVAPORATION        | MODELS FOR INFERRING EVAPORATION FROM METEOROLOGICAL MEASUREMENTS. (MUNN, ET AL. 1970)                                                                      | TR047        |
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| FACTORS            | THE ROLE OF ABIOTIC FACTORS IN THE STRUCTURE AND FUNCTION OF THE GRASSLAND ECOSYSTEM. (BURZLAFF 1969)                                                       | SS02.117-123 |
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| FEEDING            | THE EFFECT OF INSECT PREDATORS AND PARASITES ON GRASS FEEDING INSECTS. (LAVIGNE 1969)                                                                       | AR69-2564.3  |
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| FEEDING            | PROGRESS REPORT, WORK ON BIRD FEEDING AND NESTING BEHAVIOR AT THE PAWNEE SITE. (CREIGHTON 1971)                                                             | TR067        |
| FEEDING            | EFFECT OF INSECT PREDATORS AND PARASITES ON GRASS FEEDING INSECTS, PAWNEE SITE. (LAVIGNE AND ROGERS 1970)                                                   | JR020        |
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| FISTULA      | A COMPARISON OF THE ESOPHAGEAL FISTULA WITH RUMEN SAMPLES FOR THE DETERMINATION OF THE BOTANICAL AND CHEMICAL COMPOSITION OF THE DIET OF HERBIVORES. (PRICE, ET. AL. 1969) | TR011         |
| FISTULATED   | SALIVARY CONTAMINATION OF FORAGE SELECTED BY ESOPHAGEAL FISTULATED STEERS GRAXING SAN DHILL GRASSLAND. (WALLACE, ET. AL. 1972)                                             | OL050         |
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| FIXATION     | ENERGY FIXATION AND THE ROLE OF PRIMARY PRODUCERS IN ENERGY-FLUX OF GRASSLAND ECOSYSTEMS. (MOIR 1969)                                                                      | SS02,125-147  |
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| FOOD         | FOOD CONSUMPTION AND FEEDING RATES IN THE LARK BUNTING. (BALDWIN AND BOVD 1973)                                                                                            | TR235         |
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| FOOD         | AVIAN FOOD STUDIES AT THE PANNEE SITE. (BALDWIN 1970)                                                                                                                      | SS07,84-85    |
| FOOD         | LIFE HISTORY, FOOD HABITS, HABITAT REQUIREMENTS, AND POPULATION DYNAMICS OF SMALL HERBIVORES ON SEMI-DESERT GRASSLANDS. (LAYCOCK 1970)                                     | SS061,198-212 |
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| FORAGE       | HERBAGE GROWTH RATE, FORAGE INTAKE, AND FORAGE QUALITY IN 1970 ON HEAVILY AND LIGHTLY GRAZED BLUE GRAMA PASTURES. (DYCK AND BEMENT 1971)                                   | OL038         |
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| FORAGE       | SALIVARY CONTAMINATION OF FORAGE SELECTED BY ESOPHAGEAL FISTULATED STEERS GRAXING SAN DHILL GRASSLAND. (WALLACE, ET. AL. 1972)                                             | OL006         |
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|               | OF THE SHORTGRASS PRAIRIE AS INPUT INTO BIOSYSTEM MODELS.                             |               |
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| STRUCTURE | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, BIOME PROPOSAL 1967. (VAN DYNE 1967)                                                            | BP67                       |
| STRUCTURE | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                   | PR73-14                    |

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| STRUCTURE        | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.<br>(VAN DYNE 1973)                                                                | PR73-113      |
| STRUCTURE        | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-8.53<br>(VAN DYNE 1969)                                                    | PR69-8.53     |
| STRUCTURE        | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-8.52<br>(VAN DYNE 1969)                                                    | PR69-8.52     |
| STRUCTURE        | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.<br>(VAN DYNE 1973)                                                                | PR73-15       |
| STRUCTURE        | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-2.4.<br>(VAN DYNE 1970)                                                    | PR70-2.4      |
| STRUCTURE        | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.<br>(VAN DYNE 1973)                                                                | PR73-16       |
| STRUCTURE        | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-8.4.<br>(VAN DYNE 1969)                                                    | PR69-8.4      |
| STRUCTURE        | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1969-5.<br>(VAN DYNE 1969)                                                      | PR69-5.       |
| STRUCTURE        | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.<br>(VAN DYNE 1973)                                                                | PR73-19       |
| STRUCTURE        | ANALYSIS OF STRUCTURE AND FUNCTION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1970-2.5.<br>(VAN DYNE 1970)                                                    | PR70-2.5      |
| STRUCTURE        | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.<br>(VAN DYNE 1973)                                                                | PR73-115      |
| STRUCTURE        | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS.<br>(VAN DYNE 1973)                                                                | PR73-116      |
| STRUCTURE        | SOME MEASUREMENTS OF VEGETATION STRUCTURE ON THE PANNEE GRASSLAND, 1970.<br>(KNIGHT 1971)                                                                   | TR072         |
| STYLE            | STYLE AND FORMAT OF TECHNICAL REPORTS. (MENDRICKS 1970)                                                                                                     | TR056         |
| SUBSEQUENT       | AN ANALYSIS OF VEGETATION STRUCTURE ON THE PANNEE GRASSLAND, WITH SUBSEQUENT EVALUATIONS OF THE INFLUENCE OF STRUCTURE ON ECOSYSTEM FUNCTION. (KNIGHT 1969) | AR69-2553.2   |
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| SUBSYSTEM        | CONSUMER SUBSYSTEM: ENERGY MODEL. (OYER 1973)                                                                                                               | TR220.321-444 |
| SUBSYSTEM        | CONSUMER SUBSYSTEM: DIET-SELECTION MODEL. (ELLIS 1973)                                                                                                      | TR220.299-319 |
| SUBSYSTEM        | DECOMPOSER SUBSYSTEM. (KLEIN AND CLARK 1973)                                                                                                                | TR220.245-297 |
| SUBSYSTEM        | NUTRIENT SUBSYSTEM: PHOSPHORUS AND NITROGEN MODELS. (REUSS, ET AL. 1973)                                                                                    | TR220.123-148 |
| SUBSYSTEMS       | ABIOTIC SUBSYSTEMS: HEAT AND WATER MODELS. (SMITH 1973)                                                                                                     | TR220.13-121  |
| SUCCESSION       | STOCHASTIC ABILITY AND SECONDARY SUCCESSION. (JAMESON 1970)                                                                                                 | SS061.191-197 |
| SUCCESSION       | A COMPARTMENT MODEL SIMULATION OF SECONDARY SUCCESSION.<br>(BLEDSOE AND VAN DYNE 1971)                                                                      | OL010         |
| SUCCESSIONAL     | SPATIAL DISTRIBUTION AND SUCCESSIONAL STATE OF GRASSLAND VEGETATION RELATED TO GRAZING INTENSITY TREATMENTS. (MITCHELL 1971)                                | TR101         |
| SUCCESSIONAL     | SOIL CARBON-BALANCE IN A SUCCESSIONAL GRASSLAND. (COLEMAN 1972)                                                                                             | OL084         |
| SUPPLEMENTAL     | SUPPLEMENTAL REPORT ON PRIMARY PRODUCTIVITY AND ABIOTIC STUDIES AT THE DICKINSON SITE<br>: 1970 SEASON. (WHITMAN 1972)                                      | TR190         |
| SURFACE          | SURFACE ENERGY AND WATER BUDGET OVER THE GRASSLAND, 1970.<br>(ALMEYDA AND RASMUSSEN 1972)                                                                   | TR202         |
| SURVEY           | SMALL MAMMAL SURVEY ON THE BISON, BRIDGER, COTTONWOOD, DICKINSON, AND OSAGE SITES.<br>(HOFFMANN, ET AL. 1971)                                               | TR109         |
| SURVEY           | SMALL MAMMAL SURVEY ON THE JORNADA AND PANTEX SITES. (PACKARD 1971)                                                                                         | TR114         |
| SWARDS           | A FIELD LABORATORY FOR GAS-EXCHANGE MEASUREMENTS OF GRASSLAND SWARDS.<br>(TRICA, ET AL. 1973)                                                               | OL080         |
| SWEEP            | SAMPLING INSECT POPULATIONS BY SWEEP NET ON THE PANNEE SITE.<br>(THATCHER, ET AL. 1970)                                                                     | TR050         |
| SYMPOSIUM        | GRASSLAND RIME GRADUATE STUDENT SYMPOSIUM -- A REVIEW. (WRIGHT AND SMITH 1970)                                                                              | TR059         |
| SYNTHESIS        | PRELIMINARY PRODUCER DATA SYNTHESIS, 1970 COMPREHENSIVE SITES. (RISSER 1972)                                                                                | TR161         |
| SYNTHESIS        | THE GRASSLAND BIOME: A SYNTHESIS OF STRUCTURE AND FUNCTION, 1970. (LEWIS 1973)                                                                              | SS10.317-387  |
| SYSTEM           | A PHOTOSYNTHESIS MEASUREMENT SYSTEM FOR THE PANNEE SITE. (MOIR 1970)                                                                                        | SS07.151-154  |
| SYSTEM           | PROGRAM INSTAR: AN INFORMATION STORAGE AND RETRIEVAL SYSTEM USER'S MANUAL.<br>(ROBINSON 1972)                                                               | TR147         |

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| SYSTEM       | METEOROLOGICAL DATA ACQUISITION SYSTEM, SEPTEMBER 1, 1970 - DECEMBER 31, 1970. (NUNN, ET. AL. 1971)                                                                                           | TR073       |
| SYSTEMS      | SYSTEMS ANALYSIS OF DECOMPOSER FUNCTIONS IN THE GRASSLAND ECOSYSTEM. (KLEIN 1972)                                                                                                             | TR201       |
| SYSTEMS      | SIMULATION OF ILL-DEFINED SYSTEMS: SOME PROBLEMS AND PROGRESS. (INNIS 1972)                                                                                                                   | OL054       |
| SYSTEMS      | SIMULATION OF BIOLOGICAL SYSTEMS: SOME PROBLEMS AND PROGRESS. (INNIS 1972)                                                                                                                    | OL077       |
| SYSTEMS      | SIMULATION OF GRAZING SYSTEMS. (GOODALL 1970)                                                                                                                                                 | SS05,51-74  |
| SYSTEMS      | GRASSLANDS MANAGEMENT, RESEARCH, AND TRAINING VIEWED IN A SYSTEMS CONTEXT. (VAN DYNE 1969)                                                                                                    | SS03,1-39   |
| SYSTEMS      | SOME ANALYTICAL AND OPERATIONAL APPROACHES TO DEVELOPING DYNAMIC MODELS OF ECOLOGICAL SYSTEMS. (VAN DYNE, ET. AL. 1971)                                                                       | OL019       |
| SYSTEMS      | A SYSTEMS APPROACH TO GRASSLANDS. (VAN DYNE 1970)                                                                                                                                             | OL034       |
| SYSTEMS      | EVALUATION OF A DIGITAL COMPUTER METHOD FOR ANALYSIS OF COMPARTMENTAL MODELS OF ECOLOGICAL SYSTEMS. (HEDSOE AND VAN DYNE 1969)                                                                | OL022       |
| SYSTEMS      | SYSTEMS ECOLOGY. (VAN DYNE 1970)                                                                                                                                                              | OL035       |
| TALLGRASS    | HERBAGE DYNAMICS OF A TALLGRASS PRAIRIE, OSAGE, 1971. (RISSER AND KENNEDY 1972)                                                                                                               | TR173       |
| TALLGRASS    | INSECTS AND OTHER MAJOR ARTHROPODS OF A TALLGRASS PRAIRIE. (REED 1972)                                                                                                                        | TR166       |
| TALLGRASS    | A PRELIMINARY COMPARTMENT MODEL OF A TALLGRASS PRAIRIE, OSAGE SITE, 1970. (RISSER 1972)                                                                                                       | TR159       |
| TARSALIS     | A SIMULATION MODEL FOR POPULATIONS OF THE MOSQUITO, CULEX TARSALIS. (HUNT AND HEDDLESTON 1973)                                                                                                | OL071       |
| TAXONOMIC    | TAXONOMIC SUPPORT FOR THE GRASSLAND BIOME STUDY. (KLEIN 1969)                                                                                                                                 | AR69-2510   |
| TECHNIQUE    | A TECHNIQUE FOR RAPID IDENTIFICATION OF INITIAL PHOTOSYNTHETIC PRODUCTS. (WILLIAMS AND MARKLEY 1973)                                                                                          | TR228       |
| TECHNIQUE    | AN ANALYSIS OF THE BETA-ATTENUATION TECHNIQUE FOR ESTIMATING STANDING CROP OF PRAIRIE RANGE. (MITCHELL 1972)                                                                                  | OL043       |
| TECHNIQUES   | OPTIMIZATION TECHNIQUES IN ECOSYSTEM AND LAND USE PLANNING. (SWARTZMAN 1972)                                                                                                                  | TR143       |
| TECHNIQUES   | A PRELIMINARY REPORT ON NEW SEPARATION TECHNIQUES FOR LIVE-DEAD ABOVEGROUND GRASS HERBAGE AND ROOTS FROM DRY SOIL CORES. (VAN WYK 1972)                                                       | TR144       |
| TECHNIQUES   | AN EXAMPLE OF OPTIMIZATION TECHNIQUES IN LAND MANAGEMENT: THE RESOURCE ALLOCATION MODEL. (PRICE 1970)                                                                                         | SS05,89-100 |
| TECHNIQUES   | SIMULATION TECHNIQUES IN WILDLIFE HABITAT MANAGEMENT. (GILES AND SNYDER 1970)                                                                                                                 | SS05,23-49  |
| TECHNIQUES   | TECHNIQUES IN MEASURING BIOMASS OF PRODUCERS. (VAN DYNE, ET. AL. 1970)                                                                                                                        | SS07,62-64  |
| TECHNIQUES   | SIMULATION TECHNIQUES IN FOREST-RANGE MANAGEMENT. (CLIFFORD AND CURRIE 1970)                                                                                                                  | SS05,17-22  |
| TECHNIQUES   | AN EXAMPLE OF OPTIMIZATION TECHNIQUES IN LAND MANAGEMENT: THE ELDORADO MODEL. (BELL 1970)                                                                                                     | SS05,75-87  |
| TECHNIQUES   | SOME OPTIMIZATION TECHNIQUES AND PROBLEMS IN THE NATURAL-RESOURCE-SCIENCES. (VAN DYNE, ET. AL. 1970)                                                                                          | OL036       |
| TEMPERATURE  | CARBOHYDRATE TRANSLOCATION IN BLUE GRAMA, BUFFALO-GRASS, AND WESTERN WHEATGRASS AS INFLUENCED BY TEMPERATURE AND GROWTH STAGE. (SCHMER AND KNEIPEL 1972)                                      | TR160       |
| TEMPERATURE  | A MODEL FOR PREDICTING SOIL TEMPERATURE FROM AIR TEMPERATURE. (HASFURTH, ET. AL. 1972)                                                                                                        | TR178       |
| TEMPERATURE  | A MODEL FOR PREDICTING SOIL TEMPERATURE FROM AIR TEMPERATURE. (HASFURTH, ET. AL. 1972)                                                                                                        | TR178       |
| TERRIONIDAE  | IDENTIFYING TERNIONIDAE (DARKLING BEETLES). (BELL 1970)                                                                                                                                       | TR058       |
| TENNESSEE    | MODELS OF SEASONAL PRIMARY PRODUCTIVITY IN EASTERN TENNESSEE FESTUCA AND ANDROPOGON ECOSYSTEMS. (KELLY, ET. AL. 1969)                                                                         | OL028       |
| THUNDERSTORM | GROWTH RESPONSE OF BLUE GRAMA TO THUNDERSTORM RAINFALL. (SMITH 1972)                                                                                                                          | TR157       |
| TRACER       | PRELIMINARY RESULTS OF GROWTH CHARACTERISTICS OF BUFFALOGRASS, BLUE GRAMA, AND WESTERN WHEATGRASS, AND METHODOLOGY FOR TRANSLOCATION STUDIES USING 14C AS A TRACER. (KNEIPEL AND SCHMER 1971) | TR086       |
| TRACERS      | METABOLIC COMPONENTS OF CATTLE: WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTITIONING BY CATTLE. (HYDER, ET. AL. 1969)                                                        | TR010       |
| TRACERS      | WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTITIONING BY CATTLE. (HYDER 1969)                                                                                                 | AR69-2561.1 |
| TRAINING     | ASPECTS OF QUANTITATIVE TRAINING IN THE NATURAL-RESOURCE-SCIENCES. (VAN DYNE 1971)                                                                                                            | OL018       |
| TRAINING     | IMPLEMENTING THE ECOSYSTEM CONCEPT IN TRAINING IN NATURAL-RESOURCE-SCIENCES. (VAN DYNE 1969)                                                                                                  | OL033       |
| TRAINING     | GRASSLANDS MANAGEMENT, RESEARCH, AND TRAINING VIEWED IN A SYSTEMS CONTEXT. (VAN DYNE 1969)                                                                                                    | SS03,1-39   |

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## SIGNIFICANT-WORD

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| TRANSLOCATION | THE MOBILITY AND TRANSLOCATION OF NITROGEN IN GRASS PLANTS. (PORTER 1969)                                                                                                                               | AR69-2552.3  |
| TRANSLOCATION | PRELIMINARY RESULTS OF GROWTH CHARACTERISTICS OF BUFFALOGRASS, BLUE GRAMA, AND WESTER N WHEATGRASS. AND METHODOLOGY FOR TRANSLOCATION STUDIES USING 14C AS A TRACER. (KNIEVEL AND SCHMER 1971)          | TR086        |
| TRANSLOCATION | CARBOHYDRATE TRANSLOCATION IN BLUE GRAMA, BUFFALO-GRASS, AND WESTERN WHEATGRASS AS IN FLUENCED BY TEMPERATURE AND GROWTH STAGE. (SCHMER AND KNIEVEL 1972)                                               | TR160        |
| TREATMENTS    | POPULATION DENSITIES AND BIOMASS OF ABOVEGROUND ARTHROPODS UNDER VARIOUS GRAZING AND ENVIRONMENTAL STRESS TREATMENTS ON THE PAMNEE SITE. (LAVIGNE, ET AL. 1972)                                         | TR204        |
| TREATMENTS    | STUDIES OF POPULATIONS OF ADULTS AND IMMATURE INSECTS AND MITES FROM TWO TREATMENTS A T COTTONWOOD, SOUTH DAKOTA. (MCDANIEL 1971)                                                                       | TR112        |
| TREATMENTS    | SPATIAL DISTRIBUTION AND SUCCESSIONAL STATE OF GRASSLAND VEGETATION RELATED TO GRAZIN G INTENSITY TREATMENTS. (MITCHELL 1971)                                                                           | TR101        |
| TREATMENTS    | HERBAGE DYNAMICS ON THE PAMNEE SITE: ABOVEGROUND AND BELOWGROUND HERBAGE DYNAMICS ON THE FOUR GRAZING INTENSITY TREATMENTS; AND PRELIMINARY SAMPLING ON THE ECOSYSTEM STR ESS SITE. (SIMS, ET AL. 1971) | TR099        |
| TRIPHOSPHATE  | ADENOSINE TRIPHOSPHATE (ATP) IN GRASSLAND SOIL: ITS RELATIONSHIP TO MICROBIAL BIONAS S AND ACTIVITY. (SPARROW AND DOXTADER 1973)                                                                        | TR224        |
| TROPHIC       | EXAMPLES OF TROPHIC LEVEL AND TOTAL ECOSYSTEM MODELS. (VAN DYNE 1970)                                                                                                                                   | SS07.191-198 |
| TROPICAL      | CALORIC VALUES OF IMPORTANT PLANT AND INSECT SPECIES OF A TROPICAL GRASSLAND AT KURUK SHETRA, INDIA. (SINGH AND YADAVA 1972)                                                                            | OL083        |
| TUNDRA        | IBP GRASSLAND/TUNDRA INTERNATIONAL MODELLING-SYNTHESIS WORKSHOP: SUMMARY OF OUTPUT W ORKBOOK. (WIELGOLASKI 1972)                                                                                        | TR197        |
| TURNOVER      | METABOLIC COMPONENTS OF CATTLE: WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTITIONING BY CATTLE. (HYDER, ET AL. 1969)                                                                   | TR010        |
| TURNOVER      | WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTIONING BY CATTLE. (HYDER 1969).                                                                                                            | AR69-2561.1  |
| TMS           | A FIELD LIGHT-QUALITY LABORATORY--INITIAL EXPERIMENT: T85 MEASUREMENT OF PERCENT OF FUNCTIONING VEGETATION IN GRASSLAND AREAS BY REMOTE SENSING METHODOLOGY. (PEARSON, ET AL. 1971)                     | TR090        |
| UNGRAZED      | COMPARISONS OF ABOVEGROUND PLANT BIOMASS ON UNGRAZED PASTURES VS. PASTURES GRAZED BY LARGE HERBIVORES, 1970 SEASON. (GRANT 1971)                                                                        | TR131        |
| UNGRAZED      | HERBAGE DYNAMICS AND NET PRIMARY PRODUCTION IN CERTAIN UNGRAZED AND GRAZED GRASSLANDS IN NORTH AMERICA. (SIMS AND SINGH 1971)                                                                           | SS10.59-124  |
| UNIT          | A SIMPLIFIED UNIT FOR EVALUATION OF SOIL CORE RESPIROMETRIC ACTIVITY. (KLEIN, ET AL. 1972)                                                                                                              | OL067        |
| USDA          | MEMORANDA OF AGREEMENT AND PROCEDURES FOR WORKING ON FEDERAL LANDS OF THE USDA. (JAMESON AND NELL 1970)                                                                                                 | TR008        |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | PR73-115     |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | PR73-113     |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REP ORT 1971-2.7. (VAN DYNE 1971)                                                                                     | PR71-2.7     |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REP ORT 1971-4.4. (VAN DYNE 1971)                                                                                     | PR71-4.4     |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REP ORT 1971-2.5. (VAN DYNE 1971)                                                                                     | PR71-2.5     |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS RE PORT 1971-6. (VAN DYNE 1971)                                                                                      | PR71-6       |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | PR73-11      |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | PR73-12      |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | PR73-114     |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | PR73-13      |
| UTILIZATION   | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                                               | PR73-14      |

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| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                            | PR73-112     |
| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                            | PR73-19      |
| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                            | PR73-15      |
| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                            | PR73-111     |
| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-2.4. (VAN DYNE 1971)                                                                   | PR71-2.4     |
| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                            | PR73-116     |
| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                            | PR73-16      |
| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION, AND UTILIZATION OF GRASSLAND ECOSYSTEMS. (VAN DYNE 1973)                                                                                            | PR73-117     |
| UTILIZATION  | ANALYSIS OF STRUCTURE, FUNCTION AND UTILIZATION OF GRASSLAND ECOSYSTEMS, PROGRESS REPORT 1971-2.6. (VAN DYNE 1971)                                                                   | PR71-2.6     |
| VALUES       | CALORIC VALUES OF IMPORTANT PLANT AND INSECT SPECIES OF A TROPICAL GRASSLAND AT KURUK SHETRA, INDIA. (SINGH AND YADAVA 1972)                                                         | OL083        |
| VARIABILITY  | PREDICTABILITY OF PATTERNS AND VARIABILITY OF PRECIPITATION IN GRASSLANDS. (WIENS 1972)                                                                                              | TR168        |
| VARIATION    | OPUNTIA CLUMP SIZE VARIATION ON THE SHORTGRASS PLAINS, PAMNEE SITE, MUNN, COLORADO. (LESTER AND FISHER 1970)                                                                         | OL014        |
| VARIETY      | THE NATURE AND SIGNIFICANCE OF ECO-GENETIC VARIATION IN ECOSYSTEMS. (WARD 1969)                                                                                                      | SS02,148-152 |
| VEGETATION   | STATISTICAL ANALYSIS OF INTRASEASONAL HERBAGE DYNAMICS IN A VARIETY OF GRASSLAND COMMUNITIES. (FRANCIS AND CAMPION 1972)                                                             | TR141        |
| VEGETATION   | DETAILED VEGETATION MAPPING ON THE IBP PAMNEE SITE. (SHAWER AND FISHER 1972)                                                                                                         | TR150        |
| VEGETATION   | SOME MEASUREMENTS OF VEGETATION STRUCTURE ON THE PAMNEE GRASSLAND, 1970. (KNIGHT 1971)                                                                                               | TR072        |
| VEGETATION   | A FIELD LIGHT-QUALITY LABORATORY--INITIAL EXPERIMENT: TBS MEASUREMENT OF PERCENT OF FUNCTIONING VEGETATION IN GRASSLAND AREAS BY REMOTE SENSING METHODOLOGY. (PEARSON, ET. AL. 1971) | TR090        |
| VEGETATION   | SPATIAL DISTRIBUTION AND SUCCESSIONAL STATE OF GRASSLAND VEGETATION RELATED TO GRAZING INTENSITY TREATMENTS. (MITCHELL 1971)                                                         | TR101        |
| VEGETATION   | DYNAMICS OF STANDING DEAD VEGETATION ON THE SHORTGRASS PLAINS. (BEMENT 1969)                                                                                                         | SS02,221-224 |
| VEGETATION   | SOME INFLUENCES OF VEGETATION STRUCTURE ON ENERGY-FLUX, WATER-FLUX, AND NUTRIENT-FLUX IN GRASSLAND ECOSYSTEMS. (KNIGHT 1969)                                                         | SS02,197-220 |
| VEGETATION   | AN ANALYSIS OF VEGETATION STRUCTURE ON THE PAMNEE GRASSLAND, WITH SUBSEQUENT EVALUATIONS OF THE INFLUENCE OF STRUCTURE ON ECOSYSTEM FUNCTION. (KNIGHT 1969)                          | AR69-2553.2  |
| VEGETATION   | THE MEASUREMENT OF PERCENT OF FUNCTIONING VEGETATION IN GRASSLAND AREAS. (MILLER 1969)                                                                                               | AR69-2520    |
| VEGETATIONAL | VEGETATIONAL STUDIES ON THE ALE RESERVE, 1971. (RICKARD, ET AL. 1972)                                                                                                                | TR191        |
| VITAE        | CURRICULUM VITAE OF SCIENTISTS TO PARTICIPATE IN THE U.S. IBP GRASSLAND BIOME STUDIES PROPOSED FOR 1972 AND 1973. (WRIGHT 1971)                                                      | TR125        |
| WATER        | CURRICULUM VITAE OF SCIENTISTS WHO PARTICIPATED IN THE U.S. IBP GRASSLAND BIOME STUDIES FOR 1971 AND 1972. (HENDRICKS 1973)                                                          | TR223        |
| WATER        | ABIOTIC SUBSYSTEMS: HEAT AND WATER MODELS. (SMITH 1973)                                                                                                                              | TR220,13-121 |
| WATER        | EFFECTS OF WATER AND NITROGEN STRESSES ON A SHORTGRASS PRAIRIE ECOSYSTEM. (LAUENROTH AND SIMS 1973)                                                                                  | TR232        |
| WATER        | WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTITIONING BY CATTLE. (HYDER 1969)                                                                                        | AR69-2561.1  |
| WATER        | ENERGY-FLUX AND WATER KINETICS IN YOUNG PRONGHORN ANTELOPE. (WESLEY, ET. AL. 1970)                                                                                                   | OL040        |
| WATER        | WATER KINETICS IN PRONGHORN ANTELOPE. (WESLEY, ET. AL. 1969)                                                                                                                         | OL039        |
| WATER        | WATER KINETICS IN PRONGHORN ANTELOPE. (WESLEY, ET. AL. 1969)                                                                                                                         | OL007        |
| WATER        | PSYCHROMETRY IN WATER RELATIONS RESEARCH: A REVIEW. (VAN HAVEREN 1971)                                                                                                               | TR132        |
| WATER        | SURFACE ENERGY AND WATER BUDGET OVER THE GRASSLAND, 1970. (ALMEYDA AND RASMUSSEN 1972)                                                                                               | TR202        |

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| WATER         | MEASUREMENT OF THE ENERGY STATUS OF WATER IN A GRASSLAND ECOSYSTEM.<br>(VAN HAVEREN 1971)                                                                                                        | TR076         |
| WATER         | METABOLIC COMPONENTS OF CATTLE: WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTITIONING BY CATTLE. (HYDER, ET. AL. 1969)                                                           | TR010         |
| WATER         | SOIL WATER STUDY OF A SHORTGRASS PRAIRIE ECOSYSTEM, PANNEE SITE. (GALBRAITH 1969)                                                                                                                | TR006         |
| WATER         | MEASUREMENT OF THE COMBINED-EFFECT OF GREEN BIOMASS, CHLOROPHYLL, AND LEAF WATER ON C ANOPY SPECTROREFLECTANCE OF THE SHORTGRASS PRAIRIE. (TUCKER, ET. AL. 1973)                                 | OL066         |
| WATER-BALANCE | HYDROLOGY AND WATER-BALANCE OF SEMI-DESERT SOILS. (COOPER 1970)                                                                                                                                  | SS061,119-128 |
| WATER-FLUX    | SOME INFLUENCES OF VEGETATION STRUCTURE ON ENERGY-FLUX, WATER-FLUX, AND NUTRIENT-FLUX IN GRASSLAND ECOSYSTEMS. (KNIGHT 1969)                                                                     | SS02,197-220  |
| WATER-SOLUBLE | WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTITIONING BY CATTLE.<br>(HYDER 1969)                                                                                                 | AR69-2561.1   |
| WATER-SOLUBLE | METABOLIC COMPONENTS OF CATTLE: WATER-SOLUBLE TRACERS FOR DETERMINING WATER TURNOVER AND PARTITIONING BY CATTLE. (HYDER, ET. AL. 1969)                                                           | TR010         |
| WATERSHED     | THE DESIGN OF A SPATIAL DATA FRAMEWORK: CENTRAL BASIN WATERSHED, PANNEE SITE.<br>(OLIVER AND MILLER 1971)                                                                                        | TR089         |
| WEIGHT        | A STUDY OF THE WEIGHT ESTIMATION METHOD OF BOTANICAL ANALYSIS.                                                                                                                                   | TR117         |
| WEIGHT        | (FRANCIS, ET. AL. 1971)                                                                                                                                                                          | TR019         |
| WEIGHT        | DRY WEIGHT BIOMASS DATA FOR FOUR ABUNDANT GRASSHOPPER SPECIES OF THE PANNEE SITE.<br>(VANHORN 1969)                                                                                              | AR69-2562.1   |
| WEIGHT        | RELATIVE DRY WEIGHT ESTIMATES IN DIETS OF HERBIVORES BY THE MICROSCOPIC METHOD, AND 5 MALL MAMMAL BIOMASS ESTIMATION AT THE PANNEE SITE. (HANSEN, ET. AL. 1969)                                  | OL011         |
| WEIGHT        | METHODS OF ESTIMATING DRY WEIGHT COMPOSITION IN DIETS OF STEERS.<br>(FREE, ET. AL. 1971)                                                                                                         | OL003         |
| WEIGHTS       | ESTIMATING DRY WEIGHTS OF FOOD PLANTS IN FECES OF HERBIVORES. (FREE, ET. AL. 1970)                                                                                                               | TR086         |
| WHEATGRASS    | PRELIMINARY RESULTS OF GROWTH CHARACTERISTICS OF BUFFALOGRASS, BLUE GRAMA, AND WESTERN WHEATGRASS, AND METHODOLOGY FOR TRANSLOCATION STUDIES USING 14C AS A TRACER.<br>(KNIEVEL AND SCHMER 1971) | TR160         |
| WHEATGRASS    | CARBOHYDRATE TRANSLOCATION IN BLUE GRAMA, BUFFALO-GRASS, AND WESTERN WHEATGRASS AS IN FLUENCED BY TEMPERATURE AND GROWTH STAGE. (SCHMER AND KNIEVEL 1972)                                        | SS05,23-49    |
| WILDLIFE      | SIMULATION TECHNIQUES IN WILDLIFE HABITAT MANAGEMENT. (GILES AND SNYDER 1970)                                                                                                                    | SS02,172-182  |
| WOODY         | THE NATURE AND IMPORTANCE OF COMPETITION BETWEEN WOODY AND HERBACEOUS PLANTS IN A GRASSLAND ECOSYSTEM. (SHUBERT 1969)                                                                            | TR197         |
| WORKBOOK      | IBP GRASSLAND/TUNDRA INTERNATIONAL MODELLING-SYNTHESIS WORKSHOP: SUMMARY OF OUTPUT W ORKBOOK. (WIELGOLASKI 1972)                                                                                 | TR197         |
| WORKSHOP      | IBP GRASSLAND/TUNDRA INTERNATIONAL MODELLING-SYNTHESIS WORKSHOP: SUMMARY OF OUTPUT W ORKBOOK. (WIELGOLASKI 1972)                                                                                 | TR220         |
| WORKSHOP      | PROCESS STUDIES WORKSHOP REPORT. (JAMESON AND DYER 1973)                                                                                                                                         | SS0611,1-69   |
| WORKSHOP      | RESULTS OF WORKSHOP GROUPS. (WRIGHT AND VAN DYNE 1970)                                                                                                                                           | OL057         |
| YEARLING      | CHEMICAL COMPOSITION OF THE DIET, INTAKE AND GAIN OF YEARLING CATTLE ON DIFFERENT GRASSING INTENSITIES. (VAURA, ET. AL. 1973)                                                                    |               |



# ABSTRACTS

## Technical Reports

- TR139 Dickinson, C. E., and C. V. Baker. 1972. Pawnee Site field plant list. US/IBP Grassland Biome Tech. Rep. No. 139. Colorado State Univ., Fort Collins. 44 p.

### Pawnee, Plant-checklist

This paper gives a series of cross referenced plant code lists for plants occurring on the Pawnee Site. Recent synonyms are given, as are longevity, seasonality, and class of plant. Included are alphabetical lists by code, scientific and common name, as well as presence lists by grazing treatment and replicate. A standardized coding procedure is described. One section of the report provides room for field notes for individual users.

- TR140 Dickinson, C. E. 1972. Pawnee Site plant live-dead separation. US/IBP Grassland Biome Tech. Rep. No. 140. Colorado State Univ., Fort Collins. 18 p.

### Pawnee, Aboveground-plant-biomass, Standing-dead, Plant-live-dead-separation

For species which were not easily separated in the field, a reconnaissance procedure was used to separate aboveground plant biomass into a this year's growth and a previous year's growth fraction. Checks were made by mechanical and hand sorting methods. A complete data listing is included.

- TR141 Francis, R. C., and M. Campion. 1972. Statistical analysis of intraseasonal herbage dynamics in a variety of grassland communities. US/IBP Grassland Biome Tech. Rep. No. 141. Colorado State Univ., Fort Collins. 142 p.

Bison-Site, Bridger, Cottonwood, Dickinson, Hays, Jornada, Osage, Pantex, Pawnee, Principal-component-analysis, Grazing-influence, Aboveground-plant-biomass, Standing-dead, Intersite-comparison

Intrasite comparisons of aboveground plant biomass were made using data from the 1970 field season. Ordinations were made using analysis of variance and principal component analysis in an attempt to reveal the structural components of the herbage biomass across the grasslands. The nine sites analyzed were Bison, Bridger, Dickinson, Cottonwood, Hays, Jornada, Pantex, Pawnee, and Osage.

- TR142 Yount, V. A., and T. O. Thatcher. 1972. Plant/insect interactions of selected insects at the Pawnee Site. US/IBP Grassland Biome Tech. Rep. No. 142. Colorado State Univ., Fort Collins. 34 p.

Pawnee, Insects, Plant-fragment-identification, Beetle, Food-composition, Insect-checklist, Bug, Leaf-hopper, Tree-hopper, Insect-foodweb

The diets of prevalent phytophagous insects other than orthopterans were studied on the light and no grazing pastures at the IBP Pawnee Site eight miles northeast of Nunn, Colorado, during the summer of 1970.

The methods used were those of visual observation and microscopic analysis of the contents of beetle stomachs. Plant-insect matrices were used for interpretation of the results of observations. The relative percent dry weight of the species of plants in the insect diets and indices of preference were calculated for those beetles whose diets were studied by the microscopic technique.

*Eleodes obsoleta* fed primarily on *Psoralea tenuiflora* and *Oenothera coronopifolia*. *E. fusiformis* chose *Bouteloua gracilis* and *Carex heliophila* consistently. *E. extricata* had *O. coronopifolia* and *C. heliophila* as major foods. *E. hispilabris* selected *B. gracilis* and *O. coronopifolia* predominantly. *E. tricostrata* ate chiefly *Thelesperma megapotamicum* and *P. tenuiflora*. *Edrotes* sp. ate primarily *B. gracilis*, while *Epicauta parva* chose chiefly *Oxytropis sericea*. *Lytta* sp. selected *Sophora sericea* primarily. *Crataeanthus dubius* fed on *B. gracilis* and *Agropyron smithii*, while *monilema annulata* ate chiefly *Opuntia polyacantha*.

The family of insects most commonly observed was Aphididae, followed by Cicadellidae, Chrysomelidae, Membracidae, and Meloidae. Cicadellidae was the insect family observed in the greatest numbers on the most species of plants, followed by Chrysomelidae, Meloidae, and Formicidae.

*Cuerna costalis* was the most observed species of insect, followed by *Campylenchia latipes*, *Carpophilus pallipennis*, *Epicauta stuarti*, *Nodonata puncticollis*, and *Chauliognathus limbicollis*. *Gutierrezia sarothrae* was the species of plant most often visited by insect species, followed by *Chrysothamnus nauseosus* and *Cirsium undulatum*.

- TR143 Swartzman, G. L. [Ed. and Coordinator]. 1972. Optimization techniques in ecosystem and land use planning. US/IBP Grassland Biome Tech. Rep. No. 143. Colorado State Univ., Fort Collins. 164 p.

### Optimization, Modeling-concept, Simulation, Models

This paper reviews a series of techniques which have been used by the systems planner to aid him in best achieving his objectives in light of the physical limitations imposed upon him by the system. These techniques have been collectively called optimization techniques. The report briefly reviews these techniques from a mathematical viewpoint and then proceeds to summarize the applications of these techniques to ecosystem problems. Another section speculates on other possible

applications of optimization techniques in ecosystem problems.

Finally, the paper reviews the general application of optimization techniques to land use planning and tries to develop a general procedure for maximizing the "equality of life" in a community by the proper allocation of land in the community between the urban, agricultural, and range sections. This problem represents an interdisciplinary approach to the solution of land resource planning problems and combines the inputs of the various disciplines into an optimization framework.

- TR144 Van Wyk, J. J. P. 1972. A preliminary report on new separation techniques for live-dead aboveground grass herbage and roots from dry soil cores. US/IBP Grassland Biome Tech. Rep. No. 144. Colorado State Univ., Fort Collins. 16 p.

Pawnee, Plant-live-dead-separation, Root-soil-separation

Separation of live from dead herbage and roots from soil can be expensive and time consuming operations. Equipment has been designed to greatly assist in each of these operations. The live-dead herbage separation operates on the principle of aerodynamic differences between live and dead herbage in an airstream. The root-soil device is a dry crusher-separator which is particularly well suited for obtaining non-washed roots for chemical analyses.

- TR145 Swift, D. M., and N. R. French [Coordinators]. 1972. Basic field data collection procedures for the Grassland Biome 1972 season. US/IBP Grassland Biome Tech. Rep. No. 145. Colorado State Univ., Fort Collins. 86 p.

Field-data-procedures

Details of the treatment design and sampling scheme to accumulate a basic set of state variable and driving variable data from the Grassland Biome sites during the 1972 field season is described. Sample data forms are included, and their uses are explained. *Changes from procedures followed in the 1971 field season (described in Technical Report No. 85) are signified by a double asterisk (\*\*) in the right-hand margin.*

- TR146 Swift, D. M., and U. G. Bokhari. 1972. Basic sample collection and handling Procedures for the Grassland Biome 1972 season. US/IBP Grassland Biome Tech. Rep. No. 146. Colorado State Univ., Fort Collins. 17 p.

Sample-processing, Sample-collection

This report details sample collection requirements at all Grassland Biome sites. Methods and frequencies of collection of each type of sample material are explained along

with instructions for handling and shipping of sample material to the Natural Resource Ecology Laboratory. In addition, the operations of the three laboratory facilities utilized in sample analysis are outlined.

- TR147 Robinson, B. 1972. Program INSTAR: An information storage and retrieval system user's manual. US/IBP Grassland Biome Tech. Rep. No. 147. Colorado State Univ., Fort Collins. 72 p.

Computer-programs, Information-storage, Information-retrieval

INSTAR is a storage and retrieval system for creating and maintaining large data banks consisting of data sets and copies of analyses performed on those data sets. INSTAR allows the retrieval of selected portions of a data set and the combination of several portions to form a new data set. File descriptions and data set abstracts are maintained with each set in the bank.

The user's manual includes instructions for:

- i. Reserving a data set,
- ii. Describing a data set,
- iii. Modifying a data set,
- iv. Modifying a data set description,
- v. Displaying a director of the data sets,
- vi. Retrieving a data set description,
- vii. Copying a data set,
- viii. Selecting information from a data set, and
- ix. Building a new data set from existing data.

Several examples are also listed and described.

INSTAR is written entirely in FORTRAN extended for use on the CDC 6400 computer system at Colorado State University.

- TR148 Van Horn, D. H. 1972. Grasshopper population numbers and biomass dynamics on the Pawnee Site from fall of 1968 through 1970. US/IBP Grassland Biome Tech. Rep. No. 148. Colorado State Univ., Fort Collins. 70 p.

Pawnee, Grasshopper, Grasshopper-biomass, Insects, Insect-density, Insect-biomass, Insect-checklist, Food-composition, Insect-foodweb

Quantitative samples of orthopteroid insects, especially grasshoppers, have been accumulated from October 1968 through December 1970 on three pasture types of the Pawnee Site. The sampling was done, mainly using

a mobile cage and a string frame, each device enclosing a 2 m<sup>2</sup> area.

Insects of 43 species have been identified using the above and other methods. Common grasshoppers (family Acrididae) comprise 34 of these species of which 11 are important contributors to the population density and biomass of the pastures sampled. There appeared to be some tendency for a few species to be restricted to lowlands where the plant community is different from that of upland sites.

Population density of adults was greatest in late summer (August) or early fall (September and October) and was comprised mainly of four to six species of grasshoppers. Peak densities of adult grasshopper populations for the three years were: 1968 (October), 19.4/10 m<sup>2</sup>; 1969 (September), 7.8/10 m<sup>2</sup>; and 1970 (August-September), 5.1/10 m<sup>2</sup>.

There is also a group of four species whose eggs hatch during the summer and over winter as late instar nymphs. These nymphs may be active consumers during warm, calm winter days. Adults of these species appear in late April and early May and remain until approximately the end of June, thus constituting an early summer adult population composed of a much lower density (and biomass) than the fall population.

Ovendry weight data have been accumulated for both sexes of all nymphal instars and adults for most of the abundant and common species. These have been used to calculate biomass for the grasshopper fauna on the Pawnee Site. In 1970 total biomass during the spring was approximately 80 mg/10 m<sup>2</sup> and climbed to a peak of approximately 320 mg/10 m<sup>2</sup> during September, then fell precipitously to about 100 mg/10 m<sup>2</sup> as the adults died off at the end of the year (composed of the late instar nymphs mentioned above). Annual species biomass curves resemble the general form of the total biomass curve with the six important fall species showing their peaks of biomass at the same time (September) as the total curve while the four early summer species show peak biomass during May. Thus, while the total population density may be greatest in midsummer due to the presence of a large nymphal component, the increase in biomass of the grasshopper population is much more a function of the appearance of adults during the late summer and early fall.

Both peak adult population densities and peak biomass varied from 1968 through 1970. In 1968 the peak biomass was 1.37 g/10 m<sup>2</sup> but only 0.55 g/10 m<sup>2</sup> in 1969 and 0.33 g/10 m<sup>2</sup> in 1970.

An analysis of Central Plains Experimental Range precipitation and temperature data for 1968 and 1969 lends support to the hypothesis that hot, dry weather in June (as in 1968) encourages the emergence and survival of first instar nymphs which results

in a larger adult population in the fall, whereas cold, wet weather in June (1969) increases egg and/or early nymph mortality, thus depressing the resultant adult population density and its biomass.

- TR149 Sparks, K. L. 1972. Grazing behavior of bison and cattle on a shortgrass prairie. US/IBP Grassland Biome Tech. Rep. No. 149. Colorado State Univ., Fort Collins. 7 p.

Pawnee, Bison, Cattle, Mammals, Grazing-Influence

Two 24-hour observations were made on a mixed species herd of cattle and bison: one on a heavily grazed pasture and the other on a lightly grazed pasture. Only two main activities were recorded, resting and grazing. No large species differences were recorded in the amounts of time spent grazing or resting. Several important interactions were observed, the most notable being that the bison were dominant over the cattle in selection of grazing areas, bedding grounds, and water holes. Other differences included the more protective nature of bison for the individuals in the herd and their unwillingness to be separated from the herd.

- TR150 Shaver, J. C., and H. G. Fisser. 1972. Detailed vegetation mapping of the IBP Pawnee Site. US/IBP Grassland Biome Tech. Rep. No. 150. Colorado State Univ., Fort Collins. 44 p.

Pawnee, Leaf-area-index, Vegetation-mapping

The Pawnee Site rangelands, although relatively uniform and dominated by blue grama, exhibit phytosociological variation resulting from soil, moisture, relief, and grazing treatment influences upon vegetation. The spatial modeling effort of the Grassland Biome program requires a detailed vegetation map with definitive type units no larger than 0.1 ha (10 m x 10 m). To this end, three forms of remote sensing imagery were utilized: panchromatic photographs at a scale of 1:5800 and color and infrared prints at a slightly smaller scale. Utilizing mirror and lens stereoscopes, first-order delineations were applied to the panchromatic photographs with further detail added following comparison to the color and infrared prints. Type lines were drawn on the black-and-white prints based on photographic tone, texture, pattern, topographic location, and color variations observable on the three imagery forms. Through a secondary photographic procedure the type lines were transferred to a topographic base map with a scale of 1:4800. Ground truth data were based on Leaf Area Indices (LAI) derived from point hits utilizing a motorized point frame with a movable pin.

TR151 Olendorff, R. R. 1972. The large birds of prey of the Pawnee National Grassland: Nesting habits and productivity, 1969-1971. US/IBP Grassland Biome Tech. Rep. No. 151. Colorado State Univ., Fort Collins. 59 p.

Pawnee, Birds, Nesting, Bird-production, Raptor, Swainson's-Hawk, Ferruginous-Hawk, Hawk, Owl, Horned-Owl, Golden-Eagle, Eagle, Falcon, Bird-checklist, Bird-biomass

The potential of the Pawnee National Grassland and adjacent areas for long-term raptor research and management is great. This paper considers fundamental data on nesting and productivity of the large birds of prey in that area during 1970 and 1971. The study was an effort to document the status and timing of the raptors' reproductive cycles, their absolute population densities, nesting habits, biomasses, and interactions with man.

Lengthy discussions of biomass, intra- and interspecific nesting competition, and the relationship between man and the grassland raptors are included, as are tables of standard productivity data such as clutch sizes, brood sizes, pairs per unit area, young produced per unit area, abandonment rates, young per successful nest, and young produced per pair. Differential utilization of grassland habitats is considered in detail.

Determination of absolute nesting densities of Swainson's Hawks, Ferruginous Hawks, Great Horned Owls, and Golden Eagles showed that 42 pairs of large birds of prey nested in a 414-sq mile area in 1971, about 10 pairs per 100 sq miles. These birds produced 11.1 young per 100 sq miles. Figures are also given in the metric system in the text.) The adults and young on the 414-sq mile study area represented a biomass of 151.5 g/km<sup>2</sup>. Considering estimated populations in a 2,266-sq mile portion of Weld County, Colorado, a collective biomass of 230.2 g/km<sup>2</sup> was calculated for the large birds of prey.

With regard to nesting habits, it was quantitatively demonstrated that man has played an important role--often a positive role--in the utilization of grasslands by birds of prey. Over one-quarter of all nestings by birds of prey are in situations created directly or indirectly by man. Differential utilization of grassland habitats was analyzed using the following habitat categories: bluff lines, cultivated land, creek bottoms, and pure grasslands. Swainson's Hawks and Great Horned Owls most often nested in creek bottoms, while Ferruginous Hawks nested in pure grasslands more commonly. All Prairie Falcons and most Golden Eagles nested along bluff lines. Only the Swainson's Hawk consistently nested near cultivated land with widely scattered trees.

TR152 Copley, P. W., and J. O. Reuss. 1972. Evaluation of biological N<sub>2</sub> fixation in a grassland ecosystem. US/IBP Grassland Biome Tech. Rep. No. 152. Colorado State Univ., Fort Collins. 90 p.

Pawnee, Nitrogen-fixation

A series of investigations were conducted to determine the significance of biological nitrogen fixation on the Pawnee Site, the intensive study area of the U.S. International Biological Program Grassland Biome. Additional studies were carried out to investigate the rates of N<sub>2</sub> fixation by leguminous plants as a function of plant age. The acetylene reduction assay, an indirect method of measuring N<sub>2</sub> fixation, was used in all studies. All calculations of N<sub>2</sub> fixation rates were based on a conversion factor of 1 mole of N<sub>2</sub> fixed/3 moles of ethylene produced. The acetylene reduction assay proved to be a sensitive method for measuring low rates of N<sub>2</sub> fixation.

Under field capacity moisture levels without an added energy source, asymbiotic N<sub>2</sub> fixation rates were <50 µg/m<sup>2</sup>/day, the lower limit of detection in the systems studied. With the addition of readily assimilable carbon, 0.1 to 0.2 mg N<sub>2</sub> was fixed/m<sup>2</sup>/day. Under saturated moisture conditions without additional energy supplied, N<sub>2</sub> fixation rates were under 1 mg/m<sup>2</sup>/day. With the addition of sucrose to saturated soil cores, N<sub>2</sub> fixation rates were approximately 0.1 to 0.2 g/m<sup>2</sup>/day.

With the addition of sucrose, asymbiotic N<sub>2</sub> fixation rates were greatest (0.25 g/m<sup>2</sup>/day) in saturated soils under a helium atmosphere; about equal (0.12 g/m<sup>2</sup>/day) with soils at field capacity under a helium atmosphere and with saturated soils under an 80:20 helium:oxygen atmosphere; and lowest (0.15 mg/m<sup>2</sup>/day) in soils at field capacity under an 80:20 helium:oxygen atmosphere. Readily assimilable sucrose added to saturated grassland soils at levels of 14-56 g C/m<sup>2</sup> resulted in the fixation of 9-10 mg N<sub>2</sub>/g C.

Nitrogen fixation was severely restricted at temperatures of 16°C and lower. Because of the moisture and temperature conditions found at the Pawnee Site, N<sub>2</sub> fixation by heterotrophic organisms is probably of limited significance.

Studies showed that symbiotic N<sub>2</sub> fixation by leguminous plants could represent an important source of nitrogen on grassland ecosystems where legumes compose a significant fraction of the vegetation. *Oxytropis sericea* demonstrated an average N<sub>2</sub> fixation rate of 0.61 mg/plant/day. However, low legume plant densities on the Pawnee Site suggest that this source of nitrogen is not likely to be significant in this ecosystem.

In single plant comparisons of N<sub>2</sub> fixation rates, soybeans, sweetclover, sainfoin and alfalfa demonstrated maximum N<sub>2</sub> fixation (C<sub>2</sub>H<sub>2</sub>-C<sub>2</sub>H<sub>4</sub> assay) rates of 4.7, 3.3, 3.0

and 2.6 mg/plant/day respectively. Differences in the  $N_2$  fixation rates between light and dark incubations were significant for soybeans only.

- TR153 Parton, W. J., and G. S. Innis. 1972. Some graphs and their functional forms. US/IBP Grassland Biome Tech. Rep. No. 153. Colorado State Univ., Fort Collins. 41 p.

Computer-programs, Modeling-concept, Functional-graphs

The modeling of biological systems often involves the insertion of a functional form to represent the response of a state variable to a stimulus. This technical report depicts the curves, describes a functional form for that curve, and illustrates the effects of parameter variation. Other functions have similar graphs and the FORTRAN code implementing the function is not unique.

- TR154 Harris, L. D., and L. Paur. 1972. A quantitative food web analysis of a shortgrass community. US/IBP Grassland Biome Tech. Rep. No. 154. Colorado State Univ., Fort Collins. 22 p.

Food-composition, Food-web, Dietary-matrix, Mammals, Insects, Birds, Reptiles

Several modes of analysis were imposed upon certain data sets contained in the US/IBP Grassland Biome central data bank. The first analysis resulted in a vector of food items occurring in the summer diet for each of 36 different consumer groups. These data were then collated to form a  $36 \times 112$  dietary-composition matrix for the major consumer groups of a shortgrass prairie ecosystem. A second analysis produced a matrix of pairwise dietary-overlap values based upon the species composition of the observed diets. Finally, we attempted to estimate the relative importance of the various consumer groups by synthesizing the approximate densities, the number of active days per year, and the daily consumption rates.

Results indicate a clear dichotomy between herbivore and carnivore groups, but overlap values are as high as 100% within the two major groups. It also appears that at a modest stocking rate of one animal unit per 30 acres, domestic stock may account for as much as 68% of the annual aboveground energy transferral.

- TR155 Singh, J. S. 1972. US/IBP Grassland Biome literature: A KWIC index and abstracts. US/IBP Grassland Biome Tech. Rep. No. 155. Colorado State Univ., Fort Collins. 176 p.

KWIC-index, SWIT-index, Biome-literature

A total of 311 articles originating from the efforts of the US/IBP Grassland Biome Program up to 1971 have been abstracted and

indexed in this report. Indices include a KWIC index (Key Word In Context) and a SWIT index (Significant Word In Title). In all, 474 key words have been used. The key words were allotted to each article on the basis of its entire text. Instructions for the use of the indices are detailed in the report.

- TR156 Anway, J. C., E. G. Brittain, H. W. Hunt, G. S. Innis, W. J. Parton, C. F. Rodell, and R. H. Sauer. 1972. ELM: Version 1.0. US/IBP Grassland Biome Tech. Rep. No. 156. Colorado State Univ., Fort Collins. 285 p.

Models, Ecosystem-model, Abiotic-model, Producer-model, Mammal-model, Decomposer-model, ELM-model, Simulation, Computer-programs

This report contains a description of a model called "ELM." The report focuses on the structure and organization of the model rather than on the specific application of the model to a particular research site. The purpose of this report is primarily to provide an information document on the progress of this modeling activity. It is not considered to be complete in terms of a functional ecosystem model, but it does purport to describe completely a structure and organization for the development of such a total ecosystem model, and does present details of the development of some portions of that model.

This model will be used as a starting point by the liaison staff at the Natural Resource Ecology Laboratory from which to develop a model for each of the Comprehensive Network Sites. This application will obviously involve not only tuning of what currently exists, but also development of new material as necessary.

- TR157 Smith, F. M. 1972. Growth response of blue grama to thunderstorm rainfall. US/IBP Grassland Biome Tech. Rep. No. 157. Colorado State Univ., Fort Collins. 31 p.

Blue-grama, Precipitation, Plant-growth

This paper is a review of literature pertinent to the growth of blue grama with respect to thunderstorm rainfall in the short-grass grasslands of central North America. The review is not exhaustive, but it does serve to draw attention to this climatic-biotic relation.

- TR158 Harris, L. D., and R. C. Francis. 1972. AFCONS: A dynamic simulation model of an interactive herbivore community. US/IBP Grassland Biome Tech. Rep. No. 158. Colorado State Univ., Fort Collins. 88 p.

Models, Simulation, AFCONS-model, Consumer-model, Computer-programs

AFCONS, an acronym for African Consumers, is a nonlinear, differential equation model of an interactive consumer community. Age classes of several herbivore, carnivore, and scavenger species are represented by 38 principal system variables as well as abiotic and vegetation driving variables. Over 800 FORTRAN coded statements constitute the program deck.

Three concurrently operative routines solve sets of equations for energy, balance, change in weight, and change in numbers. Feedback between the routines allows food quality and quantity control of birth, death, and predation rates as well as competitive shifts in diet.

- TR159 Risser, P. G. [Ed.]. 1972. A preliminary compartment model of a tallgrass prairie, Osage Site, 1970. US/IBP Grassland Biome Tech. Rep. No. 159. Colorado State Univ., Fort Collins. 21 p.

Osage, Models, Compartment-model, Ecosystem-model

A compartment model was constructed from the 1970 data collected on the Osage Site. The state variables were estimated from field data and the time of peak live plant production. Flow rates of carbon between compartments were estimated both from field data and literature values. The producer portion of this tallgrass ecosystem composed 73% of the biomass, and the decomposer biomass contributed 26%. The invertebrates, birds, and mammals together contributed less than 1% of the total biomass feature. Efforts with this model will include time varying considerations.

- TR160 Schmer, D. A., and D. P. Knieval. 1972. Carbohydrate translocation in blue grama, buffalo grass, and western wheatgrass as influenced by temperature and growth stage. US/IBP Grassland Biome Tech. Rep. No. 160. Colorado State Univ., Fort Collins. 72 p.

Blue-grama, Buffalo-grass, Western-wheatgrass, Translocation, Carbon-14

A study was undertaken to examine the effects of temperature and stage of growth on the translocation of  $^{14}\text{C}$  to blue grama, buffalo grass, and western wheatgrass roots. Accumulation of  $^{14}\text{C}$  in blue grama and western wheatgrass roots was significantly affected by temperature and growth stage, respectively. Temperature and growth stage did not significantly influence  $^{14}\text{C}$  accumulation in buffalo grass roots.

- TR161 Risser, P. G. [Ed.]. 1972. Preliminary producer data synthesis, 1970 Comprehensive Sites. US/IBP Grassland Biome Tech. Rep. No. 161. Colorado State Univ., Fort Collins. 148 p.

Bison-Site, Bridger, Cottonwood, Dickinson, Hays, Jornada, Osage, Pantex, Pawnee, Growing-season, Air-temperature, Precipitation, Solar-radiation, Soil-water, Evaporation, Intersite-comparison, Aboveground-plant-biomass, Primary-production, Yield, Shoot-root-ratio, Belowground-plant-biomass, Litter, Standing-dead, Plant-checklist

The 1970 field data from the US/IBP Comprehensive Network Sites were analyzed by my students from the University of Oklahoma. The data analysis emphasized intersite comparisons of producer and abiotic components of the grassland ecosystems. When various sites were ordered with ordination techniques using environmental vegetation and floristic values, there was an overall similarity in end-stand differences. Total biomass production as well as productivity were correlated with various environmental parameters and vegetation types. Multiple regression analysis was used to separate the manner in which particular species responded to climatic conditions. Three measures of biomass production were compared and found to give significantly different results. In more xeric sites, root turnover rates and root-shoot-ratios were higher. Both phenology and species association were evaluated, but the data was not entirely appropriate.

- TR162 Van Dyne, G. M., and G. S. Innis [Ed.]. 1972. Macrolevel ecosystem models in relation to man: A preliminary analysis of concepts and approaches. US/IBP Grassland Biome Tech. Rep. No. 162. Colorado State Univ., Fort Collins. 61 p.

Models, Modeling-concept, Ecosystem-model, Resource-model

Man now accepts that he is both part of, and a manipulator of, ecosystems and that such systems are the basic units in renewable resource management. Ecosystems, however, can be considered simple subsystems of biomes. Biomes, in turn, can be combined into regional systems and regional systems into national systems. Through these increasing spatial scales one enters different components into the macrosystem--abiotic, biotic, economic, sociologic, and politic. Understanding the structure, function, and stability of ecosystems is important in affecting and varying the determinants of quality of human life. Quality of human life is reciprocally related to changing human attitudes towards uses of the resources of the biosphere. Man finds increasing need to be able to predict the ways his manipulations will affect the behavior of these complex biotic-economic-sociologic systems. His predictions must be by means other than simple contemplation, discussion, argument, or guesswork because these procedures, which may be adequate for simple systems are inadequate for complex systems. Recent advances in mathematical modeling and computer technology, because they are more complete than is intuition alone, can provide outputs useful to the decision-making process.

Several needs and types of large-scale or macromodels are recognized. Output from solutions of these models can enable scientists, managers, and decision makers to examine the future consequences of systems manipulations and potential policy alternatives. We have identified 8 major types of uses of such macromodels and 13 major user groups. Categories of uses include scientific, resource management, and human resource. Categories of user groups relate to the time at which the models may be utilizable, i.e., short-range, medium-range, and long-range. User groups include scientists involved in integrated ecological research programs, program planning office personnel, natural resource management agencies, international planning agency programs, educational institutions, international investment and advisory groups, and other groups including legislators and the general public.

Eight major problems related to prospective advances in ecological and systems science, resource management systems, and human resource systems are identified: (i) techniques for modeling the interactions between biomes and the linkages between ecosystems and social systems are barely available; (ii) a macrolevel synthesis of biome or microsystem models has yet to be attempted; (iii) the macrosystem models useful for the assessment of environmental impact and the evaluation of environmental impact statements are not available; (iv) the dialog which must precede the establishment of data banks and models in the socioecological area has not yet begun in earnest; (v) macromodels that effectively address practical management problems in the natural resource area are not widely available; (vi) advances in scientific and management processes are inadequate without edification of resource managers, and inadequate training represents a significant impediment; (vii) macrolevel models will not achieve their ultimate potential of improving man's existence unless the present gap in providing the public and its various constituents information from the models can be overcome; (viii) the implications of a national population growth strategy, land use policy, new town program, or other such programs are unknown.

Six broad recommendations regarding macromodeling are identified: (i) the holistic, macromodeling approach toward the solution to environmental problems should be accepted in principle; (ii) an interdisciplinary task force should be mobilized to review, critically abstract, index into a functional framework, and document existing macroscale models; (iii) a national macroscale model should be developed using inputs from the US/IBP programs with the objective of advancing our understanding of macromodeling techniques; (iv) projects should be undertaken to demonstrate the potential of using ecosystem models to aid in evaluation of environmental impact statements and management manipulations of natural resources; (v) efforts should be initiated to examine alternative ways to

bridge the gap from basic ecological research outputs up to regional and national political systems and to include societal feedbacks; and (vi) structure of, and output from, macroecosystem models should be explained to various educational and public groups from which feedback should be elicited.

This report, developed in a workshop format by a 15-man task force, also provides minimal time and cost estimates and procedural suggestions for accomplishing some of the tasks outlined. Specific attention is given to clarifying concepts of hierarchies of models and to providing a skeleton outline for a national modeling effort, based on biome and non-biome efforts both, to investigate the impact of abiotic factors, population growth and shifts, and land use policies on the production of food and fiber in the United States.

TR163 Grant, W. E. 1972. Small mammal studies on the Pawnee Site during the 1971 field season. US/IBP Grassland Biome Tech. Rep. No. 163. Colorado State Univ., Fort Collins. 51 p.

Pawnee, Mammals, Mammal-density, Grazing-influence, Ecosystem-stress, Mammal-biomass, Mammal-energetics, Energy-flow, Food-composition, Dietary-matrix, Aboveground-plant-biomass, Grasshopper-mouse, Deermice, Deermice-density, Deermice-biomass, Grasshopper-mouse-density, Grasshopper-mouse-biomass, Ground-squirrel, Ground-squirrel-density, Ground-squirrel-biomass, Kangaroo-rat, Kangaroo-rat-density, Kangaroo-rat-biomass

Results of small mammal trapping at the Pawnee Site during the 1971 field season are summarized. Population density estimates are made for each small mammal species on each of six treatments for each trapping period. The six treatments are compared with respect to small mammal biomass, and estimates are made concerning the energy needs of each species. Mean summer diets of the five small mammal species are compared. Niche segregation of small mammals at the Pawnee Site is discussed.

TR164 Knight, D. H. 1972. Leaf area dynamics on the Pawnee Grassland, 1970-1971. US/IBP Grassland Biome Tech. Rep. No. 164. Colorado State Univ., Fort Collins. 22 p.

Pawnee, Leaf-area, Leaf-area-index, Short-grass, Blue-grama, Buffalo-grass, Plant-cover, Prickly-pear, Precipitation, Grazing-influence, Primary-production

This report contains data on the leaf area dynamics of the Pawnee National Grassland in northern Colorado. Specific objectives were (i) to measure seasonal changes in leaf area during 1970 and 1971, (ii) to estimate the influence of irrigation, irrigation plus nitrogen fertilization, and grazing on leaf area, and (iii) to calculate

average daily aboveground productivity per unit of leaf area during the peak of the growing season. The point quadrat method was used for leaf area measurement. Peak leaf area was reached in mid-June of both years with a maximum Leaf Area Index (LAI) of 0.55 in 1970. Both years were drier than average, but seasonal distribution of rainfall was different with a corresponding seasonal difference in LAI. Irrigation alone increased LAI by about two-thirds, and irrigation plus fertilization increased LAI by approximately tenfold. The different grazing treatments had very similar leaf area values. Aboveground productivity per unit leaf area averaged about 5 g/day/m<sup>2</sup> of leaf area in May and about 4 g in June and July 1970. An appendix includes supplementary information on (i) the relationship of green leaf area and shoot dry weight for *Bouteloua gracilis* and (ii) the percent interception of direct sunlight by green leaves at different times of the day. The minimum interception is during midday.

- TR165 Armijo, J. D. 1972. Development of a large, undisturbed weighing lysimeter for evapotranspiration studies on grassland. US/IBP Grassland Biome Tech. Rep. No. 165. Colorado State Univ., Fort Collins. 153 p.

Pawnee, Instrumentation, Lysimeter, Evapotranspiration, Meteorology, Soil-water, Texture, Soil-temperature, Microwatershed, Precipitation

For the Grassland Biome, United States International Biological Program for Analysis of Structure, Function, and Utilization of Grassland Ecosystems, a large weighing lysimeter was developed, 1969 to 1972.

This dissertation describes the research, planning, design, construction, calibration, operation, maintenance, and performance of the lysimeter. Special emphasis is given to the undisturbed features of the soil core and perimeter area of the lysimeter, features which make it unique in the field of lysimetry.

Preliminary analysis and evaluation of one year's data are given, paving the way for several years of study into evapotranspiration and its role in the energy-dependent biological processes of the grassland.

- TR166 Reed, R. C. 1972. Insects and other major arthropods of a tallgrass prairie. US/IBP Grassland Biome Tech. Rep. No. 166. Colorado State Univ., Fort Collins. 144 p.

Osage, Insects, Insect-density, Insect-biomass, Grazing-influence, Instrumentation, Plant-checklist, Insect-systematics, Insect-checklist, Feeding-habit

Rangeland offers ideal habitats where populations of insects can multiply almost unnoticed. Ecological data are generally not

available for insect herbivores, with the exception of some species of Acrididae.

Invertebrate data were obtained at the IBP Comprehensive Osage Site, Foraker, Oklahoma for 1970-1971. Eighteen collections were taken between July 3, 1970 and November 7, 1971 in grazed and ungrazed treatments. Each treatment consisted of two replications of five quadrats each. All biomass figures (g/m<sup>2</sup>) and numbers (mean number/m<sup>2</sup>) were obtained using a modified quick trap, vacuum collector combination.

Major groups of insects for the grazed and ungrazed treatments were Formicidae, Thysanoptera, and Entomobryidae, respectively. Secondary contributors were Sminthuridae, Coccoidea, Nitidulidae and Cicadellidae. Major groups of insects according to biomass were Formicidae, Cicadellidae, and Curculionidae, respectively. Secondary contributors were Gryllidae, Chrysomelidae, Acrididae, and immature Lepidoptera.

Total number of insects (mean number/m<sup>2</sup>) were larger in 1971 than in 1970. Numbers were low in April and May but increased until July, followed by a decline in August and September, moderate increases in October, and a decline in November. Trends of total invertebrate numbers were close to those of total insect numbers.

Biomass in the ungrazed area decreased in August while that of the grazed increased during both seasons. Peaks of biomass occurred in the latter part of August in both 1970-71 in the grazed and ungrazed areas. Biomass declined in September, stayed approximately the same in October, then tapered off in November.

Araneida numbers were lower than other invertebrates but biomass exceeded .01 g/m<sup>2</sup> in several collections. Biomass was found to be highest when numbers were lowest, in April, May, June, and August on the ungrazed treatment. Biomass in the grazed area generally followed the mean number/m<sup>2</sup>.

Acarina numbers were generally higher in the grazed than the ungrazed treatment. The grazed treatment supported greater biomass than the ungrazed in both 1970 and 1971.

For 1971, it was estimated that an average of 59 per cent of the total invertebrate biomass in the ungrazed and 66 per cent in the grazed treatment was composed of herbivores.

- TR167 Pearson, R. L., and L. D. Miller. 1972. Remote spectral measurements as a method for determining plant cover. US/IBP Grassland Biome Tech. Rep. No. 167. Colorado State Univ., Fort Collins. 48 p.

Pawnee, Blue-grama, Aboveground-plant-biomass, Instrumentation, Reflectivity, Plant-cover

This technical report contains the progress report (January 1971 through January 1972) and the planning report (January 1972 through January 1973) for the Field Light Quality Laboratory of the Grassland Biome of the International Biological Program. Included in the report are descriptions of the investigation completed during 1971.

The most important result obtained from the year's investigation was the demonstration of a linear relationship between the standing green biomass on a grassland plot and the spectroradiance from that same plot. This relationship will be utilized to develop a hand-held radiometer which will display directly the green biomass of the vegetation on the plot being viewed without the need of destructive clipping of the plot.

Another set of results is the determination of the spectroradiance for a complete diurnal cycle beneath the gas analyzer dome of the IBP Grassland Biome field photosynthesis experiment. These data will be used to calibrate radiometrically the photocell used to measure the amount of incoming solar radiation by the photosynthesis experiment.

- TR168 Wiens, J. A. 1972. Predictability of patterns and variability of precipitation in grasslands. US/IBP Grassland Biome Tech. Rep. No. 168. Colorado State Univ., Fort Collins. 23 p.

#### Precipitation, Meteorology

Climatic instability may restrict the biotic diversity of an area by imposing frequent but unpredictable stresses upon the adaptive systems of species, while areas with relatively stable climates may have a greater number of species due, at least in part, to enhanced opportunities for resource partitioning. To provide a framework for evaluation of the biotic diversity of different grassland systems, precipitation regimes from 44 U.S. Weather Bureau stations located in tallgrass, mixed-grass, shortgrass, Palouse, and shrub-steppe habitats were analyzed. Special emphasis was given to the predictability of the pattern of precipitation and variability of precipitation. On a monthly basis rainfall regimes were most predictable (in decreasing order) in tallgrass, mixed-grass, and shortgrass prairies, while the pattern of precipitation in Palouse and shrub-steppe types was predictable only from one year to the next and then less than in the Great Plains grasslands. Shortgrass stations had significantly more variability in annual precipitation than mixed-grass areas, and tallgrass stations were the least variable. Palouse and shrub-steppe areas were intermediate in annual variability of precipitation in relation to the "true" grassland types. Stations in central and northeastern Oklahoma did not adhere to these patterns, having less predictable rainfall patterns, a smaller proportion of the yearly rainfall during the summer, and a greater frequency of years in

which the rainfall deviated strongly from the long-term average than other mixed-grass or tallgrass stations. The implications of these rainfall patterns for ecosystem diversity and stability are discussed.

- TR169 Clark, F. E., and D. C. Coleman. 1972. Secondary productivity below ground in Pawnee Grassland, 1971. US/IBP Grassland Biome Tech. Rep. No. 169. Colorado State Univ., Fort Collins. 23 p.

Pawnee, Soil-respiration, Root-respiration, Soil-water, Soil-temperature, Crown-respiration, Decomposition, Decomposition-litter, Litter-decomposition

Carbon cycling below ground at Pawnee was studied by monitoring carbon dioxide evolution from soil and by measuring carbon losses from litter materials buried in the soil. In unirrigated grassland during the late April to the early September portion of the growing season in 1971,  $\text{CO}_2$  evolution ranged from a low of  $1.03 \text{ g/m}^2/\text{day}$  to a high of  $13.38 \text{ g}$ . In general, the data indicated that major spurts of microbial activity follow any major precipitation or irrigation event occurring during the warm season and that this activity is located principally in the uppermost portion (0 to 5 cm depth) of the soil profile. With soil drying, respiratory activity in the upper profile dropped to a negligible level. During 1971 the soil drying was sufficiently severe that the daily output of respiratory  $\text{CO}_2$  was arising almost wholly from that portion of the soil profile deeper than 20 cm.

Carbon losses from buried litters at Pawnee in 1971 occurred principally during the interval mid-April to mid-June; they became negligible during the time of the severe midsummer drought. Carbon losses from four plant materials and two collections of cow manure given soil burial in the laboratory were measured; the loss differences encountered were sufficiently striking to suggest that more data are needed concerning the susceptibility to decomposition of the entire range of litter materials found in grassland.

- TR170 Pengra, R. M. 1972. Cellulose and litter decomposition and evolution of carbon dioxide from soils at the Cottonwood Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 170. Colorado State Univ., Fort Collins. 20 p.

Cottonwood, Decomposition, Decomposition-cellulose, Decomposition-litter, Litter-decomposition, Soil-respiration, Soil-water, Bluestem, Decomposition-root, Root-decomposition

The measurement of carbon dioxide was neither quantitative nor reproducible, and our method for the coming season will be the standard one decided upon by the biome microbiologists.

Although certain trends could be seen and some correlation could be demonstrated between moisture, temperature, and the rate of litter and cellulose decomposition, our data are not such that we can draw any meaningful conclusions from them. Here also, refinement of methods for the coming season will be made.

- TR171 Ryder, R. A. 1972. Avian population studies on the Pawnee Site, 1968-1971. US/IBP Grassland Biome Tech. Rep. No. 171. Colorado State Univ., Fort Collins. 62 p.

Pawnee, Birds, Raptor, Nesting, Feeding-habit, Bird-biomass, Horned-Lark, Horned-Lark-biomass, McCown's-Longspur, McCown's-Longspur-biomass, Meadowlark, Meadowlark-biomass, Lark-Bunting, Lark-Bunting-biomass, Brewer's-Sparrow, Brewer's-Sparrow-biomass, Mountain-Plover, Mountain-Plover-biomass, Golden-Eagle, Hawk

The numbers and biomass of the dominant birds have been studied on and around the Pawnee Site since July 1968. Counts were made at approximately weekly intervals (April 15 to August 15) in six 20-acre (8.1 ha) plots and along a 50-stop, 24½ mile (39.4 km) roadside route. The remainder of the year, counts were less frequent, usually every 2 weeks in 1968-70 but only monthly in 1971. Raptors were counted in a 56-sq mile (145 km²) study area and along various roadside routes. Counts from the Pawnee Site are compared to those from seven other 50-stop routes in Colorado which are part of the North American Breeding Bird Survey.

In 1971 the total number of breeding pairs (59.0) on the six 20-acre plots was approximately the same as that observed in 1970 (58.2). However, a decrease was noted in Horned Larks and an increase in McCown's Longspurs and Western Meadowlarks. Lark Bunting, Brewer's Sparrow, and Mountain Plover populations remained about constant both years. Overall, breeding bird densities on the plots in 1971 were below those noted in 1969, but above those noted in 1968. In general, the IBP 50-stop roadside count findings were comparable to those noted on five other routes in Colorado for the years 1968-71.

Raptor numbers noted in the fall of 1969 and 1971 were quite similar, although the migration was somewhat later in 1969. Wintering populations for three winters, however, differed considerably. Although Golden Eagles were the most abundant all three winters and Rough-legged Hawks second in abundance, the latter species was much less common in 1969-70 than in 1968-69 or 1970-71. Golden Eagles were unusually abundant in 1969-70.

The productivity of the large birds of prey in 1971 was analyzed and compared with data in 1970. Prairie Falcons produced the most young per nest (4.00 in 1971) and Swainson's Hawk the least (0.64 in 1970).

Food habits for Golden Eagles and Great Horned Owls are described. Both rely heavily upon lagomorphs.

Since 1961, over 3,000 birds representing 60 species have been banded at the Pawnee Site. Comparatively fewer distant recoveries have been reported than for the birds of prey. In contrast, a number of local returns have been noted for various passerines.

- TR172 Kumar, R., R. J. Lavigne, J. E. Lloyd, R. E. Pfadt, J. Chu, R. R. Grow, and L. E. Rogers. 1972. Insects of the Pawnee Site. US/IBP Grassland Biome Tech. Rep. No. 172. Colorado State Univ., Fort Collins. 44 p.

Pawnee, Insects, Insect-checklist, Insect-systematics

Insects that have been collected on the Pawnee Site since the initiation of the Grassland Biome Studies at that site and which were available for identification by specialists are listed. Identification to the species or higher taxonomic level was not always possible. Many specimens are still with the specialists and awaiting identification. The list includes forms other than insects, such as spiders, nematodes, annelids, and mites.

- TR173 Risser, P. G., and R. K. Kennedy. 1972. Herbage dynamics of a tallgrass prairie, Osage, 1971. US/IBP Grassland Biome Tech. Rep. No. 173. Colorado State Univ., Fort Collins. 75 p.

Osage, Meteorology, Air-temperature, Soil-temperature, Wind, Precipitation, Solar-radiation, Aboveground-plant-biomass, Standing-dead, Litter, Weight-estimate-method, Litter-accumulation, Decomposition, Litter-decomposition, Decomposition-litter, Belowground-plant-biomass, Grazing-influence, Plant-checklist

The results contained in this report represent the abiotic and producer data collected during the 1971 growing season on a tallgrass prairie at the Osage Comprehensive Network Site. Precipitation and soil water were higher during 1971 than in 1970, and temperature minima and maxima were not as variable during the second year. Aboveground biomass was greater during 1971. Measured litter values were also greater in 1971, but this is partially due to vacuum techniques of collection used during the current year. Belowground biomass amounts were essentially equivalent for both years. Live aboveground biomass was approximately the same on both treatments, but standing dead was greater on the ungrazed treatment. The amount of accumulated litter was greater on the grazed treatment. Belowground biomass values did not change appreciably during the growing season and were similar under both treatments.

- TR174 O'Farrell, T. P., J. D. Hedlund, R. A. Gies, R. J. Olson, and R. O. Gilbert. 1972. Small mammal studies on the ALE Reserve, 1971. US/IBP Grassland Biome Tech. Rep. No. 174. Colorado State Univ., Fort Collins. 32 p.

ALE, Mammals, Mammal-density, Mammal-biomass, Cattle, Jackrabbit, Jackrabbit-biomass, Cattle-biomass

Studies of small mammals were conducted on grazed and ungrazed grassland sites in south central Washington to quantify changes in species composition, relative abundance, biomass, and reproductive performance. During seven trapping sessions in 1971 eight species of small mammals were recorded: *Perognathus parvus*, *Peromyscus maniculatus*, *Spermophilus townsendii*, *Onychomys leucogaster*, *Reithrodontomys megalotis*, *Lagurus curtatus*, *Rattus norvegicus*, and *Thomomys talpoides*. The first four species accounted for 98% of all captures. Pocket mice were the most numerous species ( $\approx 20/\text{ha}$ ), and ground squirrels attained the highest biomass. The total peak biomass in June was 1.3 and 0.7 kg/ha for the ungrazed and grazed sites, respectively. Fifteen yearling steers gained 34 kg/ha in 58 days of grazing. No jackrabbits or other larger native herbivores were observed. Small mammals disturbed less than 1% of the total surface area by burrowing. There were no apparent differences in small mammal populations attributable to the impact of grazing.

- TR175 Wildung, R. E., and R. L. Schmidt. 1972. Soil microbiological studies on the ALE Reserve, 1971. US/IBP Grassland Biome Tech. Rep. No. 175. Colorado State Univ., Fort Collins. 27 p.

ALE, Soil-types, Texture, Soil-water, Soil-temperature, Soil-respiration, Grazing-Influence, Decomposition, Decomposition-plant, Decomposition-root, Root-decomposition

In order to accurately predict carbon and energy flow through the terrestrial ecosystem, it is necessary to understand the influence of environmental factors on the rate of  $\text{CO}_2$  evolution from soil. Studies were therefore initiated to determine the influence of soil temperature, soil water, and grazing on the rate of  $\text{CO}_2$  evolution from soil.

Sampling locations were selected from both grazed and ungrazed grassland sites on the Arid Land Ecology Reserve operated by the U.S. Atomic Energy Commission in south central Washington. The soil  $\text{CO}_2$  evolution rate was measured at periodic intervals from April to September 1971. Concurrently, surface soil water and temperature were also monitored.

To provide an estimate of the rate of plant tissue decomposition in soil, shoot and root tissues (*Agropyron spicatum*) in nylon-mesh bags were buried in the soil at sites employed for soil respiration measurements, and the bags were retrieved at periodic intervals during the growing season. Tissue

weight losses and net decreases in organic carbon were taken as indices of decomposition.

Seasonal changes in soil temperature (ranging 6.4 to 31.0°C) were not significantly correlated with changes in soil  $\text{CO}_2$  evolution rate. Soil water content (ranging 1.2 to 19.7%) was, however, correlated ( $r = 0.77$ ,  $p < 0.001$ ) with  $\text{CO}_2$  evolution rate suggesting that carbon flow through unperturbed arid ecosystems during the spring and summer is limited largely by adequate soil water.

The  $\text{CO}_2$  evolution rates on grazed and ungrazed plots were not significantly different. Grazing effects may be expected to become more pronounced as grazing (initiated in 1971) is continued in subsequent years.

Total decomposition of shoot tissues measured gravimetrically over the growing season amounted to approximately 21% of the tissues originally buried. Root tissues decomposed less rapidly, exhibiting less than a 10% weight loss over the same period. Grazing did not influence the decomposition rates of shoot or root tissues.

Plant tissue organic carbon content increased, and the C/H ratio decreased with time as readily decomposable plant components were degraded and resistant lignaceous components of the tissue increased in proportion. Net carbon losses over the growing season approximated 10% for shoot tissues, whereas there was no net loss of carbon from root tissues.

- TR176 Pfadt, R. E. 1972. Orthoptera of the Pawnee Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 176. Colorado State Univ., Fort Collins. 49 p.

Pawnee, Insects, Grasshopper, Grasshopper-checklist, Grasshopper-systematics, Grasshopper-distribution, Insect-distribution, Insect-systematics, Life-history, Food-composition, Food-consumption, Grasshopper-production, Insect-production, Digestion, Insect-energetics, Metabolism, Habitat

In this monograph of the Orthoptera of the Pawnee Site, Colorado, we plan two major phases or divisions of the work: (i) to summarize all that is published and known about each of the resident species and to write a review of several special topics and (ii) to analyze and summarize the Orthopteran data that have been generated on the Pawnee Site itself. Because much of the latter data are still unavailable and some still are being gathered, we have chosen to start with the literature review and when this is completed to concentrate on the summarization of original Pawnee data.

- TR177 Alldredge, A. W., and F. W. Whicker. 1972. 1970-1971 soil movement at the Pawnee Intensive Site. US/IBP Grassland Biome Tech. Rep. No. 177. Colorado State Univ., Fort Collins. 32 p.

Pawnee, Beta-attenuation, Erosion, Soil-movement, Grazing-influence

Results from field application of a strontium-90 beta particle attenuation method for measuring soil movement at the Pawnee Intensive Site are presented. Generally, it is concluded from 1970-1971 data that soil type and grazing treatment have not significantly influenced soil movement, although a trend of more soil-litter accumulation in the lightly grazed pasture as compared to the heavily grazed pasture was observed. Climatic factors associated with season are highly significant in their effect on soil movement with winter being a period of erosion and spring, fall, and summer generally showing accumulation. The yearly mean accumulation of 16 g/m<sup>2</sup>/month (.24 mm/year) is not significantly different from zero, indicating that on a short-term basis there is little net soil movement in the area of our plots.

- TR178 Hasfurther, V., R. D. Burman, and J. Nunn. 1972. A model for predicting soil temperature from air temperature. US/IBP Grassland Biome Tech. Rep. No. 178. Colorado State Univ., Fort Collins. 18 p.

Models, Soil-temperature, Air-temperature, Abiotic-model

The prediction of soil temperature at the 1-inch depth from air temperature was accomplished by using a linear model developed from a Fourier series analysis of existing data. Values for soil temperature below the 1-inch depth were predicted by a one-dimensional heat flow equation.

- TR179 Armijo, J. D., J. R. Nunn, G. Twitchell, and R. D. Burman. 1972. A lysimeter for the Pawnee Site. US/IBP Grassland Biome Tech. Rep. No. 179. Colorado State Univ., Fort Collins. 15 p.

Pawnee, Lysimeter, Instrumentation

"Undisturbed" is the unique word which describes the weighing lysimeter, installed for studies on prairie grassland at the Pawnee Site. Previously constructed lysimeters, designed for irrigated row crops, have used installation techniques which were highly disturbing to the soil and perimeter surface conditions. Such disturbance and resulting necessary cover regeneration were not considered applicable to delicate prairie grassland. The sparse nature of the grassland surface dictated a need for a large surface area to adequately obtain a representative sample, and for access to the lysimeter to be sufficiently removed from the soil container to minimize effects of unnatural area.

The lysimeter description is followed with a discussion of the continuous and integrated data recording device and overall performance of the system.

- TR180 Nunn, J. R., C. F. Becker, G. Twitchell, R. D. Burman, and J. D. Armijo. 1972. Meteorological instrumentation, data, and data analysis, 1971. US/IBP Grassland Biome Tech. Rep. No. 180. Colorado State Univ., Fort Collins. 20 p.

Meteorology, Instrumentation, Pawnee, Evapotranspiration, Net-radiation

At the Pawnee Site 1-min integrated samples of wind velocity and direction, soil temperature and air temperature gradients, and incoming solar, net, and reflected radiation were continued with the simultaneous and continuous meteorological recording equipment. An informatic data sheet was prepared to depict data availability for other IBP scientists. Hourly averages of each parameter were compiled for distribution to interested investigators. Major modifications to the data acquisition system were initiated in order to realize more fully the potential use of data from the lysimeter and to meet intra-biome needs. Construction of the Grassland Biome's Intensive Site lysimeter was completed. A summarization of equipment and construction technique as well as an evaluation of the lysimeter was prepared.

Data analysis programs resulted in compact 800 BPI (bits per inch) data tapes for the Natural Resource Ecology Laboratory and keyed LABEL tapes for augmenting University of Wyoming modeling. Progress has been made toward the development of a model to predict net radiation from solar radiation. Work on prediction of evapotranspiration was introduced.

- TR181 Dye, A. J., L. F. Brown, and M. J. Trlica. 1972. Carbon dioxide exchange of blue grama as influenced by several ecological parameters, 1971. US/IBP Grassland Biome Tech. Rep. No. 181. Colorado State Univ., Fort Collins. 44 p.

Pawnee, Blue-grama, Carbon-dioxide-exchange, Instrumentation, Photosynthesis, Respiration, Plant-respiration

Progress to November 1971 consisted of improving environmental control and sampling procedures for both a field system and a laboratory system. A new environmental control unit was constructed for the field system so that temperatures could be controlled more precisely ( $\pm 1.0^\circ\text{C}$ ) and all sensor responses could be recorded onto a multipoint recorder. The laboratory unit consisted of a closed gas exchange system where the carbon dioxide ( $\text{CO}_2$ ) exchange rate was determined by changes in  $\text{CO}_2$  concentrations over time.

Carbon dioxide exchange of blue grama (*Bouteloua gracilis*) sods under field conditions was determined from early June through October 19 (Appendix I). Peak assimilation rates on untreated native sods were observed on June 16 to be 4.4 g  $\text{CO}_2$ /(m<sup>2</sup> × hr) leaf area (one side). There was little rainfall in July and August at the Pawnee Site, and

living blue grama foliage decreased. Therefore, the photosynthesis trailer was moved to the Environmental Stress Area in mid-July to observe gas exchange rates of fertilized and irrigated blue grama vegetation. Prior to the change of location, the average fixation rates of blue grama vegetation were about  $0.1 \text{ g CO}_2/(\text{m}^2 \times \text{hr})$  leaf area.

The laboratory system was used to determine effects of soil water potential, temperature, and irradiance (335 to 660 nm) on photosynthetic rates of blue grama. A split plot ( $3 \times 3 \times 3$  factorial design) was implemented with observation on three replications of blue grama sods for each of the above variables. The mean maximum photosynthetic rate of blue grama was  $0.29 \text{ mg CO}_2/\text{g dry wt/min}$ . This rate was observed at a soil water potential of 0 and a temperature of  $30^\circ\text{C}$ , with both 1.12 and  $1.54 \text{ langleys/min}$ , as well as  $40^\circ\text{C}$  and  $1.54 \text{ langleys/min}$ . All three variables, soil water potential, temperature, and irradiance, significantly affected photosynthetic rates of blue grama. Decreases in photosynthetic rates were noted at high temperatures ( $40^\circ\text{C}$ ), low irradiance ( $0.30 \text{ langleys/min}$ ), and high soil water stress ( $-30 \text{ bars}$ ). Interactions among these variables also significantly affected photosynthesis of blue grama.

- TR182 Dyck, G. W., and R. E. Bement. 1972. Herbage growth rate, forage intake, and forage quality in 1971 on heavily- and lightly-grazed blue grama pastures. US/IBP Grassland Biome Tech. Rep. No. 182. Colorado State Univ., Fort Collins. 17 p.

Pawnee, Blue-grama, Grazing-influence, Water-efficiency, Aboveground-plant-biomass, Growth-rate, Cattle, Heifer, Mammals, Ingestion, Cattle-growth, Cattle-production, Mammal-production

Herbage growth rate, forage intake, and forage quality were measured on heavily and lightly grazed pastures during the summer of 1971. When a growth opportunity occurred, herbage growth rate was greater in the lightly grazed pasture than in the heavily grazed pasture. Total herbage growth was significantly greater ( $P > .05$ ) in the lightly grazed pasture. Forage intake by individual heifers grazing the heavy- and light-use pastures did not differ significantly ( $P > .05$ ). Forage quality in the heavily and lightly grazed pastures did not differ significantly ( $P > .05$ ) when standing herbage was greater than  $25 \text{ g/m}^2$ .

- TR183 Crossley, D. A., Jr., C. W. Proctor, Jr., and C. S. Gist. 1972. Soil microarthropod fauna of the Pawnee National Grassland, 1970. US/IBP Grassland Biome Tech. Rep. No. 183. Colorado State Univ., Fort Collins. 36 p.

Pawnee, Soil-fauna, Soil-fauna-biomass, Grazing-influence, Soil-fauna-checklist, Insects, Insect-checklist

The biomass of soil microarthropods at Pawnee National Grassland was estimated from Tullgren extractions of core samples taken during summer 1970. A grand mean of  $413 \text{ mg/m}^2$  (dry weight) was obtained, in a range of values from  $0.03$  to  $1.40 \text{ g/m}^2$ . Biomass estimates included some herbivorous species as well as true soil-litter arthropods, but nevertheless were lower than biomass values reported for other grassland areas or for forest floors. Separate estimates are given for the various faunal groups, and weekly variation throughout the summer is considered.

- TR184 Thayer, D. W. 1972. Microbiological studies at Pantex Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 184. Colorado State Univ., Fort Collins. 29 p.

Pantex, Algae, Bacteria, Fungi, Microbial-population, Microbial-density, Actinomycetes, Bacteria-density, Fungi-density, Soil-physical-characteristics, Grazing-influence, Soil-respiration, Decomposition, Decomposition-cellulose, Decomposition-plant, Soil-water

This report covers the microbiology studies and decomposition studies at the Pantex Site during 1971. Bacteria and fungi were estimated by plate count procedures. The rates of grass and paper decomposition were determined. Several physical parameters such as soil-water and density were determined. Significant differences were detected in the microbial populations between grazed and ungrazed treatments, between grass and prickly pear ground cover, between shaded and unshaded plots, and between different depths in the soil. Significant populations of anaerobic as well as aerobic bacteria were found, and relatively large numbers of algae were detected in the top 5 cm of the soil. A method for determining the effect of fertilizer treatment (or other treatment) on cellulose decomposition was evaluated.

- TR185 Baldwin, P. H., and P. D. Creighton. 1972. Feeding ecology and nesting behavior of grassland birds at the Pawnee Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 185. Colorado State Univ., Fort Collins. 38 p.

Pawnee, Birds, Nesting, Feeding-habit, Lark-bunting, McCown's Longspur, Horned-Lark, Mountain-Plover, Breeding-rate, Predation, Insect-fragment-identification, Ingestion, Bird-energetics, Bird-energy-flow, Energy-flow

Dietary studies were continued on insectivorous and granivorous birds of the shortgrass prairie as found at the Pawnee Site. In 1971, 281 stomach samples were obtained for 23 species of grassland birds. Laboratory analyses for identification and measurement of foods were carried out on 223 stomach content samples. Technical reports were prepared on the diets of three birds: the Mountain Plover, the Killdeer, and the Mourning Dove. All birds so far

examined feeding at the Pawnee Site are utilizing approximately 125 genera of seeds for food. These organisms comprise the principal pathways for materials and energy in that part of the food net with which birds are concerned.

Field studies of the interrelationships of four species of grassland passerines, Lark Buntings (*Calamospiza melanocorys*), McCown's Longspurs (*Rhynchophanes macownii*), Chestnut-collared Longspurs (*Calcarius ornatus*), and Horned Larks (*Eremophila alpestris*), were made at the Pawnee Site during the spring and summer of 1971. Investigations were initiated with two questions in mind: (i) Are there temporal segregations of ecological demands of these species on the ecosystem, and (ii) Is there a spatial distribution and vegetational preference shown by these species?

Food capture tactics and formation of species ethograms were studied by taking behavioral schedules of randomly selected birds for 20-minute periods. Discrete behaviors are analyzed for relative frequency of performance and correlated to known stages of the nesting cycle. Spatial distribution is observed by censusing random areas of the Central Plains Experimental Range and recording the vegetational type referenced by each bird sighting.

Computer analysis of behavioral and vegetational observations is incomplete; however, preliminary examination of the data indicates competition is reduced by temporal differences in initiation of nesting, by nesting in discrete habitats, and by employing different prey capture tactics.

- TR186 Stroud, D. W., and H. G. Fisser. 1972. Plant pattern, microrelief and *Bouteloua gracilis* culm density studies on the Pawnee Site: 1970-1971. US/IBP Grassland Biome Tech. Rep. No. 186. Colorado State Univ., Fort Collins. 26 p.

Bluegrama, Plant-pattern, Microrelief, Grazing-influence, Vegetation-structure

Plant distribution, microrelief, and *Bouteloua gracilis* culm density were intensively measured in a 30-year enclosure and in the pastures with light, medium, and heavy rates of utilization at the IBP Pawnee Site on the Pawnee National Grassland. Measurements were made using a .5 x 1 m microplotter with horizontal X and Y axes and a vertical Z axis. *Bouteloua gracilis* was the dominant species with composition of 55.6% on medium, 44.4% on light, and 32.5% on the heavy grazed pasture. The degree of roughness was found to be similar for the 30-year enclosure as well as the light and medium grazed pastures, but showed a definite decrease on the heavy grazed site. Culm density within clumps of *Bouteloua gracilis* showed a definite increase from 3.5 per 5 cm<sup>2</sup> surface area on the light grazed to a net 7.3 on the heavy grazed site.

- TR187 Hoffmann, R. S., and E. C. Birney. 1972. Ecological studies of small mammal populations at the Cottonwood and Osage Sites, 1971. US/IBP Grassland Biome Tech. Rep. No. 187. Colorado State Univ., Fort Collins. 45 p.

Cottonwood, Osage, Mammals, Vole, Mammal-biomass, Jackrabbit, Cottontail, Jackrabbit-biomass, Cottontail-biomass, Mammal-density, Sex-ratio, Age-structure, Lagomorph

Livetrapping on grids at two Network Sites on the northern Great Plains (Osage and Cottonwood) provides the basis for estimates of small mammal standing crop biomass density at three times during the growing season.

Small mammal densities at Osage were low in May, but increased from then until October. Wet weight and dry weight (in parentheses) biomass density was calculated as 38.5 (11.6) g/ha in May, 348.9 (104.7) g/ha in August, and 1600.0 (480.0) g/ha in October. This increase in biomass density resulted primarily from increasing numbers of *Sigmodon hispidus*, which increased from 0 (0) g/ha to 192.8 (57.8) g/ha to 1372.8 (411.8) g/ha during the three collecting periods, and secondarily from those of *Microtus ochrogaster*, which increased from 7.0 (2.1) g/ha to 109.0 (32.7) g/ha to 118.7 (35.6) g/ha during the three collecting periods.

Small mammal densities at Cottonwood were relatively low at all three collecting periods. Biomass density estimates were 37.9 (11.4) g/ha, 379.0 (112.9) g/ha, and 225.3 (67.6) g/ha, respectively for the June, July, and September samples. The higher biomass density in July relative to that in September resulted largely from the number of thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*) on the grids in July. Biomass density for ground squirrels alone was 280.5 (84.2) g/ha at that period. Ground squirrels were not captured on the grids in either June or September.

Lagomorphs on both sites were censused by means of roadside transects. A survey of disturbance caused by small mammals was also conducted at each site. Results and limitations of these studies are discussed. Demographic trends of small mammals on both sites through 2 years (1970 and 1971) are also considered.

- TR188 Packard, R. L. 1972. Small mammal studies on Jornada and Pantex Sites, 1970-1971. US/IBP Grassland Biome Tech. Rep. No. 188. Colorado State Univ., Fort Collins. 81 p.

Jornada, Mammals, Pantex, Jackrabbit, Cottontail, Rodent Rodent-density, Mammal-density, Lagomorph, Jackrabbit-biomass, Cottontail-biomass, Jackrabbit-density, Cottontail-density

Results of the small mammal studies on the Jornada and Pantex Sites of the Grassland Biome revealed populations of rodents markedly reduced in 1971 from 1970. Biomass estimates of rodents in grams per hectare on the Jornada in 1971 as compared to 1970 revealed amounts that were 75% less in the spring, 65% less in summer, and 56% less in the autumn. The rodent biomass at Pantex was also less (except in autumn) in 1971 than in 1970: spring, 33% less; summer, 84% less; and autumn, 26% greater. Lagomorph populations remained about the same or greater in 1971 than in 1970. Because a different census technique was used in 1971 than in 1970, data were difficult to compare. Studies of the impact heteromyid rodents have on the desert grassland of the Jornada were assayed by excavating and mapping their burrow systems. An aboveground index of belowground burrow extent was developed.

Rodents, rabbits, and bats were also collected to obtain weight, reproductive, food habit, and additional demographic data. A total of 300 specimens was taken, representing 19 different species. Considerable effort was devoted to snap trapping since rodent populations were low.

The extended drought on both study plots, with resultant general absence of aboveground forage and seeds, may have been the principal factor in the low population densities of rodents.

- TR189 Hulett, G. K., and G. W. Tomanek. 1972. Herbage dynamics on a mixed prairie grassland, 1968-1970. US/IBP Grassland Biome Tech. Rep. No. 189. Colorado State Univ., Fort Collins. 60 p.

Hays, Soil-physical-characteristics, Aboveground-plant-biomass, Belowground-plant-biomass, Vegetation-structure, Primary-production, Standing-dead, Litter, Calorimetry, Grazing-influence, Plant-checklist, Precipitation, Wind, Air-temperature, Atmospheric-water, Evaporation

Selected functional attributes of a mixed-prairie site near Hays, Kansas, were investigated during the period 1968 to 1970. This report includes estimates of aboveground and belowground net primary productivity. Vegetation on the ungrazed treatment was mostly tall- and mid-grasses, such as big bluestem (*Andropogon gerardi*), little bluestem (*A. scoparius*), and sideoats grama (*Bouteloua curtipendula*). Vegetation on the grazed treatment was dominated by three grasses and one forb: big bluestem (*A. gerardi*), sideoats grama (*B. curtipendula*), blue grama (*B. gracilis*), and few-flowered scurf pea (*Psoralea tenuiflora*). The principal difference between the two treatments was the presence of more shortgrasses and annual grasses but less forbs on the grazed treatment. The community peak standing crop on the ungrazed treatment was reached in late July during 1968 and 1969. The ungrazed treatment had two production peaks during 1970: one in mid-April and the other

in mid-May. Productivity on the grazed treatment was higher than on the ungrazed treatment. This may be a result of more rapid warming of the soil, as a consequence of the thick layers of mulch which may retard growth rates early in the growing season. Differences in ash-free caloric values of plant material were small.

- TR190 Whitman, W. C. 1972. Supplemental report on primary productivity and abiotic studies at the Dickinson Site: 1970 season. US/IBP Grassland Biome Tech. Rep. No. 190. Colorado State Univ., Fort Collins. 37 p.

Dickinson, Water-balance, Aboveground-plant-biomass, Growth-rate, Primary-production, Grazing-influence, Belowground-plant-biomass, Precipitation, Heat-balance, Soil-temperature, Net-radiation, Soil-heat-flux, Evapotranspiration, Energy-balance

This supplementary report to Technical Report 116 develops additional aspects of plant productivity on the Dickinson Site during the 1970 season and describes quantitatively the energetics of the ecosystem on the grazed and ungrazed treatments at this site. Standing crop production was determined on grazed and ungrazed treatments on the basis of community peak standing crop, species peak standing crop, and the sum of positive growth increments. On the grazed treatment the species peak and the positive growth increment production estimates were both greater than the production estimate obtained from the community peak data. In this case, the species peak estimate was 19.4% greater than the community peak estimate, while the positive increment estimate was 44.4% greater than the community peak estimate. On the ungrazed treatment the estimate based on species peaks was 10.5% greater, and the positive growth increment estimate 27.2% greater than the community peak production estimate. On the basis of the variability in the production data, the positive growth increment method of estimating production did not seem to be valid. There did seem to be considerable justification for the use of species peak standing crops for the estimate of total community production.

Rates of above- and belowground production were also evaluated, with maximum aboveground production rates being obtained during the third week in June under both grazing treatments. Major belowground production took place at approximately the same time on both treatments as did major aboveground production.

Energy budgets for both treatments were developed using plant production data, precipitation and soil water values, soil heat flux data, and net radiation values. On a percentage basis, the grazed treatment net energy utilized was plant production, 0.79%; evapotranspiration, 57.57%; soil heat flux, 0.14%; and sensible heat, 41.50%. On the ungrazed treatment equivalent values were plant production, 1.04%; evapotranspiration,

50.77%; soil heat flux, 0.42%; and sensible heat, 47.77%. In the early part of the season evapotranspiration demands on the grazed treatment were so heavy that part of the energy used in the phenomenon was taken from the ambient air. On the ungrazed treatment there was no indication that advected heat was used in the energetics of the system.

- TR191 Rickard, W. H., R. O. Gilbert, and J. F. Cline. 1972. Vegetational studies on the ALE Reserve, 1971. US/IBP Grassland Biome Tech. Rep. No. 191. Colorado State Univ., Fort Collins. 56 p.

ALE, Aboveground-plant-biomass, Precipitation, Solar-radiation, Air-temperature, Soil-water, Plant-cover, Grazing-influence, Standing-dead, Litter, Primary-production, Belowground-plant-biomass, Plant-nutrients, Nitrogen

This paper summarizes the results of six harvest periods during the 1971 spring growing season on the ALE Site.

The ALE Site consists of 36 ha of shrub-steppe vegetation in which the dominant plant is the cool season bunchgrass *Agropyron spicatum*. Cattle grazing was introduced as a stress on 18 ha after an absence of at least 28 years.

On the four harvest days after cattle were introduced the living aboveground biomass provided by non-shrub species was always greater on the ungrazed pastures. On the ungrazed pastures the peak of living non-shrub biomass was 63 g/m<sup>2</sup> produced in mid-May. The peak biomass of *Agropyron* amounted to 42 g/m<sup>2</sup> in mid-June. The biomass of standing dead material, crowns, and litter combined was estimated at 270 g/m<sup>2</sup>.

*Artemisia tridentata*, the only shrub on the site, averaged 33 g/m<sup>2</sup> of standing dead-wood, 37 g/m<sup>2</sup> of live wood, and 70 g/m<sup>2</sup> of wood litter. Leaf biomass amounted to 4.7 g/m<sup>2</sup>. It was estimated that about 7 g/m<sup>2</sup> of *Artemisia* wood and leaves were produced during the 1971 spring growing season.

The belowground biomass was estimated at 1366 g/m<sup>2</sup> in mid-July.

An old field with a long history of no grazing and dominated by an annual grass, *Bromus tectorum*, produced 211 g/m<sup>2</sup> of above-ground biomass in the spring of 1971. This is more than twice that produced by perennial species in the shrub-steppe vegetation on similar soil and under a similar climatic regime.

- TR192 Huddleston, E. W., C. W. O'Brien, W. J. Fournier, G. R. Graves, and C. R. Ward. 1972. Insect population studies on the Pantex Site, 1970-1971. US/IBP Grassland Biome Tech. Rep. No. 192. Colorado State Univ., Fort Collins. 62 p.

Pantex, Insects, Insect-checklist, Insect-density, Insect-biomass, Grazing-influence,

Herbivory, Species-diversity, Ecosystem-stress, Energy-flow, Decomposition-cellulose

This report is a summary of insect population studies at the Pantex Site, US/IBP, for the period of October 1970 through August 1971. In addition to the standard IBP "quick-trap-D-vac" sampling technique, pitfall traps, light traps, sweep nets, and direct observations were used to study the insect fauna. Two levels of herbivory--ungrazed and moderately grazed--were studied. Two replicates of each treatment were sampled at approximately biweekly intervals during the growing season and monthly during the remainder of the year. Twelve randomly selected quadrats were sampled within each replicate. Beginning in June 1971 a stratified sampling scheme was used to measure the impact of prickly pear on insect population dispersion. Despite improved sampling and extraction methods, insect numbers were lower in 1971 than in 1970. This may well be due to the severe drought of 1970 which expressed itself through reduced insect numbers in 1971. Insect biomass, due in part to species detected through the improved sampling method, was greater in 1971 than in 1970. Maximum standing crop insect biomass on an oven-dry basis on the ungrazed site was 0.22 g/m<sup>2</sup> in 1970 and 0.51 g/m<sup>2</sup> in 1971. On the moderately grazed site the maximum standing crop was 0.15 g/m<sup>2</sup> in 1970 and 1.57 g/m<sup>2</sup> in 1971. The presence of prickly pear was found to cause distinct clumping of insects and to affect species diversity. The effects of preliminary insecticide stressing experiments are discussed. Some preliminary thoughts on energy flow are given, and these indicate that the aboveground insects may require from 10 to 20% of the energy present in aboveground primary production.

- TR193 Fagan, R. E., and R. D. Pettit. 1972. Herbage dynamics studies at the Pantex Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 193. Colorado State Univ., Fort Collins. 30 p.

Pantex, Precipitation, Aboveground-plant-biomass, Belowground-plant-biomass, Blue-grama, Prickly-pear, Litter, Grazing-influence, Plant-checklist, Climate

Throughout the 1971 sampling season power shears were used to harvest vegetation at the Pantex Site. A stratified sampling procedure (blue grama and prickly pear strata) was used to increase precision and accuracy. At each sampling date 24 plots were clipped in both the ungrazed and grazed treatment.

On all sampling dates the prickly pear stratum had more standing crop than did the blue grama plots. Maximum standing crop in the pear stratum was 1099 g/m<sup>2</sup> on August 2, while least biomass in the grass stratum was 103 g/m<sup>2</sup> and 349 g/m<sup>2</sup> which corresponded to the May 14 and August 23 dates, respectively. On most sampling dates the grazed treatment had more standing crop in both strata.

Litter accumulations were greatest in both strata on May 14. Over 1100 g/m<sup>2</sup> of litter were harvested from prickly pear plots at this date, while 653 g/m<sup>2</sup> were found in the grass stratum. These values had decreased to 134 g/m<sup>2</sup> and 92 g/m<sup>2</sup> for the prickly pear and grass strata on September 28. Reasons for this great reduction are unclear.

Very little difference was found in crown biomass when comparing strata. Least crown biomass (112 g/m<sup>2</sup>) was harvested in the grass stratum May 14. On this date prickly pear had 163 g/m<sup>2</sup> of crown material. On June 21 maximum crown weights were found, 400 and 397 g/m<sup>2</sup> in the grass and prickly pear strata, respectively.

Root biomass to a depth of 30 cm was determined at four sampling dates. Most biomass was found in the blue grama stratum on May 16 when 989 g/m<sup>2</sup> were present. At this date 654 g/m<sup>2</sup> were harvested in the prickly pear stratum. After the first sampling date little variation was found in root biomass between treatments and strata.

We feel that refined techniques need to be used to obtain better root biomass data. In addition, the use of power shears harvests litter that has fallen into the tufts of grass. This erroneously places some of the litter component into the aboveground standing crop.

- TR194 Reed, R., and H. D. Blocker. 1972. Insect studies at the Osage Comprehensive Site, 1971 season. US/IBP Grassland Biome Tech. Rep. No. 194. Colorado State Univ., Fort Collins. 74 p.

Osage, Insects, Grazing-influence, Insect-checklist, Insect-trophic-level, Insect-density, Insect-biomass, Herbivory

Invertebrate data for 1971 from the Osage Site are summarized and compared with 1970 data. Eleven collections were taken between April 24 and November 7, 1971, in grazed and ungrazed treatments. Each treatment consisted of two replications containing five quadrats each. The vegetation in each quadrat was estimated by the primary producer workers prior to each collection, and these data are available for subsequent analysis. A circular 0.5-m<sup>2</sup> quick trap and D-Vac suction apparatus were used for invertebrate samples; additional collecting methods were employed to check the effectiveness of this method. Comparative aboveground and incomplete below-ground data for 1971 are given in Appendices I and II, respectively.

- TR195 Caldwell, M. M., and D. Innes. 1972. Photosynthetic time response of three grassland species. US/IBP Grassland Biome Tech. Rep. No. 195. Colorado State Univ., Fort Collins. 32 p.

Photosynthesis, Carbon-dioxide-exchange, Leaf-temperature, Leaf-area, Photosynthesis-response-curves, Snakeweed, Western-wheatgrass, Scarlet-globe-mallow

The timed response of photosynthesis as a function of changing leaf temperatures and irradiation intensities were determined for three grassland species: *Gutierrezia sarothrae*, *Sphaeralcea coccinea*, and *Agropyron smithii*. All three species responded very rapidly to increases in irradiation intensity and underwent light saturation of photosynthesis at approximately  $3.5 \times 10^4 \mu\text{w cm}^{-2}$  (400 to 700 nm). Photosynthetic response to slowly increasing temperatures (1°C increase per 5 min) were quite similar for individuals of the same species although there were marked differences among the three species. All three species performed optimally between 18° and 30°C. Intricacies in the photosynthetic response to temperature are discussed. Photosynthetic data for *Gutierrezia sarothrae* in the field suggested that absolute rates of photosynthesis are highly dependent upon the phenological status of the plants. Qualifications in the interpretation and incorporation of these data into the Grassland Biome modeling effort are discussed.

- TR196 Striffler, W. D. 1972. Hydrologic data at Pawnee Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 196. Colorado State Univ., Fort Collins. 67 p.

Pawnee, Hydrology, Precipitation, Runoff, Soil-water, Soil-temperature, Water-potential, Atmospheric-water, Barometric-pressure, Microwatersheds, Meteorology, Climate

This paper presents the hydrologic data collected during the 1971 calendar year as part of the Hydrologic Process Studies of the Grassland Biome Intensive Site Studies, IBP.

The year 1971 can be characterized as a dry year on the Pawnee Site. Winter precipitation was less than normal, resulting in poor soil water recharge. Precipitation in April was above normal, helping to offset the dry winter. However, rainfall during June, July, and August was well below normal (27.5 mm vs. 646 mm) so that soil water was depleted to the driest level yet measured. Soil water potentials in the surface soils (0-60 cm) were below -60 bars by the end of July.

- TR197 Wielgolaski, F. E. 1972. IBP Grassland/Tundra International Modeling-Synthesis Workshop: Summary of output workbook. US/IBP Grassland Biome Tech. Rep. No. 197. Colorado State Univ., Fort Collins. 34 p.

Workshop-report, Grassland-Tundra-workshop, Models

From 14 to 26 August 1972 the Grassland and Tundra Biomes of the International Biological Program hosted a workshop attended by some 75 participants from 19 countries. Prior to the workshop, data collected by the IBP research sites in these countries were sent to the Natural Resource Ecology Laboratory of Colorado State University and processed into machine readable form. A

workbook summarizing these materials was presented to each participant early in the workshop.

During the intensive 2-week meeting, these data, additional data brought by participants, and numerous ideas about biological systems and data synthesis were reviewed, analyzed, and tried. This learning experience and exchange of ideas were the principal benefits of the workshop. This report is a summary of the activities of the workshop. A more detailed output workbook containing the detailed, if preliminary, results of the workshop is the major source document. Because of its great size and preliminary nature, the output workbook has been distributed only to workshop participants.

- TR198 Collins, D. D., and T. W. Weaver III. 1972. Grassland Biome studies at the Bridger Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 198. Colorado State Univ., Fort Collins. 21 p.

Bridger, Precipitation, Air-temperature, Aboveground-plant-biomass, Standing-dead, Litter, Soil-temperature, Wind, Soil-water, Primary-production, Cloud-cover, Climate

The Bridger Site and 1971 activities performed there are briefly described. Production data are presented and compared with 1970 figures in the light of environmental conditions during each year. Gopher (*Thomomys*) numbers were similar to those recorded for 1970, but vole (*Microtus*) populations declined sharply.

- TR199 Gaul, W. D. 1972. Breeding biology of the Mountain Plover (*Charadrius montanus*), 1969-1972. US/IBP Grassland Biome Tech. Rep. No. 199. Colorado State Univ., Fort Collins. 15 p.

Birds, Mountain-Plover, Breeding-rate, Nesting, Clutch-size, Precipitation, Pawnee, Predation

A summary of the research conducted on breeding biology of Mountain Plover (*Charadrius montanus*) is presented in this report. Observations were made of birds from daylight until dark with some night observations and include dates of arrival in area, number of nests, dates of egg laying, clutch size, nest habitat, and incubation period.

- TR200 Pieper, R. D., M. Ellstrom, E. Staffeldt, and R. Raitt. 1972. Primary producers, invertebrates, birds, and decomposers on the Jornada Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 200. Colorado State Univ., Fort Collins. 73 p.

Jornada, Precipitation, Aboveground-plant-biomass, Grazing-influence, Standing-dead, Litter, Insects, Insect-density, Insect-biomass, Insect-trophic-level, Decomposition, Decomposition-plant, Decomposition-cellulose, Birds, Nesting, Feeding-habit, Bird-density, Bird-biomass, Bird-checklist

Sampling for aboveground biomass of primary producers, invertebrates, birds, and decomposers was continued on the Jornada Site during 1971. Most of the sampling was conducted on the 25-acre permanent ungrazed area and in the temporary 5-acre enclosure on the grazed area.

Because of the drought continuing into the summer, biological activity remained at a low level until late in the summer. Each period of rainfall measurement recorded less than 15 mm of precipitation until August 2 and 6 when about 45 mm fell.

The peak aboveground biomass of standing live was 49.70 g/m<sup>2</sup> on the ungrazed area and 25.84 g/m<sup>2</sup> on the grazed area on September 11, 1971. The recent standing dead declined from the dormant season into the summer when there was very little present on either area. Old standing dead was somewhat variable, but apparently reached a low point during the early part of the summer.

Bird densities were very low during 1971. The average density was 3.9 birds/100 ha as determined by the plot census method. The average biomass of birds was 3.0 g/ha during the breeding season and 18.6 g/ha during the migration season. The Loggerhead Shrike was the most abundant bird during the breeding season followed by the Cactus Wren and the Mockingbird. During the migration season the Lark Bunting was the most abundant bird followed by Brewer's Sparrow and the Loggerhead Shrike.

Decomposer work showed that in these arid grassland soils, decomposition appears to be very closely associated with the amount of water being added to the soil. Substantial amounts of organic carbon were transformed when quantities of precipitation exceeded 25 mm. This so-called decomposition occurred in a relatively short time (possibly 3 days). This suggests that decomposition in arid environments may be an explosive process and not a slow, protracted activity.

- TR201 Klein, D. A. 1972. Systems analysis of decomposer functions in the grassland ecosystem. US/IBP Grassland Biome Tech. Rep. No. 201. Colorado State Univ., Fort Collins. 95 p.

Pawnee, Amoeba, Amoeba-feeding, Microbial-respiration, Microbial-population, Microbial-density, Microbial-biomass, Microbial-activity, Respiration-quotient, Plant-leachate

Experimental data were derived regarding the seasonal responses of Pawnee grassland soils to variations in temperature, soil water, nitrogen addition, and treatment with varied types and levels of carbonaceous materials. Response of differing microbial types, oxygen uptake, carbon dioxide evolution, and other parameters were evaluated. Seasonal responses of soils indicate that the

respiratory quotient (RQ) is a sensitive indicator of carbon flow. Marked decreases in RQ values observed later in the summer are indicative of a change in the nutrient status of microbes from carbohydrate to amino acid metabolism. Studies of plant leachate influences in soil processes have indicated that even a 15-min leaching event can transport nutrients from plant material to the soil, which cause major shifts in soil respiration and microbial populations. Amoebal components of the decomposer ecosystem have been investigated, and amoebae respond to soil perturbations related to changes in microbial populations and nutrient status of the soil. Initial statistical analyses and synthesis of data have been completed to allow application of these data to development of an expanded decomposer model.

model. US/IBP Grassland Biome Tech. Rep. No. 203. Colorado State Univ., Fort Collins. 75 p.

Models, Simulation, Decomposer-model, Carbon-flow-model

A relatively low resolution nonlinear carbon flow and nutrient cycling model has been developed for use in international comparison of primary production and decomposition in grazing lands ecosystems. The plant state variables are live green, above- and belowground reserves, and roots for each of the plant groups including shrubs, perennials, annuals, and cryptogams.

The producer carbon submodel is divided into three parts: assimilation, translocation, and death. The functions are dependent on radiation, temperature, soil water, and the amount of biomass. Site specific sine wave curves are used to describe radiation and air and soil temperatures, while soil water is described as a piecewise function with time. The soil parameters are described for three soil layers, determined by root biomass in the various depths.

The decomposition submodel is a carbon flow model. The biomass of herbaceous and woody litter and dead belowground parts as well as dead cryptogams are separated into "easy," "medium," and "difficult" decomposed fractions. A constant maximum decomposition rate is used for each fraction, modified by environmental factors.

The nutrient submodel is made dependent on carbon flows both in the producer carbon submodel and the decomposition submodel. Similar diagrams are used for various nutrients, having an "unavailable" pool of nutrients in the soil. Nutrients available to the plants are slowly released from this to various layers in the soil. The nutrients may be taken up by roots or leached down in the soil. For nitrogen it was found necessary to include the possibility for nitrogen fixation in addition to the general pathway.

The model has been tried for a lichen heath and a perennial grassland site and has given reasonable output.

- TR202 Almeyda, G. F., and J. L. Rasmussen. 1972. Surface energy and water budget over the grassland, 1970. US/IBP Grassland Biome Tech. Rep. No. 202. Colorado State Univ., Fort Collins. 45 p.

Energy-balance, Water-balance, Solar-radiation, Albedo, Net-radiation, Heat-transfer, Evaporation, Precipitation, Dickinson, Cottonwood

The components of the energy budget at the surface were studied for grassland terrain. This study was performed for the sites of Dickinson (North Dakota) and Cottonwood (South Dakota), located in the US/IBP Grassland Biome, for the growing season of 1970 (May to October). In addition to the energy budget, the water budget and the Thornthwaite-Mather water balance were computed from data from the same sites for the purpose of comparison. Radiosonde data from stations close to the two sites were used to obtain the daily magnitudes of the downward infrared radiation from the atmosphere as well as the sensible heat transfer from the surface.

The latent heat transfer calculated as a residual from the energy budget was tested against the evapotranspiration obtained from the water budget and compared to the evapotranspiration calculated from the Thornthwaite-Mather water balance. Good quantitative agreement was attained. This indicates that the easily computed Thornthwaite-Mather water balance can be used as a first approximation of the water balance in a region where no soil water measurements exist.

The study of the radiation budget shows that the net radiation at the surface is largely determined by the incoming solar radiation. In late spring and early summer the net radiation goes equally into sensible and latent heat while it is unequally distributed at other times. The net heat flux into the ground is small.

- TR204 Lavigne, R. J., R. Kumar, J. Leetham, and V. Keith. 1972. Population densities and biomass of aboveground arthropods under various grazing and environmental stress treatments on the Pawnee Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 204. Colorado State Univ., Fort Collins. 203 p.

Pawnee, Ecosystem-stress, Grazing-influence, Insects, Insect-trophic-level, Insect-density, Insect-biomass, Feeding-habit

- TR203 Wielgolaski, F. E., K. P. Haydock, and D. J. Connor. 1972. A grazing lands plant-decomposition, carbon-mineral simulation

The arthropod component on the Pawnee grassland was sampled during the 1971 season primarily through the use of a D-vac suction apparatus. Samples taken included bimonthly

samples on ungrazed plots and grazed (1970)-ungrazed (1971) plots, samples on four dates on differentially grazed pastures (ungrazed, light, moderate, and heavily grazed), samples on five dates on environmentally stressed areas (no treatment, nitrogen added, water added, and water plus nitrogen added), pit trap sampling, and individual plant sampling.

Bimonthly sampling revealed greater numbers of arthropods in the permanently ungrazed plots throughout the season. Biomass figures followed the same general pattern. The data from the differentially grazed pastures provided similar density curves for the lightly grazed and permanently ungrazed plots with a somewhat lower curve for the moderately grazed plots with the lowest numbers of arthropods occurring in the heavily grazed plots. Population density curves derived for the environmentally stressed areas show that arthropods, as a group, responded most to the water plus nitrogen treatment followed by water alone, both in mean numbers and biomass. Some increase was shown in the nitrogen treated plots over the untreated plots on one sampling date only (May 21), but this response was undoubtedly correlated with abundant rainfall during the previous 20 days.

Plotting these arthropods according to feeding habit revealed that plant sucking insects showed the greatest response to water plus nitrogen followed by water, no treatment, and nitrogen, the latter two curves being very close. Omnivores (primarily ants) showed the greatest response to water plus nitrogen on May 21, and thereafter all curves were close together. Plant tissue feeding arthropods responded to the water plus nitrogen on July 8, but otherwise all curves were close. Predators responded to water plus nitrogen on August 24, but otherwise all curves were close. Scavenger arthropods responded slightly to the water plus nitrogen treatments on all dates.

Arthropods were not collected in sufficient numbers in the pit traps to compare the effect of differential grazing. Sampling of insects on three forb species (*Gutierrezia sarothrae*, *Artemisia frigida*, and *Chrysothamnus nauseosus*) revealed an increasing amount of arthropod biomass present on the plants in the light use pasture as the season progressed despite the fact that arthropod numbers showed a decrease on the last sampling date.

TR205 Wiens, J. A., J. T. Rotenberry, and J. F. Ward. 1972. Avian populations at IBP Grassland Biome sites: 1971. US/IBP Grassland Biome Tech. Rep. No. 205. Colorado State Univ., Fort Collins. 126 p.

Birds, ALE, Pantex, Osage, Pawnee, Cottonwood, Bird-density, Bird-biomass, Grazing-influence, McCown's-Longspur, Horned-Lark, Brewer's-Sparrow, Lark-Bunting, Meadowlark, Grasshopper-Sparrow, Mourning-Dove, Dickcissel, Raptor, Territoriality, Bird-pattern

This report summarizes studies of breeding bird populations conducted at the ALE, Pantex, Osage, Pawnee, and Cottonwood Sites of the US/IBP Grassland Biome during 1971. Data obtained from plot censuses and roadside counts were analyzed to determine local, regional, seasonal, and yearly patterns of variation in species presence and abundance, density, standing crop biomass, and avifaunal diversity and ecological differentiation.

Replicated sample plots frequently differed in their population characteristics, and these differences are considered to be more indicative of local heterogeneity in population dispersion than of sampling error. Changes in density and standing crop from 1970 to 1971 were considerable at some plots and minor at others. The breeding species composition at the sites was relatively unchanged between years, but the abundance of individual species fluctuated markedly at some sites. These yearly changes showed no direct relationship to variations in major environmental variables. It is suggested that these annual variations may be due in part to changes in dispersion patterns within populations, which may be largely unrelated to local plot conditions.

Roadside counts were conducted on standardized routes at Pantex, Osage, and Cottonwood by both an IBP team and local observers. Annual variations were assessed using the results of the IBP team censuses. Total densities of individuals were greater in 1971 than in 1970 at all sites, but in most cases fewer species were seen in 1971. Individual species showed variable changes in abundance between years, and the changes which did occur did not always parallel the changes recorded in plot censuses. Roadside counts conducted by local observers provided indications of seasonal shifts in species presence and abundance. Interseasonal species turnover ranged from 33 to 77%, but generally involved primarily uncommon species. Analysis of count results by ecological categories rather than species revealed that the ecological composition of the breeding avifaunas recorded at these sites remained relatively constant from year to year, but changed seasonally, especially at Osage.

Roadside count data also provide information on dispersion characteristics of species or ecological categories, and a graphical model is developed to analyze results in this framework. This model may have general applicability to censuses where information is gathered on frequency of occurrence and abundance.

TR206 Rogers, L. E. 1972. The ecological effects of the western harvester ant (*Pogonomyrmex occidentalis*) in the shortgrass plains ecosystem. US/IBP Grassland Biome Tech. Rep. No. 206. Colorado State Univ., Fort Collins. 110 p.

Ant, Calorimetry, Energy-flow, Pawnee, Grazing-influence, Ant-density, Feeding-habit,

Instrumentation, Food-consumption, Ant-biomass, Ant-production, Soil-water, Soil-physical-characteristics, Soil-chemical-characteristics, Bulk-density, Ant-energetics

Ecological effects of the western harvester ant, *Pogonomyrmex occidentalis* (Cresson), were studied on the US/IBP Grassland Biome Intensive Site located in northeastern Colorado. Energy values were determined for populations in differentially grazed pastures by estimating the energy required for ant production and respiratory heat loss.

Colony density was measured in four differentially grazed areas: ungrazed, lightly grazed, moderately grazed, and heavily grazed. Densities ranged from 31 colonies/ha under moderate grazing pressure to 3 colonies/ha with heavy grazing. There are an estimated 2032 worker ants produced per colony each year based on counts from colony excavations. This estimate plus the production of 315 winged reproductives per colony result in an estimated 48.64 kcal/colony required for secondary production, a range of 0.01 to 0.15 kcal/m<sup>2</sup>/year across study areas.

Energy for heat production was estimated by measuring CO<sub>2</sub> production of laboratory colonies at representative field temperatures. CO<sub>2</sub> production was monitored with a Beckman infrared gas analyzer. Calculations of respiratory energy loss were made separately for (i) foraging ants inside the nest at night, (ii) foraging ants outside the nest during the day, (iii) worker ants inside all season, and (iv) total colony population inside during the winter. An estimate of 418.42 kcal/colony was made for respiratory heat loss. The respiratory energy requirements of the populations in the differentially grazed pastures ranged from 0.13 to 1.30 kcal/m<sup>2</sup>/year.

Energy flow (heat production plus tissue production) ranged from 0.14 to 1.45 kcal/m<sup>2</sup>/year in the study pastures, considerably less than for the southern harvester ant, *Pogonomyrmex badius* (Latreille). The major area of difference occurs in estimates made of energy required for heat production.

The plant clearing habits of these ants were found to exert only a minor influence at the Pawnee Site, clearing a maximum of .28% of the total area. A compensating increase in vegetation standing crop values around the cleared disc (border effect) was also found which partially compensates for the clearings.

Other findings indicate that the ants move a large amount of soil during colony excavations (2.8 kg/colony) and modify certain soil characteristics. Bulk density was lower beneath the mound, and percent sand content of the colony area was higher than in the vegetated area. Nitrate and phosphorus content were higher in the vicinity of the mound.

The activity times of the ants were found to vary with soil surface temperatures.

The relationship between surface temperatures and the number of foraging ants leaving the colony per minute is described by a polynomial equation.

Some 39% of forage particles brought into the colony were seeds, and 24% were litter. The remainder consisted of dead insect material, insect prey, fecal matter, and rocks being brought in for mound construction. Studies conducted on the populations in the light and heavily grazed pastures showed no significant differences in the rate of forage extraction, foraging distance, time per foraging trip, or in the availability of seeds. There was, however, a significant difference in the number of colonies in these two study areas.

TR207 Bauerle, B. 1972. Biological productivity of snakes of the Pawnee Site, 1970-1971. US/IBP Grassland Biome Tech. Rep. No. 207. Colorado State Univ., Fort Collins. 72 p.

Reptiles, Snake, Pawnee, Snake-energy-flow, Snake-density, Snake-biomass, Reptile-density, Reptile-biomass, Snake-production, Growth-rate, Snake-respiration

An estimate of energy flow through snakes on the shortgrass prairie was provided by employing information from the literature, performing specific pilot studies in the laboratory, and determining species composition and some aspects of population dynamics in the field. During 1970 and 1971, 228 prairie garter snakes (*Thamnophis radix*), 33 prairie rattlesnakes (*Crotalus viridis*), 31 gopher snakes (*Pituophis catenifer*), and 17 western hog-nosed snakes (*Heterodon nasicus*) were collected, marked, weighed, measured, and released on the Pawnee Site of the US/IBP Grassland Biome. Of the 309 snakes released, 48 were recaptured at least once. The mean live weight of resident snakes of all dry-land species was found to be 84.3 g/ha during the summer months. A study plot near the only permanent water on the Pawnee Site was found to have a live weight summer biomass of *T. radix* of 1248 g/ha. Pilot studies measured respiration rates, excretion rates, and gross energy of snakes.

A model was developed showing energy input from prey species into snake populations and the subsequent major energy losses. This model will become one component of a complex series of models produced by the IBP Program, which will represent the major energy relationships within different trophic levels on the shortgrass prairie. The eventual result of the IBP effort will be the mathematical manipulation of selected factors in the ecosystem, leading to predictions about the effect of each factor on productivity in the Grassland Biome sites.

TR208 Connor, D. J. 1973. GROMAX: A potential productivity routine for a total grassland ecosystem model. US/IBP Grassland Biome Tech. Rep. No. 208. Colorado State Univ., Fort Collins. 27 p.

# Models, Photosynthesis-model, Producer-model

GROMAX is a community photosynthesis model designed to describe the daily gross photosynthetic behavior of a mixed grassland community in response to daily radiation input. The community leaf structure is defined in terms of an area and angle combination for each of the component primary producers, and their intrinsic photosynthetic response is given in terms of either a measured or an idealized leaf photosynthesis-irradiance function. For a given community, gross daily carbon uptake is calculated for any site (latitude) and time (day of year) under clear sky conditions, overcast conditions, and by interpolation under the observed daily radiation.

- TR209 Lauenroth, W. K., and P. L. Sims. 1973. Effects of environmental stresses on a shortgrass prairie ecosystem, 1970 and 1971. US/IBP Grassland Biome Tech. Rep. No. 209. Colorado State Univ., Fort Collins. 103 p.

Pawnee, Shortgrass, Ecosystem-stress, Aboveground-plant-biomass, Belowground-plant-biomass, Mammals, Soil-nitrogen, Mammal-checklist, Mammal-density, Plant-cover, Water-balance, Precipitation, Soil-water, Plant-checklist

This report presents 1970 and 1971 data from water and nitrogen stress experiments on the Pawnee Site. Results for aboveground herbage dynamics for 1970 and 1971, belowground plant dynamics for 1971, species composition, basal cover, small mammal species composition, soil water, and water budgets are presented.

- TR210 Coleman, D. C. 1973. Comparative investigations in the US/IBP Grassland Biome: Decomposition section. US/IBP Grassland Biome Tech. Rep. No. 210. Colorado State Univ., Fort Collins. 23 p.

Soil-respiration, ALE, Jornada, Pawnee, Osage, Litter-decomposition, Decomposition, Decomposition-cellulose, Soil-temperature, Soil-water

Litter decomposition and total soil respiration were studied on several US/IBP Grassland Biome sites in 1970 and 1971. This report presents data on decomposition activity of buried substrates and total CO<sub>2</sub> mineralization and examines key abiotic variables, i.e., soil water percentage and soil temperature as they influence decomposition.

Various linear regression models explained as much as 75% of the total variability in decomposition, the higher values being associated with soil respiration activities at the ALE and Osage Sites. The need for C/N ratios and year-round measurements is emphasized, so that key chemical and historical aspects of decomposition can be included for greater understanding and predictability of grassland decomposition and nutrient cycling.

- TR211 Olendorff, R. R. 1973. The ecology of the nesting birds of prey of northeastern Colorado. US/IBP Grassland Biome Tech. Rep. No. 211. Colorado State Univ., Fort Collins. 234 p.

Birds, Raptor, Nesting, Clutch-size, Breeding-rate, Bird-production, Bird-biomass, Predation, Bird-management, Bird-checklist, Habitat, Food-composition, Swainson's-hawk, Ferruginous-hawk, Hawk, Golden-eagle, Eagle, Falcon, Owl

The potential for long-term raptor research and management in northeastern Colorado is great. This paper includes fundamental data concerning nesting phenologies, general life histories, population densities, biomasses, reproductive performances, and food habits of raptors which nest on the shortgrass prairies of Colorado. The data were collected between 1 May 1969 and 1 September 1972. Also included are analyses and/or discussions of the following: (1) field techniques and definitions of nesting parameters, (2) the effects of historical and current activities of man on nesting performances, (3) comparisons of current and past population levels of selected species, (4) the effects of certain weather conditions on nesting phenologies and successes, (5) differential use of summer habitats and nest supports, and (6) the importance of interspecific differences in nesting phenologies. Finally, a thorough, long-term study of population dynamics, management techniques and emergency conservation measures applicable to raptorial birds is outlined in detail. All of this information should benefit ecosystem analysts and/or wildlife managers in their respective endeavors involving grassland birds of prey.

- TR212 Wildung, R. E., T. R. Garland, and R. L. Schmidt. 1973. Influence of environmental factors on the respiration rate of grassland soils--A model. US/IBP Grassland Biome Tech. Rep. No. 212. Colorado State Univ., Fort Collins. 32 p.

ALE, Decomposition, Soil-respiration, Grazing-influence, Soil-temperature, Soil-water, Decomposition-plant, Decomposition-root

In order to accurately predict carbon and energy flow through the terrestrial ecosystem, it is necessary to understand the influence of environmental factors on the soil respiration rate, i.e., the rate of CO<sub>2</sub> evolution from soil. Studies were therefore initiated to determine the influence of soil water, soil temperature, and grazing on the rate of CO<sub>2</sub> evolution from soil.

Sampling locations were selected from both grazed and ungrazed grassland sites on the Arid Land Ecology Reserve operated by the U.S. Atomic Energy Commission in south-central Washington. The soil CO<sub>2</sub> evolution rate and surface soil water and temperature were measured at periodic intervals from April 1, 1971 to November 18, 1972.

To provide an estimate of the rate of plant tissue decomposition in soil, shoot, and root tissues (*Agropyron spicatum*) in nylon-mesh bags were buried in the soil at sites employed for soil respiration measurements, and the bags were retrieved at periodic intervals. Tissue weight losses and net changes in organic C and total N were taken as indices of decomposition.

The sensitivity of CO<sub>2</sub> measurements was augmented by improvement of titrimetric methods and by adjustment of the concentration of base utilized for collection of CO<sub>2</sub>. The concentration of base was estimated from expected CO<sub>2</sub> evolution rates. The CO<sub>2</sub> evolution rates were predicted from preliminary regression models employing soil water and temperature. With the improved sensitivity, field blanks recorded in 1971 and 1972 became significant. Adjustment of all CO<sub>2</sub> values for the field blanks allowed detection of subtle effects of soil water and temperature on respiration rate.

Using a multiple regression model, it was possible to explain a major portion (approximately 75%) of the variation in soil respiration rate on the basis of changes in soil water and soil temperature. The model was sufficiently versatile to describe marked changes in soil respiration rate resulting from summer rains. Soil water was evidently the limiting factor in the late spring, summer, and early fall when soil temperatures were above approximately 15°C; whereas temperature was likely a major factor in the late fall, winter and early spring when soil water content was at a level approximating 50% soil water capacity.

The CO<sub>2</sub> evolution rates on grazed fields were significantly lower (sign test) than ungrazed fields in 1972, perhaps as a result of a decrease in belowground biomass and root respiration. Grazing effects may be expected to become more pronounced as grazing is continued in subsequent years.

Total decomposition of shoot tissues, measured gravimetrically after burial for periods of 12 to 15 months, ranged from 30% to 45% of the tissues originally buried. Root tissues decomposed less rapidly exhibiting less than a 13% weight loss over the same period. Grazing did not influence the decomposition rates of shoot or root tissues.

Plant tissue organic C content generally did not change markedly with time, and net C losses therefore approximated those losses measured gravimetrically. The C/N ratios decreased markedly on decomposition, likely as a result of microbial conversion of tissue C to CO<sub>2</sub>.

Pawnee, Plant-nutrients, Soil-physical-characteristics, Soil-chemical-characteristics

This study investigates the relationships of soil nutrients and plant nutrients of blue grama and wheat.

Multiple regression and three multivariate techniques were used for comparisons. The three multivariate techniques were discriminant analysis, factor analysis, and canonical correlation.

The multiple regression analyses and factor analyses proved to be the most helpful and informative in this study. The multiple regression related soil nutrients and plant nutrients; and the factor analyses pointed out relationships between two or more plant variables or between two or more soil variables. The discriminant analyses and canonical correlation results were less useful and biologically meaningful.

Relationships indicated for possible further study of blue grama soil nutrients-plant nutrients were the plant variables calcium, potassium, and iron. Soil variables of interest are potassium, soil texture, acidity, nitrate, copper, and sulfate.

Wheat plant variables of interest are calcium, potassium, manganese, copper, nitrogen, phosphorus, and sulfur. Wheat soil variables of importance are pH, electrical conductivity, manganese, sulfate, phosphorus, potassium, organic matter, and soil texture.

The null hypotheses for this study were that there are no relationships between plant nutrient concentrations and soil nutrient concentrations. The null hypotheses, except in the case of potassium, cannot be rejected as a result of the study. This indicates that modeling plant nutrient concentrations as functions of soil nutrient concentrations would be very difficult and would probably have poor results.

TR214 Pearson, R. L., and L. D. Miller. 1973. Mapping standing crop biomass by computer processing of aerial multispectral imagery. US/IBP Grassland Biome Tech. Rep. No. 214. Colorado State Univ., Fort Collins. 32 p.

Biomass-mapping, Mapping, Vegetation-mapping, Spectro-reflectance, Reflectivity, Aboveground-plant-biomass, Pawnee, Computer-programs

This technical report describes the processing of multispectral scanner data obtained over the Pawnee National Grassland in September 1968, for estimation of the amount of standing crop. Large area biomass determinations were tested on the scanner data using both a channel ratio technique and multispectral pattern recognition technique. The resulting biomass maps show correlations with several ground truth sites of 80% and 90% between the estimated biomass values from

TR213 Dittberner, P. L. 1973. Soil nutrient-plant nutrient relationships of a shortgrass ecosystem. US/IBP Grassland Biome Tech. Rep. No. 213. Colorado State Univ., Fort Collins. 112 p.

the multispectral data of an area and biomass values taken from clipped plots in the same area.

- TR215 Coleman, D. C., J. E. Lloyd, R. J. Lavigne, and A. Breymeyer. 1973. Feeding activities of soil macroarthropods at the Pawnee Site, 1971. US/IBP Grassland Biome Tech. Rep. No. 215. Colorado State Univ., Fort Collins. 10 p.

Insects, Pawnee, Soil-fauna, Feeding-habit, Food-composition

A 1-m<sup>2</sup> plot of shortgrass prairie was tagged in July 1971 with <sup>32</sup>P; and samples of roots, soil, and soil arthropods were counted for radioactivity. Two species of insects, namely *Margarodes hiemalis* and *Rhyssalus* adults, had the highest activity densities after corrections were made for soil activity.

Of the total radioactivity available to the soil arthropods, about 0.01% was ingested. However, the estimate is probably nominal in relation to season-long feeding activities which would be much higher under more favorable moisture conditions.

- TR216 Nunn, J. R. 1973. Meteorological characteristics over the Grassland Biome's Pawnee Site. US/IBP Grassland Biome Tech. Rep. No. 216. Colorado State Univ., Fort Collins. 152 p.

Pawnee, Meteorology, Climate, Instrumentation, Air-temperature, Solar-radiation, Wind, Phenology, Grazing-influence, Net-radiation, Evaporation, Albedo, Soil-temperature, Evapotranspiration, Canopy-resistance, Potential-evapotranspiration, Computer-programs

A data acquisition system was designed and constructed for securing meteorological data on a simultaneous and continuous basis at the Pawnee Site of the Grassland Biome. Meteorological transducers, system calibration procedures, and data reduction techniques are described.

Temperature, radiation, and wind speed characteristics for two grazing treatments are included. An informative meteorological data availability chart was developed for 1970 and 1971.

A method for estimating net radiation from solar radiation by regression was developed. Evaporation rates from nongrazed and heavily grazed treatments were explained by plant phenology and canopy resistance.

- TR217 Gustafson, J. D., and G. S. Innis. 1973. SIMCOMP version 2.1 user's manual and maintenance document. US/IBP Grassland Biome Tech. Rep. No. 217. Colorado State Univ., Fort Collins. 96 p. (Updated to TR218 and TR219).

Computer-programs, Models, SIMCOMP, Simulation

The SIMCOMP Version 2.1 compiler contains a basic subset of the capabilities of the SIMCOMP Version 2.0 compiler. The compiler and the generated simulation programs are written in American National Standards Institute (ANSI) FORTRAN and are therefore relatively machine-independent. Section 1 of this document describes the rules for implementing flow oriented continuous system simulations. The structure and operation of the compiler and the generated simulation program are described in Section 2. An example of a simple biological simulation is given and is used throughout this document to illustrate the utilization and maintenance of the compiler.

- TR218 Gustafson, J. D., and G. S. Innis. 1973. SIMCOMP version 3.0 user's manual. US/IBP Grassland Biome Tech. Rep. No. 218. Colorado State Univ., Fort Collins. p.

Computer-programs, Models, SIMCOMP, Simulation

SIMCOMP Version 3.0 is a FORTRAN-like computer simulation language designed to ease the development and implementation of compartmental flow/discrete event simulations. The language is an extension and refinement of SIMCOMP Version 2.0. The system is designed to reduce the programming overhead required while sufficient flexibility to solve certain problems. Compartmental-flow simulations are defined by specifying the flow rates between compartments and may be in either difference or differential equation form. Discrete events can be included in the form of event routines which are controlled by a dynamic event scheduler. Various forms of tabular and graphic output can be easily requested. An execution time interpretive debugging facility is also included. The syntactical rules for writing SIMCOMP programs are presented in this document along with a number of examples.

- TR219 Stevens, K. L., and J. D. Gustafson. 1973. SIMCOMP version 3.0 maintenance document. US/IBP Grassland Biome Tech. Rep. No. 219. Colorado State Univ., Fort Collins. p.

Computer-programs, Models, SIMCOMP, Simulation

This manual is the programmer's maintenance document for the SIMCOMP Version 3.0 simulation software. The description and usage of the language is contained in Tech. Rep. No. 218, "SIMCOMP Version 3.0 User's Manual". The design and internal operation of the software is described in this document. Each logical segment of the compiler and the simulation program is described by the aid of flowcharts and listings of the code.

- TR220, 1-12 Dyer, M. I., and D. A. Jameson. 1973. Introduction, p. 1-12. In D. A. Jameson and M. I. Dyer [ed.] Process studies workshop report. US/IBP Grassland Biome Tech. Rep. No. 220. Colorado State Univ., Fort Collins. 444 p.

## Symposia-report, Models

The Grassland Biome central laboratory held a series of three 2-day workshops approximately one month apart early in 1972 at Colorado State University, Fort Collins, to describe grassland system processes. The results of these workshops are presented in seven chapters in this report. Initial flow diagrams reporting state variable components and flow interrelationships were reported for the following: (i) Abiotic subsystems, (ii) mineral nutrient subsystems involving nitrogen and phosphorus, (iii) producer subsystems, (iv) decomposer subsystems, and (v) the consumer subsystem with diet selection and energetics. Recommendations stemming from the workshop groups are listed and discussed in the introductory section.

### TR220, 13-121

Smith, J. A. 1973. Abiotic subsystems: heat and water models, p. 13-121. In D. A. Jameson and M. I. Dyer [ed.] Process studies workshop report. US/IBP Grassland Biome Tech. Rep. No. 220. Colorado State Univ., Fort Collins. 444 p.

Abiotic-model, Heat-transfer, Water-cycle, Heat-model, Albedo, Water-model, Models

A synthesis of the working papers developed during the Process Studies Workshops for the heat and water abiotic subsystems is presented. The synthesis of each subsystem represents a compilation, reorganization, and editing of the original material presented. No further literature review or mathematical development is included. The workshops provided a fairly comprehensive development for heat exchange as basic physical processes, but demonstrated the need for further understanding of water cycling through the grassland ecosystem if water relationships are to be understood in the same basic physical sense.

The section concludes with the recommendations and summary comments of both the process study workshop participants and of the section author.

### TR220, 123-148

Reuss, J. O., C. V. Cole, and G. S. Innis. 1973. Nutrient subsystem: Phosphorus and nitrogen models, p. 123-148. In D. A. Jameson and M. I. Dyer [ed.] Process studies workshop report. US/IBP Grassland Biome Tech. Rep. No. 220. Colorado State Univ., Fort Collins. 444 p.

Models, Nitrogen-model, Phosphorus-model, Abiotic-model

Detailed nutrient flow models are being developed for both nitrogen and phosphorus. State variables for the phosphorus model include soil solution P (1), labile soil P (2), soil mineral P (3), live root P (4), dead root P (5), plant top P (6), animal P (7), litter P (8), and soil organic P (9). State variables in the nitrogen model are atmospheric source and sink (0), soil nitrate

N (1), soil ammonium N (2), N in soil minerals (3), live root N (4), dead root N (5), plant top N (6), animal N (7), litter N (8), and soil organic N (9). The similarities evident in the state variables reflect the biological similarity of the nutrients. Mechanisms used to simulate root uptake, translocation, and mineralization of organic forms are similar but not identical. In other sections mechanisms may be quite different.

Important features of both systems include (i) plant uptake controlled by temperature, water, and the amount of nutrient present in the soil solution phase, (ii) translocation controlled by the root and top concentrations and by the phenological stage, and (iii) available producer and decomposer processes controlled by nutrient concentrations in live and dead plant material.

These models are expected to be useful for examining both the intraseasonal dynamics of nutrient flow and long-term effects of management practices. While neither model is presently complete, an operational version of the phosphorus model is available.

### TR220, 149-244

Jameson, D. A. 1973. Producer subsystem, 149-244. In D. A. Jameson and M. I. Dyer [ed.] Process studies workshop report. US/IBP Grassland Biome Tech. Rep. No. 220. Colorado State Univ., Fort Collins. 444 p.

Models, Producer-model, Photosynthesis, Root-respiration, Soil-respiration, Translocation, Carbon-cycle

In many ecosystem components it has been historically possible to make repetitive measurements of the state variable in the system. With this experience relevant flow relationships developed from these state variable measurements. In the producer subsystem of grasslands the same background is not available. Since it is not possible to conveniently measure the weight of the same plant at times  $t$  and  $t+1$ , plant sampling has been accompanied by plant destruction, and this lack of background information is an important limitation to producer process studies.

Here, two levels of effort are outlined: an elementary and admittedly incomplete level and a more comprehensive level. Major above-ground transfers of plant material can be accounted for with rather simple procedures as outlined in the elementary approach. Accounting of major belowground processes at this level, however, is a formidable obstacle. A simple matter of priorities would indicate that the elementary approach be used on above-ground plant parts until the ability to handle the belowground processes has been brought into line. Simpler approaches are to be favored until progress can be made with more comprehensive approaches.

A comprehensive view would insist that belowground transfers be documented as well as

the aboveground. Major difficulties appear in such studies as root respiration, but possible approaches are outlined.

To reduce the function of the producer subsystem to a set of physical laws requires a careful analysis of the biochemistry of the system. Except in the case of photosynthesis, background information is so scanty that a meaningful discourse at this level is not possible at this time.

TR220, 245-297

Klein, D. A., and F. E. Clark. 1973. Decomposer subsystem, p. 245-297. In D. A. Jameson and M. I. Dyer [ed.] Process studies workshop report. US/IBP Grassland Biome Tech. Rep. No. 220. Colorado State Univ., Fort Collins. 444 p.

Models, Decomposer-model, Decomposition, Root-turnover

The decomposer subsystem is responsible for the major portion of mineralization processes which occur in grasslands, and the biomass in this ecosystem is found predominantly below the soil surface. The model of these processes depicts the flow of organic materials from primary production and herbivore activities to the decomposers. Materials which become available for use by the decomposers include a range of intermediary substrates which are produced by both abiotic and biotic processes. Once these intermediate substrates are available, the decomposers transform them to mineralized products subject to a series of abiotic and biotic controls.

To a certain degree, the approach follows that of the producer section. The initial section describes carbon dioxide evolution. The  $\text{CO}_2$  arises from decomposition, which is treated in two sections. An elementary section describes procedures which can be utilized in elucidating some of the overall characteristics of the subsystem. A more comprehensive section describes viewpoints which will allow a more in depth approach to the decomposer area. In general, the elementary approach utilizes the concept of simple approximations to substrate changes; the comprehensive approach uses a more detailed look at individual substrates.

TR220, 299-319

Ellis, J. E. 1973. Consumer subsystem: Diet-selection model, p. 299-319. In D. A. Jameson and M. I. Dyer [ed.] Process studies workshop report. US/IBP Grassland Biome Tech. Rep. No. 220. Colorado State Univ., Fort Collins. 444 p.

Models, Consumer-model, Diet-selection

Diet selection is considered as an ecosystem process which connects consumers to their food sources. From a flow modeling concept the process is simple, i.e., only the food intake flows from food to consumer are considered. The complexity occurs, however,

in the controls over this flow. Implications and effects of selecting particular kinds of foods on consumer morphology and behavior, on the state of consumer populations, and on the structured producer communities are proposed.

Two alternative strategies of diet selection are the maximization of net energy gain and the balancing of the diet with nutrient and energy requirements. The actual tactics of diet selection vary from one consumer group to another.

The diet selection model, as developed in the Process Studies Workshop, is presented in terms of primary controls (*food preference, food density, and consumer selectivity*) and the secondary controls which influence the primary controls. The operation of this preliminary model regulates the rates of flow of various foods to consumers. Recommendations for future investigations of the diet selection process are based upon this model.

TR220, 321-444

Dyer, M. I. 1973. Consumer subsystem: Energetics model, p. 321-444. In D. A. Jameson and M. I. Dyer [ed.] Process studies workshop report. US/IBP Grassland Biome Tech. Rep. No. 220. Colorado State Univ., Fort Collins. 444 p.

Models, Consumer-model, Consumer-energetics-model, Energy-flow

An energetics model, part of the consumer subsystem, has been described in this report of the Process Studies Workshop held early in 1972. There are 14 state variables with 16 flows described. Within the basic model, 11 state variables with 12 flows or processes and 3 state variables associated with specialized food handling functions are also discussed.

Each of the major flows is discussed and defined, and where pertinent data have been found in literature reports, selected portions or reworked values are given in this report. Much of the energetics model is centered around the controls affecting the process of eating and two processes dealing with metabolic rates, standard metabolism, and maintenance metabolism. It was discovered that many of the controls are redundant in the model, i.e., the controls operate on many different processes in the same manner. For this reason, we suggest that critical thought be given to evaluating the necessity of many of the state variables and the associated flows and, in subsequent reviews, to simplify the model accordingly. A detailed and complex matrix of consumer types and transfers of state for these several types is presented. The committee felt that many of the consumer types and states were realistic for grassland consumers in that these biological states actually exist. However, it is generally agreed that the listing is far too long and creates a great deal of unneeded complexity for an information-gathering or functioning model. Thus more thought must be given to an aggregation scheme that will decrease the complex nature of consumer types, but yet

retain a relatively high degree of resolution for the consumer model as a whole. Some attention has been given to a basic mode of dealing with all consumers by emphasizing rates of respiration of the animal in its environment.

- TR221 Pearson, R. L., and L. D. Miller. 1973.  
The biometer: A hand-held biomass meter.  
US/IBP Grassland Biome Tech. Rep. No.  
221. Colorado State Univ., Fort Collins.  
24 p.

#### Biomass-meter, Instrumentation

A simple hand-held instrument has been designed and constructed to nondestructively estimate aboveground grassland biomass using radiometric measurements. The instrument has been named a biometer, short for biomass meter. The prototype unit consists of a modified two-channel digital radiometer interfaced to a pocket calculator. A digital interface was constructed to electronically join and control the radiometer and calculator to enable the biometer to solve a linear conversion solution from radiometric units to estimated biomass. This report contains a detailed description of the electronic construction of the biometer and the results of two validation experiments which demonstrate the utility of the biometer in estimating the biomass of certain grassland plants.

- TR222 May, S. W., and P. G. Risser. 1973.  
Microbial decomposition and carbon  
dioxide evolution at Osage Site, 1972.  
US/IBP Grassland Biome Tech. Rep. No.  
222. Colorado State Univ., Fort Collins.  
22 p.

Osage, Soil-respiration, Decomposition,  
Decomposition-litter, Decomposition-cellulose,  
Decomposition-roots, Decomposition-plant,  
Litter-decomposition

Soil temperature is a more important driving variable than soil water in the decomposition model for the Osage Site. Analysis of 1971 data supports this hypothesis.

Decomposition rates for cellulose and native litter and CO<sub>2</sub> evolution were higher in the grazed treatment than in the ungrazed treatment. Though other factors may influence these processes, temperature was always higher in the grazed treatment during the growing season.

Soil water at the Osage Site may have been high enough to decrease CO<sub>2</sub> evolution. This is especially true for the ungrazed treatment, where soil water averaged 3.3% greater than the grazed treatment.

The present method for measuring root decomposition is inadequate, making it difficult to distinguish between new roots which have entered the substrate bags and the initial sample.

Carbon dioxide evolution experiments made at the Osage Site from April through December 1972 showed a difference in CO<sub>2</sub> evolution between the grazed and ungrazed treatments. There were no significant differences between replicates within each treatment. Carbon dioxide evolution correlates significantly to temperature but not to soil water.

- TR223 Hendricks, B. J. [Compiler]. 1973.  
Curriculum vitae of scientists who  
participated in the US/IBP Grassland  
Biome studies for 1971 and 1972. US/IBP  
Grassland Biome Tech. Rep. No. 223.  
Colorado State Univ., Fort Collins.  
302 p.

#### Personnel-vitae

This report is intended to serve as a directory of all participants in the US/IBP Grassland Biome studies during 1971 and 1972. All entries in this report are in alphabetical order and are written in a comparable format and contain background information on academic training and professional experience, major interests, professional activities, and all publications and technical reports. Preceding the individual vitae is an overall list of all participants contained herein, together with their formal organizational affiliation. Asterisks in some lists of publications indicate reports funded by the Grassland Biome.

- TR224 Sparrow, E. B., and K. G. Doxtader. 1973.  
Adenosine triphosphate (ATP) in grass-  
land soil: Its relationship to microbial  
biomass and activity. US/IBP Grassland  
Biome Tech. Rep. No. 224. Colorado State  
Univ., Fort Collins. 161 p.

Microbial-biomass, Soil-ATP, Pawnee, Soil-  
respiration, Soil-water, Fungi, Actinomycetes,  
Fungi-biomass, Bacteria

Measurements of adenosine triphosphate (ATP) concentration were employed as a basis for estimating microbial abundance (biomass) and respiratory activity. ATP levels were closely correlated with numbers and carbon contents of viable cells (bacteria) and with rates of O<sub>2</sub> uptake (fungi) for pure cultures of soil microorganisms grown in liquid media. Also, for soil samples incubated in the laboratory, ATP concentrations quantitatively reflected changes in numbers of viable bacteria and actinomycetes.

A study was made of the relationship of ATP levels to microbial abundance and activity in soil samples collected between June and September 1971 at the irrigated and nonirrigated sectors of the Environmental Stress Area of the Pawnee Site. Log of ATP concentration was highly correlated with log of oxygen uptake rate (measured in laboratory) and with log of numbers of viable bacteria, actinomycetes, and fungi. ATP concentration was utilized to calculate total dry weight and carbon content of the viable microflora. The possibility of using ATP and respiratory

values to calculate microbial turnover times in grassland soil was explored.

- TR225 Bhatnagar, K. N., and R. E. Pfadt. 1973. Growth, density, and biomass of grasshoppers in the shortgrass and mixed-grass associations. US/IBP Grassland Biome Tech. Rep. No. 225. Colorado State Univ., Fort Collins. 120 p.

Insects, Grasshopper, Grasshopper-biomass, Insect-biomass, Insect-density, Grasshopper-density, Insect-energetics, Calorimetry, Species-diversity, Insect-diversity, Age-structure, Grazing-influence, Plant-cover, Pawnee, Insect-checklist

A complex of grasshopper species inhabit the shortgrass and mixed-grass associations. Twenty-seven species have been recorded on the Pawnee Site (shortgrass association) and out of these, 22 species were also found on the southeast Wyoming sites (mixed-grass association). These species were arranged into 3 categories of abundance: abundant, common and rare.

Three patterns of emergence of nymphs and adults have been detected. These patterns involve grasshoppers with life cycles of two types which can be designated as "Early" and "Late." Some of the grasshoppers are also designated as "Mid," appearing between "Early" and "Late."

On the sites selected for this study, sampling of absolute population densities of each species was done by walking a transect in a general area established on each site and counting the number on 100 one-square-foot plots. Under heavy grazing on the Pawnee Grassland the maximum number of grasshoppers was 1.94/m<sup>2</sup>, whereas under light-moderate grazing pressure the density was 3.28/m<sup>2</sup>, almost double the former. It was concluded that heavy grazing does not improve the grasshopper habitat.

The type of survivorship curve of the principal species of grasshoppers was studied. In all cases it was observed that the overall density was highest when the grasshoppers were in their earlier instars. Mortality was greatest during the nymphal stage and lowest during the adult stage. It was concluded that the grasshoppers have a concave type of survivorship curve.

A study of the biomass of grasshoppers was also made at the Pawnee Site and southeast Wyoming sites. At Pawnee the peak of the biomass in the heavily grazed pasture reached 64.21 mg/m<sup>2</sup> and in the lightly-moderately grazed pasture, 97.23 mg/m<sup>2</sup>. The peaks were reached at a time when the grasshoppers were in their fifth instar and adult stages. The peak at Lusk was 1213.51 mg/m<sup>2</sup> and at Hartville, 1142.74 mg/m<sup>2</sup>. The biomass in the mixed-grass association was about 13 times that in pastures of the Pawnee Site.

There was no statistical correlation between the density of grasshoppers and

vegetation cover within the same pastures at Pawnee Site.

It was hypothesized that the total body energy in the grasshoppers increases with the age. For this, too, the principal species of grasshoppers were selected from both the shortgrass and mixed-grass associations, and calorimetry measurements were made. The results show a positive correlation between the energy and age groups. There was a steady increase in the kcal/dry body wt as the age of grasshoppers progressed, and the correlation coefficient was significant at 0.05 level of significance for all the species.

The energy content in kcal/g dry wt increased in *Aulocara ellioti* as the grasshoppers aged whereas the energy content of *Cordillaria occipitalis* and *Opeia obscura* showed an erratic trend. The dips may have been due to poor nutritional condition of the test organisms, but more likely was due to the timing of collections. The energy content of *Cordillaria crenulata* exhibited a steady increase, though the curve took a dip in the early male stage. The body weight is important for the total amount of energy contained in the organism.

- TR226 Nunn, J. R., and C. F. Becker. 1973. Meteorological data analysis, 1972. US/IBP Grassland Biome Tech. Rep. No. 226. Colorado State Univ., Fort Collins. 47 p.

Meteorology, Climate, Pawnee, Lysimeter, Canopy-resistance, Evaporation, Solar-radiation, Net-radiation, Reflectivity, Wind, Atmospheric-water, Air-temperature, Precipitation, Soil-water, Soil-temperature, Barometric-pressure, CO<sub>2</sub>-ambient

Hourly averages of measured meteorological parameters were compiled for distribution under separate cover through Dr. Freeman M. Smith, Director for Integration of Abiotic Studies. Modifications to the data acquisition system were completed and corresponding data processing needs were fulfilled. A comparison of evapotranspiration on different grazing treatments was approached with special attempts to merge biotic and abiotic data. Keys for 1971 and 1972 are appended.

- TR227 Bokhari, U. G., and M. I. Dyer. 1973. The effects of environmental stresses on growth of blue grama (*Bouteloua gracilis*) in environmental control growth chambers. US/IBP Grassland Biome Tech. Rep. No. 227. Colorado State Univ., Fort Collins. 59 p.

Blue-grama, Plant-growth, Growth-rate, Plant-nutrients, Nitrogen

Blue grama plants from Pawnee ESA (Environmental Stress Area) were placed in individual pots and subjected to water and temperature stresses in NREL growth chambers from October to December 1971. Growth was estimated in terms of yield per pot dry

weight over this period. Photosynthetic activity was determined on the basis of total available carbohydrates (TAC) after the experiment was completed.

Results indicate enhanced photosynthetic and other metabolic activities at high temperatures (29°/18°C, 12 hr:12 hr, day/night regimes) under irrigated and fertilized and irrigated conditions. The other experimental types, untreated and fertilized plants, responded well in terms of growth, TAC, phosphorus, and total nitrogen at 13°/7°C, day/night temperatures for 65 days. A decline in these constituents was noted at higher temperature level conditions at the end of the growing season. The dilution, or translocation effect, was more pronounced in untreated and fertilized plants compared to irrigated and fertilized and irrigated plants, especially at higher temperatures.

- TR228 Williams, G. J. III, and J. L. Markley. 1973. A technique for rapid identification of initial photosynthetic products. US/IBP Grassland Biome Tech. Rep. No. 228. Colorado State Univ., Fort Collins. 7 p.

C-3-pathway, C-4-pathway, Photoproduct-identification, Photosynthesis

A technique for rapid identification of initial products of photosynthesis is described. Plants exposed to  $^{14}\text{CO}_2$  after a steady-state photosynthesis condition was achieved are placed in boiling solutions of varied ratios of ethanol and water. The labeled products of photosynthesis were extracted, identified, and quantified using one-dimensional thin-layer chromatography and scintillation counting. A system of dyes and  $R_f$  values allowed for precise location of products of photosynthesis. Ratios of radioactive 3-phosphoglycerate-hexose phosphate to malate-aspartate were obtained to classify a plant species as  $\text{C}_3$  or  $\text{C}_4$ . The technique can be carried out in 24 hours and the information can be used to rapidly identify the type of photosynthesis involved.

- TR229 Williams, G. J. III, and J. L. Markley. 1973. The photosynthetic pathway type of North American shortgrass prairie species and some ecological implications. US/IBP Grassland Biome Tech. Rep. No. 229. Colorado State Univ., Fort Collins. 20 p.

C-3-pathway, C-4-pathway, Shortgrass, Carbon-dioxide-exchange,  $\text{CO}_2$ -compensation, Photosynthesis

Several dominant species of the short-grass prairie were examined to identify their photosynthetic pathways. Dominant species of the Pawnee Grassland, International Biological Program (IBP) site in northeastern Colorado, *Agropyron smithii*, *Bouteloua gracilis*, *Buchloe dactyloides*, *Artemisia frigida*, *Gutierrezia sarothrae*, and *Sphaeralcea coccinea* were grown in a greenhouse along with *Nicotiana tabacum*, a known  $\text{C}_3$  plant, and *Zea mays*, a known  $\text{C}_4$  plant. The photosynthetic

pathways of the species were identified by determining the initial products of photosynthesis,  $\text{CO}_2$  compensation points, and response of  $\text{CO}_2$  compensation points to temperature. The experimental plants fell into two distinct groups: those which exhibited responses similar to *Nicotiana tabacum* ( $\text{C}_3$ ): *Artemisia frigida*, *Gutierrezia sarothrae*, *Sphaeralcea coccinea*, and *Agropyron smithii*, and those whose responses were similar to *Zea mays* ( $\text{C}_4$ ): *Bouteloua gracilis* and *Buchloe dactyloides*. The physiological characteristics associated with  $\text{C}_3$  and  $\text{C}_4$  pathways were discussed relative to the above-named species ability to perform efficiently under the conditions prevailing at the Pawnee Site.

- TR230 Rogers, L. E. 1973. Insect studies on the ALE Reserve, 1972. US/IBP Grassland Biome Tech. Rep. No. 230. Colorado State Univ., Fort Collins. 50 p.

ALE, Insects, Soil-fauna, Insect-density, Insect-biomass, Grazing-influence

Insect ecology studies were initiated this year (1972) as part of the joint IBP-ALE investigation of the shrub-steppe ecosystem in southeastern Washington. Sample regimes were established for aboveground invertebrate, belowground macroarthropod, and belowground microarthropod populations.

Peak aboveground densities occurred during June in the ungrazed pasture and in October on the grazed area. Maximum biomass values were reached during October on both treatment areas coincident with emergences of Tenebrionid beetles, *Philolithus densicollis*, and *Stenomorphus puncticollis*.

- TR231 Schwartz, C. C., and J. G. Nagy. 1973. Pronghorn food habits studies, 1970-1972. US/IBP Grassland Biome Tech. Rep. No. 231. Colorado State Univ., Fort Collins. 31 p.

Pronghorn, Feeding-habit, Antelope, Pawnee, Food-consumption, Food-chemical-composition

Food habits of tame pronghorn antelope [*Antilocapra americana* (Ord)] were investigated from December 1970 to January 1972 in diet pastures on the Pawnee National Grassland, Colorado. Both botanical and chemical compositions of the diet are listed. Antelope seemed to prefer plants in early phenological stages and ate a large variety of forbs, grasses, and browse when these were available. Supplemental feeding of animals with concentrate had a negligible effect on food habits in the pastures. When dietary habits of tame pronghorn and wild pronghorn were compared using the fecal micro-technique, it seemed that, besides individual variation, availability of plant species was the major factor determining diet composition. Data did not indicate major differences in dietary habits of pronghorn due to background differences (tame vs. wild).

- TR232 Lauenroth, W. K., and P. L. Sims. 1973. Effects of water and nitrogen stresses on a shortgrass prairie ecosystem. US/IBP Grassland Biome Tech. Rep. No. 232. Colorado State Univ., Fort Collins. 117 p.
- Pawnee, Ecosystem-stress, Nitrogen, Above-ground-plant-biomass, Belowground-plant-biomass, Species-diversity, Plant-diversity, Evapotranspiration, Mammals, Primary-production, Plant-cover, Plant-checklist, Soil-water, Mammal-density, Mammal-biomass, Succession, Mammal-checklist
- Responses of a shortgrass prairie ecosystem to stresses created by excess inputs of water and nitrogen were studied during a 2-year period in northeastern Colorado. Nitrogen stress was created by maintaining soil mineral nitrogen at not less than 50 kg/ha greater than the control. Water stress was induced by maintaining soil water potential greater than -0.8 bars during the growing season.
- Responses measured were net primary productivity, species composition and organization of primary producers, evapotranspiration, and small mammal densities.
- Net primary productivity was more responsive to water and nitrogen in combination than to either individually. Aboveground contribution to net primary productivity was more sensitive to stresses than the belowground contribution. Ratios of above- to belowground productivity were increased by all stresses.
- The major effect of stresses on species composition of primary producers was to reorder existing species relationships and increase the number of species coexisting on the treatments.
- Primary producer organization (successional state) was assessed by diversity and dominance calculations. After 2 years of treatment the primary producers on the nitrogen treatment were at the highest level of organization and those of the water plus nitrogen treatment at the lowest level.
- Evapotranspiration of the treatments receiving additional water was close to the potential rate. The primary producers of the shortgrass prairie do not have the capacity to limit transpiration under conditions of high water availability.
- Small mammal species demonstrated clear habitat preferences to the treatments. The prairie vole was caught almost exclusively on the water plus nitrogen treatment. The deer mouse was captured in approximately equal proportions on the water and the water plus nitrogen treatments and in much lower numbers on the remaining treatments. The grasshopper mouse and thirteen-lined ground squirrel were caught in low numbers on the water treatments and in significantly higher numbers on the control and nitrogen treatments.
- TR233 Lengkeek, V. H., and R. M. Pengra. 1973. Carbon dioxide evolution and cellulose, root, and litter decomposition in soils at the Cottonwood Site, 1972. US/IBP Grassland Biome Tech. Rep. No. 233. Colorado State Univ., Fort Collins. 20 p.
- Cottonwood, Decomposition, Soil-respiration, Grazing-influence, Soil-water, Soil-temperature, Decomposition-litter, Decomposition-cellulose, Decomposition-root, Root-decomposition, Litter-decomposition
- The rate of mineralization as measured by carbon dioxide evolution from soil and decomposition of litter from litter bags and cellulose from filter paper sheets was measured. Seasonal fluctuations are apparently related to temperature and soil water variations. We were not able, however, to show good correlation between soil water content, temperature, and decomposition rates. This may be from microecosystem variation and, therefore, may require more intensive sampling.
- Both root and filter paper samples gained weight. This gain was from growth of roots and fungal mycelium into the samples.
- Most of our methods of measuring decomposer activity in soil are very crude and need to be refined and/or replaced.
- TR234 Kumar, R., R. J. Lavigne, and J. E. Lloyd. 1973. Pawnee Site insect code list. US/IBP Grassland Biome Tech. Rep. No. 234. Colorado State Univ., Fort Collins. 110 p.
- Pawnee, Insects, Insect-codes
- A list of arthropod and other invertebrate codes for the Pawnee Site is given.
- TR235 Baldwin, P. H., and R. L. Boyd. 1973. Food consumption and feeding rates in the Lark Bunting. US/IBP Grassland Biome Tech. Rep. No. 235. Colorado State Univ., Fort Collins. 75 p.
- Pawnee, Birds, Lark-Bunting, Food-composition, Food-consumption, Calorimetry, Ingestion, Bird-biomass, Bird-energetics, Energy-flow
- The foods of Lark Buntings from the Pawnee area were analyzed quantitatively in terms of kilocalories. The seasonal patterns of food intake by male and female adult Lark Buntings were similar, yet they differed statistically at certain parts of the summer. These differences corresponded mainly to shifting values for consumption of animal versus plant foods. In cumulative consumption of foods over the entire breeding season, May through August, the intake of food by females exceeded that of males by 15.2%. The body weights of male and female adults decreased in early summer but increased sharply in late July (males) and in August (females). Rates of food intake were expressed in units of kcal/bird-day. Rates were deduced from relationships among mean caloric content of

stomach samples, calculated existence energies, and calculated activity energies. Activity energies were markedly higher for females than for males, notably from late May through early July. Mean feeding rate from May through August for males was 39.50 kcal/bird-day and for females 44.11, the latter 11.7 per cent higher. Time of day had little effect on pattern of food intake,

except that more animal food was eaten in the period, 1200-1400 hours. Juveniles when first out of the nest ate entirely animal food; they increased the amount of seed food taken in successive biweekly periods until at the end of August they ate animal and plant foods in the same proportions as did adults. Time of day produced no striking differences between feeding patterns of adults and juveniles.

- SS11 Harris, L. D. 1972. An ecological description of a semi-arid East African ecosystem. Range Sci. Dep. Sci. Ser. No. 11. Colorado State Univ., Fort Collins. 80 p.

Precipitation, Air-temperature, Solar-radiation, Atmospheric-water, Wind, Climate, Aridity-index, Soil-types, Vegetation-types, Primary-production, Species-diversity, Species-association, Vegetation-structure, Tanzania, Mkomazi-Game-Reserve, Soil-chemical-characteristics, Aboveground-plant-biomass, Giraffe, Hartebeest, Elephant, Impala, Eland, Buffalo, Mammals, Birds, Mammal-biomass, Mammal-population, Bushbuck, Zebra, Rhino, Cheetah, Hunting-dog, Hyaena, Lion, Reedbuck, Ostrich, Oryx, Genrenuk, Migration, Habitat, Metabolism, Mammal-metabolism, Grazing-influence

From late 1964 through mid-1967 climatological, soils, vegetation, and animal studies were conducted in the semi-arid Mkomazi Game Reserve of northeastern Tanzania. An elevational gradient from 230 m in the east to mountain tops of nearly 1600 m above sea level in the northwest underlaid similar rainfall and temperature gradients. Aridity coefficients, based on the different temperature and rainfall conditions alone, were about 50% greater in the central section of the reserve than in the higher elevation northwest.

The soils were classified by the American 7th Approximation to a Comprehensive Classification System and were found to consist of about 75% camborthids (aridisols), 20% pellusterts (vertisols), and 5% miscellaneous types. Soil texture, organic matter content, permeability, and profile depth all reflected a gradient of conditions from west to east.

The vegetation was categorized into four major types: (i) dry montane forest, (ii) bushed and wooded grassland, (iii) seasonally inundated grassland, and (iv) bushland. Grass-forb aboveground standing crop values ranged from approximately 600 g/m<sup>2</sup> in the 500 mm rainfall regions of the bushed and wooded grassland to about 200 g/m<sup>2</sup> in the 350 mm rainfall regimes of the central-section bushland. Minimal estimates of aboveground net primary production varied from about 400 g/m<sup>2</sup>/year on previously unclipped plots in the northwest to about 170 g/m<sup>2</sup>/year in the east central section, while denuded plot productivities were about 300 and 150 g/m<sup>2</sup>/year, respectively. Differences in forage-density and ground-cover indices reflected generally poorer rangeland conditions in the central and eastern sections of the reserve.

While the mean annual large herbivore density ranged from 12 animals/km<sup>2</sup> (5,548 kg/km<sup>2</sup>) in the northwest to about 0.5 km<sup>2</sup> (700 kg) in the central and eastern sections, the dry season densities ranged from 23.7 animals/km<sup>2</sup> (12,705 kg/km<sup>2</sup>) to much less than 1 animal/km<sup>2</sup> in the eastern sections. Seasonal herbivore biomass distribution patterns reflected a large wet season ingress of elephants (*Loxodonta africana*), zebra (*Equus burchellii*), oryx (*Oryx beisa*), and Grant's gazelle (*Gazella granti*) from adjacent Kenya as well as an eastward movement of herbivores from

the dry season water source in the northwest. The east-west herbivore density gradient was nearly extinguished during the wet seasons.

Both spatial and temporal patterning within the large herbivore array is a major attribute of the animal community structure. Although 22 species of large indigenous herbivores inhabit the reserve, these are partially segregated by their affinities for the different vegetation types. A maximum of 12 and a median number of four species ( $\bar{X} = 4.26$ ) were recorded in local areas at any one time. Rhinoceros (*Diceros bicornis*) were most equitably distributed among the four major vegetation types (niche breadth index = 3.42) with eland (*Taurotragus oryx*), warthog (*Phacochoerus aethiopicus*), giraffe (*Giraffa camelopardalis*), and elephant next in order. Bushbuck (*Tragelaphus scriptus*), duiker (*Sylvicapra grimmia*), and buffalo (*Syncerus caffer*) were the least equitably distributed. Eland, genrenuk (*Litocranius walleri*), reedbuck (*Redunca redunca*), and giraffe were most equitably distributed through time. Herbivore species diversity was greatest in the bushed and wooded grassland and lower in the open grassland, bushland, and dry montane communities.

The niche overlap (on the habitat dimension) of hartebeest (*Alcelaphus buselaphus*), impala (*Aepyceros melampus*), and ostrich (*Struthio camelus*) was great (>0.8, limit = 1.0) while that of bushbuck, klipspringer (*Oreotragus oreotragus*), and duiker with most other species was slight (as low as 0.04, limit = 0.00). Of the carnivores, jackals (*Canis adustus*) reflected the greatest time and space overlap with the herbivores, while hunting dogs (*Lycan pictus*) reflected the least.

From an ecosystem point of view, three of four species were found to dominate the structure (numbers and biomass) as well as at least one measure of community function, i.e., energy exchange. About 17.5% of the aboveground primary production (in terms of biomass) was estimated to be channelled through the large herbivore-carnivore pathway. The independent effects of elephants, cattle (*Bos indicus*), and fire on the vegetation are illustrated as are the combined effects of elephants, cattle, herbivores, and fire.

- SS12 Flinders, J. T., and R. M. Hansen. 1972. Diets and habitats of jackrabbits in northeastern Colorado. Range Sci. Dep. Sci. Ser. No. 12. Colorado State Univ., Fort Collins. 29 p.

Jackrabbit, Mammals, Pawnee, Food-composition, Food-chemical-composition, Dietary-matrix, Jackrabbit-density, Jackrabbit-biomass, Mammal-biomass, Age-structure, Sex-ratio

This study considers the diets selected and the feeding habitats occupied by black-tailed (*Lepus californicus*) and white-tailed (*Lepus townsendii*) jackrabbits, in sympatry, within a shortgrass ecosystem in northeastern Colorado. Black-tailed jackrabbits immigrated into the study area prior to the turn of the century and now outnumber white-tailed jackrabbits by about five to one.

Microscopic analysis of stomach contents indicated that western wheatgrass (*Agropyron smithii*) was the most common food in the annual diets of both hares. Each hare behaved differently in selecting cultivated crops as food; alfalfa (*Medicago sativa*) was the second most important food item in the annual diets of black-tailed jackrabbits, and winter wheat (*Triticum aestivum*) was the second most important food item in the annual diets of white-tailed jackrabbits.

There was 53% similarity in the percent dry weight and composition of plant species in the mean 2-year diets of these hares. There was 57% similarity in the percent dry weight and composition of plant species in the mean 2-year feeding habitats of the two species of jackrabbits. Annual diets of black-tailed jackrabbits corresponded more closely to the availability of food plants in their feeding habitats than did the annual diets of white-tailed jackrabbits to the availability of food plants in their feeding habitats. Thus, white-tailed jackrabbits are slightly but significantly more selective as "primary consumers" than black-tailed jackrabbits.

From these data it is proposed that black-tailed jackrabbits are more efficient than white-tailed jackrabbits in foraging for food and thus, potentially, have a competitive advantage. White-tailed jackrabbits now occupy a small segment of the overall feeding habitat of jackrabbits, and the herbage in this segment is not strongly compatible to the annual diets normally selected by black-tailed jackrabbits.

- SS13 Cook, C. W. 1972. Energy budget for rabbits compared to cattle and sheep. Range Sci. Dep. Sci. Ser. No. 13. Colorado State Univ., Fort Collins. 16 p.

Mammals, Cattle, Sheep, Jackrabbit, Lagomorph, Food-consumption, Metabolism, Metabolic-rate, Mammal-energetics, Mammal-production,

Mammal-biomass, Jackrabbit-biomass, Mammal-metabolic-rate, Jackrabbit-energetics

Biological efficiency of the ecosystem is generally based upon the percentage of solar energy converted to plant biomass and thence the percentage of chemical energy in plants into animal biomass that can be expected from the system. The efficiency of energy fixation among species and the transfer to the next higher trophic level is an important management principle.

The percentage of gain of offspring that is made from mother's milk and that made from the direct consumption of energy from herbage is of great importance. Gain made from the mother's milk costs at least 50% more energy than that made from forage.

Young rabbits from the time they are born until they are weaned make approximately 43% of their gain from energy received from the forage they consume while lambs and calves make about 23% and 10% of their gain from forage respectively.

It was found that the jackrabbit produces a pound of exportable animal biomass at an energy cost of 12,248 kcal of metabolizable energy whereas sheep and cattle produce a pound of exportable biomass at an energy cost of 22,331 and 24,936 kcal, respectively. Thus the jackrabbit is about 1.82 times more efficient than the range sheep and about 2.04 times more efficient than the range cow.

It was concluded that the efficiency of energy transfer and utilization by consumers should be based upon the production and maintenance of animal biomass rather than simply the body weight gain of individuals of a species per unit of energy consumed. It was also concluded that efficiency could be increased markedly by management that addresses itself to energy flow and the products that result from its transfer and conversion throughout the system.

PR 73-I1 Van Dyne, G. M. [Principal Investigator].  
1973. Analysis of structure, function,  
and utilization of grassland ecosystems.  
Vol. 1. A continuation proposal for  
1974 through 1976. US/IBP Grassland  
Biome, Colorado State Univ., Fort  
Collins. 317 p.

#### Biome-objectives

Our current plans, to obtain the model-experiment feedback and interaction in a more quantitative way, call for detailed modeling, model sensitivity analysis, and synthesis activities in the 1973 and 1974 period to be followed by a final comparative field validation study sequence in 1975 through 1977. This period would be followed by a final phase of coordinated model development, model experimentation, and synthesis in 1978 and 1979. Although publications have been emanating from the Grassland Biome study throughout its duration, a major terminal reporting and publication phase would begin in 1980.

This sequence of activities is expected to complete the majority of the objectives of the original Grassland Biome proposal, subject to availability of funds and requiring elimination of certain study areas such as aquatic work, spatial variability, and long-term animal population dynamics.

This present Grassland Biome study proposal presents an evolved and new approach toward the analysis of ecosystems. It is based on a continuously evolving execution of the scientific method which utilizes:  
(i) a comprehensive knowledge of grasslands,  
(ii) the principles and premises of modern ecological theory, and (iii) models and simulators of grassland ecosystems. Using a structured interaction of data, ecological hypotheses, and testing of hypotheses through both physical and numerical experiments, the following objectives can be realized:

1. The formulation and organization of a large and scattered volume of information and data pertaining to grassland ecosystems into a coherent body of knowledge.
2. The development of a comprehensive theory of grassland ecosystem function that can be applied directly to the acquisition of more basic knowledge.
3. The development of a set of utilization principles for grassland ecosystems pertaining to the management and inadvertent modification of the grasslands.

Past accomplishments are also briefly discussed.

PR73-I2 Van Dyne, G. M. [Principal Investigator].  
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Biome, Colorado State Univ., Fort  
Collins. 317 p.

Ecosystem-theory, Ecosystem-hypotheses,  
Models, Modeling-concept, Selforganizing-  
ecosystem-model

The grassland program's main intent is that of integration and synthesis of grassland information into an ecosystem science which accounts for an understanding of the largest and most complex entity of ecology, the ecosystem. By this we mean to construct a framework whereby ecological information is put into a theoretical form. In order to clarify this statement, it is useful to present the antithesis wherein the body of grassland knowledge exists without an organizing vehicle. Our work will be done with the guidance of relevant ecological principles through a systems mode. It is necessary to regard the useful principles or theories through a series of testable statements (hypotheses) and to test the validity of these statements with total systems tools, namely, use of ecosystem level and subsystem level simulation models handled by digital computers.

A somewhat unique approach to ecology is via total system level models of sufficient generality to represent complex ecosystems. In order to understand the physical and biological actions within the grasslands ecosystem, it will be necessary to have a tightly structured image of these physical and biotic components. An efficient way that the ecosystem can be understood is by organizing a hierarchy of principles that explains how the system functions at any given moment. In order to understand these principles, it is necessary to regard literature evaluations which either establish strongly defended ideas or relevant hypotheses. To this end we will structure a hierarchy of basic principles and relevant hypotheses in several subject areas which we can test rigorously with our data base and simulation model.

Five fundamental ecosystem properties, each with a series of related concepts, have been used to construct our thoughts about testing ecosystem hypotheses and providing a framework for describing ecosystem principles. We will deal with the following fundamental ecosystem properties: (i) structure, (ii) dynamics, (iii) development, (iv) responses, and (v) utilization.

The system properties must all be arranged into logical sequences so that tests of hypotheses about the system or parts of the system can be interpreted. The most feasible way seems to be the construction of a hierarchy of information or data-related hypotheses which eventually leads us to statements of principles governing structure, function, and utilization in grasslands.

By adhering closely to a hierarchical structure of these hypotheses, we will be able to identify where we have sufficient information to test any of the suppositions. Where we do not, we will develop strategies for obtaining the needed information. These strategies will range from research work in the biome framework or through cooperative work with other agencies where the information is likely to exist.

- PR73-I3 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 1. A continuation proposal for 1974 through 1976. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 317 p.

#### Models, Modeling-needs, ELM, Ecosystem-model

The Grassland Biome has developed and worked with approximately 36 simulation models to this point, one of which is an ecosystem level model (ELM). All the models have been developed with different modeling objectives and approaches to achieving these objectives. The main utility of these models is that they provide a basic framework for synthesis of information. Not only is ecological information structured more succinctly, but the models themselves are used to indicate subject areas in which additional research (field and laboratory) is needed. To reiterate, the main emphasis is to build a capability for understanding the largest and most complex entity of ecology, the ecosystem.

Despite the fact that we have put together and operated a large ecosystem level model which has met its objectives, it is obvious from this work that the ability to increase the complexity and thus the utility of such models is severely limited by present technology. Thus, one of our main objectives during the tenure of this proposal is to enhance our capabilities in building such models. An approach we suggest and outline is to construct a potential for building self-organizing model systems (SOMS). For such work we will need added input from information sources and in the form of intensive study and training of biologists and mathematicians in this subject area. Additionally, we will need major developments in the computer arts, commonly known as "software development." By expanding our compiler system, SIMCOMP (a computer compiler developed by us for ecologically-oriented problems), we expect to avoid the necessity for development of the time-demanding computer code assembly necessary to restructure a system for each particular model. Thus we expect to be able to concentrate on the ecological objectives, theory, and input information and then have these structured by SOMS. The advantages of such an advance are obvious. Using SOMS, we will enjoy automatic error-free model construction (from the standpoint of algorithms) which will allow our staff more time to critique the input and output and address biological fidelity rather than having to spend an inordinate amount of time working on code mechanics.

- PR73-I4 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 1. A continuation proposal for 1974 through 1976. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 317 p.

#### Program-needs

Our research-oriented synthesis activities have summarized a large volume of information related to grasslands. This task is not complete, and it is obvious that many holes in our information base exist. Some of these are critical in the sense that they limit the advance of our understanding of ecosystem function. An example is the relationship of live and dead or functional and non-functional plant roots to primary production and decomposition rates in the grassland ecosystem. Thus, through our synthesis activities conducted during workshops and by modeling, we have identified many needs which the literature or our previous work have not fulfilled. Many needs, especially those needed most, are then translated into research programs for the next 3 years. We have identified these projects in a text form in the main body of the proposal and then have abstracted them in an appendix. For the main part, we have kept our trophic organization to outline these studies, i.e., needs in abiotic, producer, consumer, decomposition, and nutrient subject areas.

Aside from literature searches, information is gathered in two basic ways. State variables are collected at the various field sites according to a set of standardized procedures. Driving variables are collected at the Pawnee Site via an automated multi-channel system on minute schedules throughout the year, and the Comprehensive Network Sites hourly values are obtained with smaller systems. Ecosystem rate processes are studied at many locations in both field and laboratory conditions. Much of the work specified in the continuation proposal is dedicated to validation studies using the state and driving variables and to additional process-oriented projects needed to up-date the construction of the ecosystem level model.

In addition, we have identified a whole-system subject area with specific needs. In this subject area we will need ecosystem level parameters such as those obtained from observing system functions at a series of sites up to and including ecotones at the limits of the grasslands (e.g., at the boundaries of grasslands and deciduous and coniferous forests). Also we will need new information stemming from work in systems science per se, such as mathematical and computer science advances, both in hardware and software capabilities.

- PR73-I5 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 1. A continuation proposal for 1974 through 1976. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 317 p.

## Utilization-studies, RANGES

Since we have a comprehensive library of state variables collected from several grassland types and have successfully linked important processes within the ecosystem, we are in a unique position to couple this information with management and utilization models. By carefully identifying and describing objectives, we can address several whole-system and subsystem problems where there are management implications and needs. We have singled out a few such problems in this proposal as examples of things we can and ought to address. For many of these problems, such as those concerning predators in the environment, development of long-term grazing strategies, or predicting effects of weather modification, we will need the input of and will seek to work with other management groups. These other groups will range from other biomes and RANN projects funded by the National Science Foundation (e.g., the Desert Biome in the case of problems with coyotes in the livestock industry; RANGES project to recommend grazing strategies at Colorado State University) to major Federal agencies, such as the Department of the Interior Bureaus and the National Oceanographic and Atmospheric Administration, etc. By comparing ecosystem-based theory and data with needs generated by society, we can expect to obtain the most efficient progress in major problem solving areas.

PR73-I6 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 1. A continuation proposal for 1974 through 1976. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 317 p.

Land-use-problems, Synthesis, Synthesis-intrabiome, Synthesis-interbiome, Synthesis-international

In order to wrap-up some of the work specified for the International Biological Program, it is necessary to put together information obtained during the funding periods to date. For some subject areas this synthesis task is moving along quite well, e.g., for structure of grasslands in diverse areas where a varying experience of weather factors exist. But, for other subjects, such as detailed function of grassland components, it is not possible to put together anything but a preliminary picture owing to insufficient time to assess these subjects.

The synthesis reports will be developed around grassland types for our intra-biome activities. For the most part, the workers in each of seven grassland types will have a major responsibility for putting together this set of information. We expect to produce books on the following subjects related to this activity: (i) The Tallgrass Prairie, (ii) The Mixed-Grass Prairie, (iii) The Shortgrass Prairie, (iv) The Desert Grassland, (v) The Mountain Grassland, (vi) The Annual Grassland, and (vii) The Shrub-Steppe Grassland. These volumes will be dedicated to the total system with the various trophic compartments

and functional relationships of each area. Relationships across areas will be emphasized also. The use of our system and subsystem level models will be an inherent part of this synthesis exercise in addition to the analytical procedures applied through more traditional methods of examining and explaining data sets.

On a national scale we will be involved with three major activities related to a volume output. One, "The Belowground Ecosystem: A Synthesis of Plant-Associated Processes," will be the result of a symposium to be conducted at Fort Collins by Grassland Biome personnel with the full cooperation of other biomes and the central Ecosystem Analysis Offices. The symposium is to be held in 1973 and is progressing with final plans. The final output will be worked on during this proposed budgeting period and is expected to be available during 1974.

Two other volumes, "Tracer Methods in Ecological Research on Water Movement" and "Decomposition and Nutrient Cycling in Arid and Semiarid Environments," are calling heavily on our biome personnel for organization and scientific content. Considerable cooperative effort with other biomes and governmental agencies has already been necessary and will be a focal point in order to complete these volumes. The Eastern Deciduous Forest Biome, the Desert Biome, the Tundra Biome, the Coniferous Forest Biome, the Agricultural Research Service of the USDA, and representatives of the Canadian IBP organization (funded by the National Research Council of Canada) are all contributing in various ways to these two major efforts. Symposia and their output volumes are scheduled for 1974 and 1975.

Under the original agreements of data and information sharing set forth under the International Biological Program design, there is to be a series of international workshops and meetings to pull together pertinent information for International Grassland Syntheses. The first of these workshops was held in Fort Collins in August and September 1972. Two volumes are now planned and additional meetings are scheduled during 1973 and early and mid-1974. The first volume anticipated is entitled "Structure and Function of Herbaceous Terrestrial Ecosystems," and the second is entitled "Comparative Analyses of Grassland Components, Processes, and Uses." Manuscripts for these volumes are expected to be delivered to The Cambridge University Press in 1974.

PR73-I9 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 1. A continuation proposal for 1974 through 1976. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 317 p.

## Budget

This section of the proposal outlines the budget which is proposed to cover the costs of the various projects and programs presented in the foregoing sections. Since the budget for a program of this magnitude

contains many individual items, only a summary discussion is presented for the various areas. The detailed aspects of the budget may be found in the computer program printouts, submitted to the granting agency, in which the budget is broken down into the individual projects and administrative units of the program. The following summary will include a brief discussion of the budget for the various program areas as described in the preceding sections of this proposal in addition to brief comments on the various budget items. The budget items in these tables represent requests for 1974, 1975, 1976, and 1974-1976 combined, respectively, and will not be discussed separately for the 3 years unless there is a major difference in the makeup of that particular budget item.

PR73-II1 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 2. A progress report. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 305 p.

Grassland-types, World-grasslands, Grassland-climate, Grassland-soil, Grassland-vegetation, Grassland-fauna, Fire, Grassland-and-man, Systems-approach, Models

A general overview of grasslands is given to provide the wider context in which the studies of the US/IBP Grassland Biome are set. The importance of grasslands to man as croplands and grazing lands, their extent and influence are discussed. The geological history of grasslands and co-evolution of many herbivorous animals is described. Over one third of the earth's land area is covered by grasslands, many of which have been modified by man.

A world perspective for USA grasslands is provided by an account of world grasslands, their general features, climate, soils, vegetation, animals, and controlling factors of fire and man. Grassland climates are characterized by seasonal extremes of soil water and temperature with examples occurring in Arctic and alpine, temperate and tropical conditions. Soils characteristically associated with grasslands are in the Mollisol and Aridisols orders with occasional representation in the Alfisol and Vertisol orders. The distribution of major classes of grasslands, such as prairies, steppes, savannas, annual, and other grasslands, in various countries is discussed along with the major contributing grass genera and species. Grassland animals are next considered with the distribution of large and small mammalian herbivores, birds, and other grassland animals. The part played by fire in grassland ecology is discussed, particularly in view of management policies in which fire is suppressed. Finally man, in converting natural grasslands to croplands, substituting his domestic animals for the naturally diverse animal populations, and alienating grasslands for urban and communication purposes, is seen as being in need of a better information base for such future

actions and management of the grassland resource.

The very complexity of the grassland resource as an interacting system of many parts ideally suits it to the application of the systems approach. Using this approach and the associated interdisciplinary team for the needed research, a systematic consideration of the complexities is made possible. The results then allow both insights into the operation of the system and its limitations, as well as providing a more adequate base for decisions on management and use of the resource. The approach allows an ordering and synthesis of hitherto unmanageable amounts of data and information into a format which allows the structure and function of the system to be modeled. The predictive capabilities of the models are then available for use in a variety of ways related to resource and research management. Decisions, for example, in single-use management are frequently arbitrary, but as population pressures and demands increase, multiple-use management becomes more appropriate. With it, come an even more staggering array of problems for which a decision-making apparatus based on the systems approach is indispensable. The same holds for ecosystem research, in attempting to grapple with the several components and interactions of such systems to improve understanding of how they function and where they are most susceptible to alterations. Outlined is the composition and management of the interdisciplinary research team required to apply the systems approach to ecosystem research and management. Features of such research include decision making on priorities for research, the organized collection, storage, and retrieval of data, an effective communications network, and a commitment of personnel to the use of the data and other information in modeling the system.

PR73-II2 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 2. A progress report. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 305 p.

Meteorology, Climate, Hydrology, Hydrological-cycle, Grassland-types, Vegetation-types, Latitude, Altitude, Growing-season, Inter-site-comparison, Soil-types, Solar-radiation, Precipitation, Heat-transfer, Net-radiation, Air-temperature, Soil-temperature, Heat-balance, Energy-balance, Soil-water, Infiltration, Infiltration-rate, Grazing-influence, Evapotranspiration, Pawnee, ALE, Pantex, San-Joaquin, Bridger, Osage, Jornada, Cottonwood, Bison-Site, Dickinson, Hays

The physical environment of grasslands is discussed for the US/IBP Grassland Biome study sites and the grassland types they represent. A description of the geographical distribution of these types and representative study sites is followed by an account of the associated geological and geomorphological features, the climate; and the soils.

The grassland types studied include tallgrass prairie, mixed-grass prairie, shortgrass prairie, mountain grassland, shrub-steppe grassland, desert grassland, and annual grassland. Together, these types are distributed from Canada to Mexico and from the Pacific coast to the Mississippi River. For the most part the grasslands occur on level to undulating terrain on material laid down or transported in a variety of geological eras. All the grasslands studied are strongly seasonal in rainfall distribution and vary in amount of rainfall received over a fourfold range. In the Great Plains grasslands nearly 75% of the annual rainfall occurs between April and September, while about the same percentage occurs from October to March in the annual and shrub grasslands. Cluster analysis has been used to classify the research sites on the basis of rainfall and the distinctions between the groupings obtained clarified by comparing the principal eigenvectors of the rainfall regimes. Thus the incidence of principal eigenvectors distinguishes winter, early summer, and late summer-rainfall regimes. Growing season definition from a purely climatic viewpoint has met with some success. The first type defined was the potential thermal growing season dependent on the time the air temperature exceeds a threshold value. A subsequent refinement was the probability growing season, calculated as the joint probability of both rainfall and temperature exceeding given threshold values. Characteristics of these abiotically determined growing seasons, and site similarities based on these, are discussed. A variety of soil types are not surprisingly associated with the widely dispersed grassland types although, with two exceptions, they are found on soils of the Mollisol order. The exceptions, the desert and the annual grasslands, occur on soils of the Aridisol and the Alfisol orders, respectively.

The flow of energy in grassland ecosystems is discussed from a climatic driving variable viewpoint and, for emphasis, two forms are distinguished: light energy, of which the ecosystem traps an extremely small portion, and thermal energy, much of which underlies a major set of ecosystem driving variables. The pathway of light energy from its source to the chlorophyll molecules of plants is discussed. Included here are models which allow prediction of terrestrial shortwave radiation, results relating energy interception to leaf area index and leaf angle, and correlations derived from measurements of photosynthetically active radiation and total incident radiation. Thermal energy is distinguished to allow specific discussion of heat transfer which is considered, briefly, in relation to plants and animals and in more detail for soils and litter. Heat transfer in soils and the seasonal pattern of soil temperature with depth is discussed as are two relevant models, one for simulating net radiation and the other for soil temperature. The first established a relationship between net radiation and solar radiation for the Pawnee Site. The second, using the one-dimensional heat from

equation, is used to generate soil temperature profiles.

The complete energy balance is then discussed because of the coupling implied between the physical and biological worlds and its use in evaluating the primary consequences of treatments on the ecosystem or variations in its driving variables. One such change in driving variables has been the detection of a secular decrease in solar radiation over the Great Plains due to increasing atmospheric turbidity although the short and long-term consequences of this remain to be fully explored. A general discussion of energy balance features of grassland ecosystems is supplemented by data on the partitioning of net radiation (100%) over the growing season at a northern mixed-grass prairie site into latent heat energy (71%), sensible heat energy (27%), soil energy flux (1.3%), and energy for plant production (0.6%). For the same site the effect of grazing was examined in terms of energy balance when the main conclusion was relatively greater use of net radiation as latent energy in the grazed treatment with compensatory lower use as sensible energy. Among other differences apparent at that site were the higher soil temperatures associated with the grazing treatment and a diurnal soil temperature range about twice that of the ungrazed treatment. The differences in amount of litter and standing dead material were of underlying importance in the development of these temperature differences. In another study, energy balance of two mixed-grass prairie sites was compared using three independent methods of measurement and calculation. For the general purpose of the study and for time-scales exceeding 1 week, results by the three methods, energy balance, water balance, and the Thornthwaite-Mather technique, showed good correspondence. Finally, the energy balance of a northern mixed-grass prairie is contrasted, to illustrate an extreme comparison, with that of a desert grassland. In addition to the net radiation differences which largely result from latitudinal differences, the generally higher apportionment of energy into latent heat at the northern site and sensible heat at the desert (southern) site is apparent through the growing season.

The cycle of water in grassland ecosystems is treated in terms of driving variables (rainfall, snow), the single state variable (soil water), and hydrologic processes (interception, infiltration, overland flow, and evapotranspiration). The amounts, geographical and seasonal distributions of rainfall and snow, are reviewed for the grasslands. Except for the mountain grasslands snow water equivalent is not a major contribution to annual precipitation. A notable feature of the summer precipitation in the grasslands of the Great Plains are the thunderstorms which, because of their comparatively small size and the accompanying variations in frequency, duration, and rainfall intensity, present certain problems because of the consequent spatial heterogeneity. Growing season rainfall has been compared for the different grassland sites

in terms of its variability and the recurrence intervals for given amounts of rainfall between April and September. Use of recurrence interval criteria has allowed a well-defined comparison to be made of precipitation amounts received during the Grassland Biome studies at various sites in terms of the long-term average precipitation. Hence, seasons of study have been classified as "normal," "wet," or "dry." Variation in the amount of snow water contribution to annual precipitation is known to occur with different grazing intensities, generally with the amount lower, the heavier the grazing. Results from Grassland Biome studies conform with this expectancy. In the ecosystem level model, ELM, rainfall is simulated using a first-order Markov chain and the appropriate probabilities generated from long-term rainfall records from different sites.

Soil water has been measured both as soil water content and as soil water potential. Various examples are given to illustrate the variability of soil water content in time and space. Thus, for several treatments at Pawnee there is a generally decreasing trend of soil water content and soil water potential as the growing season progresses with associated changes in distribution of soil water content with depth over time. Spatial variability in soil water content related to local variations in soil properties is illustrated from detailed measurements taken in an area of less than 0.5 ha.

Finally, of the several processes in the hydrologic cycle, those of which some study has been made because of their relative importance in grasslands are discussed. These include interception, infiltration, overland flow, and evapotranspiration. The significance of interception amounts depends greatly on the context when, on an individual storm basis, it may be as high as 80%, but on an annual basis account for no more than 80%. A study of grazing effects at Pawnee in terms of infiltration indicate that light and moderate grazing have little effect on sorptivity and saturated hydraulic conductivity, with the latter dominating the process. However, with heavy grazing an effect is demonstrable and the situation is reversed, with sorptivity dominating the process. Relationships of these components of the process have been established with the amount of litter associated with the different grazing treatments. In overland flow preliminary indications from a mixed prairie grassland are that there is little difference in resistance to runoff due to friction under contrasting grazing intensities. Under heavy grazing, however, the reduced surface storage due to a leveling of surface depressions can result in greater runoff compared with light grazing treatments. This result was predicted from sensitivity analysis of a volumetric-threshold infiltration model. Several studies of evapotranspiration have been conducted. In one of these the results of a model of soil water depletion in which varying amounts of active roots and hydraulic conductivity with depth were considered,

good correspondence with field observations has been obtained. A novel study of canopy resistance to water loss of a shortgrass prairie has shown a striking relationship with the phenological stage of development of dominant species in ungrazed and grazed situations. Another novel study has yielded preliminary results of some interest where, by using a tritium labeling technique and comparing the results with water loss as measured by a lysimeter, information on transpiration water loss and total (evapotranspiration) water loss has been obtained. Throughout the discussion of these hydrologic processes commentary is made on how they are handled in the abiotic component of ELM.

PR73-II3 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 2. A progress report. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 305 p.

Primary-production, C-3-pathway, C-4-pathway, Warm-grass, Cool-grass, Aboveground-plant-biomass, Belowground-plant-biomass, Root-annual-increment, Carbon-dioxide-exchange, Efficiency-energy-capture, Energy-flow, Photosynthesis, Phenology, Plant-growth, Shoot-root-ratio, Translocation, Vegetation-types, Grassland-types, Water-use-efficiency, Ecosystem-stress, Grazing-influence, Inter-site-comparison, Growth-rate, Producer-model, Models

Within the Grassland Biome seven grassland types have been studied and various questions surrounding the producer role in these are discussed. More than 1000 plant species are represented in these grasslands, over half of which are sufficiently prominent for production data to have been collected on them individually. The practical and interpretative needs to continue using the species and sometimes the ecotype as the unit of study are discussed as are technical developments which, using spectral reflectance characteristics of vegetation, allow non-destructive sampling of aboveground biomass. The importance of information collected at the species level is the good foundation they provide for subsequent grouping of data, an example of which is a similarity classification of the grassland types based on aggregation at higher taxonomic levels. Another example is provided by the temporal and spatial diversity of plant species among the grasslands. From an ecosystem viewpoint, the concept of aggregating species into functional groups has much to offer both practically and in understanding the operation of the system as a whole. Several forms of grouping plant species are based on production and on biological strategies. An example of the former is the range managerial distinction between warm and cool season species, the contribution of which varies across the grasslands, as does the contribution of species grouped according to biological strategy.

In addition to studies of biomass and developmental changes with time, studies on

the reaction of the producer component of the ecosystem to system perturbations are proving to be very useful. These perturbations have included manipulation of grazing animals above and below ground, additions of water and of nutrients, and the removal of various plant groups. Effects of cattle grazing include reduction in contribution of susceptible species to total production and compositional and structural differences between areas of grassland with long histories of different grazing use. Differences in response to grazing of above- and below-ground production are found depending on the grassland type and the respective contributions of various species groups. In another example of grazing manipulation, reduction of grazing by nematodes below ground by a nematicide treatment resulted in up to a 59% increase in aboveground plant production. In a factorial experiment in which water, nitrogen, or both were added to a shortgrass prairie, the last of these treatments had a synergistic effect far beyond the combined effects of water and of nitrogen added separately. The study of adaptations of producers at levels from the species to the system under the diverse environmental climates of the grasslands is briefly discussed.

Production and energy flow at the producer trophic level are treated in some detail because of their fundamental importance in ecosystem function. Energy capture, in terms of dry matter fixed per unit of incoming solar radiation, is least efficient in grasslands under dry conditions, increasing in efficiency under wetter conditions. Water use efficiency, in terms of dry matter fixed per unit of available water used, is curvilinear with increasing availability of water. This is interpreted in terms of changes in strategies of different grassland types related to changes in limiting factors. Detailed studies on gross production have allowed many of the grassland species to be identified as having either the  $C_3$  or the  $C_4$  biochemical pathway of carbon fixation. The implications of this for characterizing temperature and production responses and for modeling are discussed with examples. The general correspondence of  $C_3$  and  $C_4$  pathways with cool and warm season responses in grasses has also allowed the ecological implications of the pathway types to be assessed. On a plant community production basis there is no evidence that  $C_4$  species domination results in a greater efficiency of production than  $C_3$  species domination, an unexpected result on biochemical grounds. Net production data obtained over the growing season by clipping and separating species and plant parts at sites representative of the different grassland types, show differences in annual net primary production ranging from less than 100 g/m<sup>2</sup> to over 1000 g/m<sup>2</sup>. The distribution in time, and horizontally and vertically in space, of this production is briefly discussed for the different grassland types. Up till now, translocation of fixed carbon has been given less attention as a fundamental process in the grassland studies than production. The usefulness of understanding more about the distribution and amounts of labile and

nonlabile carbon compounds in linking trophic subsystems of the ecosystem is emphasized. Within the producer system, one of the outstanding problems has been the difficulty of separating live and dead plant material below ground. This was of concern because there is about 4 to 10 times as much plant material below ground compared to above ground in the grasslands. Preliminary studies using <sup>14</sup>C<sub>2</sub> labeling now indicate that as much as 80% of that belowground material is functional, and estimations by two independent techniques indicate that about 25% of that functional material is replaced annually. Translocation patterns to other plant organs are discussed, but little information is yet available. Season-long ratios of aboveground to belowground net primary production for the grasslands appear to lie in the range 1:0.6 to 1:4.3. In a total system sense, death can be regarded as irreversible translocation. The range of processes involved in death is briefly reviewed, then death of belowground and aboveground plant parts discussed. The need for further study below ground is emphasized. The general pattern of death of aboveground plant parts obtained by separating harvested material from the different grassland types into live and recent dead categories is outlined. A similar pattern exists for the prairie grasslands while distinctive patterns are found for the mountain grassland and for the desert grassland. The several processes discussed under production and energy flow are synthesized into a compartmental diagram which summarizes, for all grasslands studies in 1970, the amounts and transfer rates of materials in the producer component of the grassland ecosystem.

Lastly, the structure and features of the producer subsystem model of ELM are discussed along with the new areas of research its construction and implementation have stimulated. The structure of the producer subsystem model is discussed using, for comparison, the earlier presented compartment diagram. The incorporation of such features as functional groups and phenology are discussed. Finally, the several gaps in our understanding of the grassland ecosystem which have been highlighted by the modeling effort are discussed as new areas of biological research.

PR73-II4 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 2. A progress report. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 305 p.

Decomposition, Microflora, Microbial-biomass, Soil-respiration, Root-respiration, Decomposition-litter, Litter-decomposition, Decomposer-model, Decomposer-ecology, Soil-fauna, Soil-ATP, Decomposition-cellulose, Nitrogen-model, Phosphorus-model, Nutrient-cycling, Models

An overview of the contribution of Grassland Biome research and related work to our understanding of saprophagic dissimulation

of organic matter in grasslands is given. Of the microfloral elements, those of the phyllosphere, rhizosphere, and open soil are considered as are endogenous mycorrhizal associations, ruminant microflora, and coprophagic organisms. Where available, information on numbers and biomass is given and the problems of determining microbial turnover discussed. The roles of the soil fauna are then discussed including, amongst microfaunal activity, the predominant part played by adult scarabaeid beetles in cow pat decomposition; the dominance in activity of nematodes amongst the microfauna; and that of mites (mainly cryptostigmatids) and collembola amongst the mesofauna.

Soil respiration results, their implications for carbon turnover, and an analysis of the principal factors controlling soil respiration are presented. Details of seasonal change in soil respiration rate are given using, as an example, data from Pawnee in which the general pattern of low rates early and late in the season with high mid-season values is compared with the seasonal pattern of soil water and soil temperature. For this site, seasonal changes in soil respiration correspond more closely with changes in soil water than soil temperature. When these two important controlling factors, soil water and soil temperature, were compared with soil respiration at other sites, soil water was usually the dominant factor. In general, however, it is both factors together which account for a substantial part of the variation in soil respiration. In laboratory studies of soil respiration of field extracted cores, a similar pattern to that obtained from field measurements throughout the season was obtained. However, the addition of water to simulate 6 mm rainfall events produced a mid-season shift in RQ values, not shown in the unwatered samples, indicating a shift in substrate from predominately carbohydrates to probably proteinaceous substances. The significance of this finding is being investigated further. Preliminary field data on the partition of soil respiration into its components indicate that root respiration accounts for approximately 15% of the total. Partition by soil depth indicates the overwhelming contribution (74%) of the top 5 cm of soil to CO<sub>2</sub> evolution, yet with as much as 15% being evolved from depths beyond 20 cm. However, these percentages are very changeable, depending on soil water status.

Decomposition rates of a variety of litter substrates have been studied. The general pattern of loss rates from these substrates at different sites has varied more in magnitude than in qualitative aspect. Thus, for a mesic, tallgrass prairie site, litter decomposition was essentially complete in 120 to 160 days, while for a blue bunchgrass-sagebrush site, only 33% loss of shoot litter, and 10% loss of roots had occurred after 443 days. The pulsed nature of decomposition associated with sporadic rainfall events becomes more pronounced the more arid the grassland, an example of which is given for desert grassland. Various problems in studying litter decomposition

using the litter bag technique have been encountered, and these are discussed. The use of <sup>14</sup>C-labeled litter has been recently initiated in seven grassland types.

The structure and implementation of the decomposition component of ELM is discussed. This submodel takes, as inputs, litter (including plant roots), and feces which are then processed by microbes to produce CO<sub>2</sub>. The organic material inputs are separated into a fast decomposing fraction and a more slowly decomposing fraction; the decomposition rates being modeled by exponential decay functions under constant conditions. Within a given series of substrates, prediction of decomposition rate is achieved by a function including <sup>3</sup>N/C. The initial proportion of fast decomposing material is significantly correlated with C/N ratio and lignin content. The decomposition behavior of plant material and of feces is sufficiently different for them to be treated separately.

Phosphorus and nitrogen models have been developed which, by incorporating soil layering, treat effects of different soil water, temperature, and root densities by depth. In the P model separation of inorganic and organic P is made, while in the N model the different forms of N (NH<sub>4</sub>-N, NO<sub>3</sub>-N, etc.) are treated, and the role of dead root material and microbial immobilization in the storage of N are recognized.

Process studies in nutrient cycling are in their initial stages. Using <sup>15</sup>N application, one study is tracing the movement of N through the components of a shortgrass prairie, while in another study using <sup>32</sup>P, P uptake and movement is being followed in the same grassland.

PR73-II5 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 2. A progress report. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 305 p.

Energy-flow, Grazing-influence, Mammals, Mammal-biomass, Jornada, Pawnee, Pantex, Cottonwood, Osage, Insect-biomass, Bird-biomass, Diversity, Dietary-matrix, Models, Consumer-model, Consumer-energetics-model, Bird-model, Bird-energetics-model, Diet-selection-model, Raptor-biomass, Metabolic-rate, Food-preference

Structure and dynamics of ecosystems are defined and discussed in relation to grassland consumers.

Consumers are discussed in their structural context within the ecosystem in terms of their biomass, trophic relationships, and diversity. Consumer biomass relationships for small mammals, nesting birds, invertebrates, and domestic herbivores were examined for several grassland types. From this it was found (i) that the proportion of total consumer biomass in the four major consumer groups was similar for the different grasslands; (ii) that, notwithstanding,

differences in consumer community structure occurred with different plant community structures under the different environmental conditions of the grassland types; and (iii) that the quantity of consumer biomass varies greatly among the grasslands and that in a general way the amount of plant production determines total consumer biomass. Relationships of the biomass of the various consumer groups with other grassland attributes has been examined and the conclusion reached that, in grasslands, consumer groups collectively are food limited.

Trophic structure analysis has been conducted along the lines of trophic pyramid construction and food web analysis, the greater effort having been on the latter. In what is probably one of the most comprehensive food web analyses attempted, the dietary composition of 36 consumers and consumer groups of shortgrass prairie grassland has been analyzed in terms of 112 dietary items. One outcome has been the identification of the relatively few pathways whereby the majority of energy is transferred in the ecosystem by consumers. As for diversity, grasslands are low in this attribute for small mammals and for birds. Their richness in invertebrate diversity has been recognized but not yet analyzed.

The dynamics of consumers in the ecosystem have been studied mainly from energetics food habit and diet selection viewpoints and thus far, considerably less from their role as controllers. A number of energy flow patterns in grassland consumers have been quantified to the extent that energy flow models have already been constructed and tested (e.g., for small mammals, birds, and cattle) or are being developed (e.g., for grasshoppers). Ideally, such models should be highly aggregated yet remain appropriately sensitive to changes in the biomass or state of important consumer groups. The high resolution, small mammal and bird energetics models are discussed, as is the cattle version of the consumer subsystem model of ELM. In addition to these operational energetics models, information on energy flow in several other specific consumers has been assembled, the most detailed of which is for grasshoppers preparatory to constructing a model of their role in energy flow. Other consumers on which energetics information is being assembled include ants, sap-sucking insects, nematodes, reptiles, and raptors in addition to supplementary information for model improvement in small mammals and large herbivores. The last of these are not only by far the most important group of grassland consumers from a biomass standpoint, but also have human utilization value. As such, they have received considerable study in their own right. For example, in studies leading to an optimal forage intake model for pronghorn antelope, bison, sheep, and cattle indications were that the digestive capacity of native herbivores was greater than that of cattle. Interest in grasslands in Africa has resulted in a simulation model of the interactions between East African herbivore populations and the quantity and quality of their food sources. Finally, a

population dynamics and secondary production model of pronghorn antelope is being developed which includes competitive interactions with other consumer groups, animal and human predation, and effects of climate fluctuations.

Basic to an understanding of the more quantitative aspects of energy flow are studies on food habits and diet selection of consumers. Here, the most extensive studies have been made in the large herbivores, cattle, sheep, bison, and antelope, to determine the plants and nutrients in their diets and variations in their diets with season and grazing intensity. Using a variety of techniques, comparisons have been made among these herbivores of their selectivity, the quality of their diets, and their mobility when grazing which, together with forage availability, lead to conclusions on potential competition between the groups under a variety of conditions. A substantial effort has also led to the analysis of species and dietary items taken by 33 grassland small mammals from several grassland types. This has shown that grassland small mammals obtain their energy from a wide variety of sources, and the data also allow study of patterns of change in diet and in consumer population with grassland type. In birds, the diets of the eight species studied from different grassland types range from a predominance of plant seeds to entirely invertebrates. Temporal variations in diet have been found, with the morning diet often markedly differing from the afternoon diet, while relationships of diet item size, diet type, and bird size have been demonstrated. Invertebrate food habits are, for several reasons, less easily studied. Nonetheless, a preliminary classification of the food habits of 87 invertebrate families and orders indicates their greatest impact on the grasslands in general is probably as chewers and suckers of plant material.

A generalized model of the diet selection process has been developed. It takes the potential food source items and controls their amount and rate of selection by environmental factors, attributes of the food items, and consumer characteristics. Total food intake is then considered in relation to food density, preference, and selectivity.

The work on consumers as controllers in the ecosystem is still developing. At the present, two areas of control are becoming clear, however: first, on the structure and production of the plant communities, and second, on the accumulation and decomposition of organic matter.

PR73-II6 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 2. A progress report. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 305 p.

#### Biological-variability

Variation of biological material is discussed and the concept of biological and of

sampling variability introduced. The separation of these components of total variability is proposed by a technique of random agglomeration of samples. The technique is shown to display promise when applied to standing crop results from all grazing treatment and control plots from IBP studies in 1972 at Pawnee. The implications of developments which would allow nondestructive sampling are discussed.

The limits of total variability of actual data are compared with the desired limits of being within 20% of the mean 80% of the time. Data used include aboveground biomass of primary producers, soil respiration, litter bag decomposition, and invertebrates from several grassland types. Belowground biomass data are analyzed using a one-way analysis of variance to detect intraseasonal fluctuations. Comparisons are also made of variability of small mammal numbers by three estimation techniques. The total variability of these data is discussed along with the appropriate comparisons.

PR73-II7 Van Dyne, G. M. [Principal Investigator]. 1973. Analysis of structure, function, and utilization of grassland ecosystems. Vol. 2. A progress report. US/IBP Grassland Biome, Colorado State Univ., Fort Collins. 305 p.

Models, Modeling-concept, Ecosystem-model, ELM, Bird-model, Systems-approach

This chapter summarizes the simulation modeling activities in the Grassland Biome. The modeling philosophy in the biome led early to a concentration on a total system context with secondary interest in subsystem modeling arising within that context. The role of simulation modeling as it has developed is outlined. Major benefits have accrued. To the biological scientists there has been both an increase in rigor of interpretation of his research and the stimulation of new research and research philosophy. To problems of management of natural resources which implicitly deal with total systems there has been and is continuing, successful application of the simulation models developed as in the RANGES model which is being applied, through the associated RANN project, to range management problems. Finally, the total system modeling effort has played an important educational role in facilitating communication between disciplines of scientists hitherto made difficult because of lack of common objective and of an advanced medium of communication. The benefits of having developed a total system viewpoint, that is, an all-encompassing viewpoint without being all-inclusive, is discussed along with the early need for appropriately sympathetic scientists from a basically strong discipline and specialist oriented, rather than generalist oriented, educational system.

The history of development of the major total systems models in the Grassland Biome is outlined and the development of these and an associated simulation language seen as an evolutionary process. Its logical continuance is projected later in the chapter.

Thus, the sequence is traced from the early grassland ecosystem model, PWNEE, a nonlinear model, through an experimental exploration originally based on that model of the extent to which the ecosystem could be represented by linear functions, with the ancillary benefits of application of well-established sensitivity analysis, finally, to ELM.

The development of the present ecosystem level model, ELM, is discussed in some detail because of the experience gained in model development, the crucial importance of clear initial objectives and techniques whereby these are specified, and the scope of that model to represent the biomass dynamics of a grassland ecosystem applicable to the seven grassland types in the western USA encompassed by the Grassland Biome studies. Notable features of the design of that model include relatively easy interaction (i.e., use and alteration by potential users within a matter of hours), its complexity (over 70 state variables and 3000 parameters), and the effort invested in its development alone (over 7 man-years). Details of the subsystem components are diagrammed in earlier chapters; instead, here, emphasis is placed on the major interconnections between those subsystems. The topics of validation and of sensitivity analysis of ELM are briefly discussed.

The simulation modeling experience of the biome has been used in a wide variety of interbiome roles. Three are outlined. The first is involvement from biome to national level in a regime of modeling termed macromodeling to connote the inclusion of economic and social systems as well as biological systems into macrosystem models of use in large-scale, political decision making. The second was the initial contribution to IBP interbiome and international synthesis efforts through the organization and running of an international tundra and grasslands modeling workshop. This workshop, alone, stimulated the production of several models. The third is effectively the subsequent use, in an interbiome and problem solving way, that a particular model, a bird energetics model, has gained.

Finally, the application and development of simulation modeling in ecosystem study is reviewed in the light of Grassland Biome experience. The rapid increase in application of simulation modeling developed in physics and engineering to the biological sciences over the past 10 years is noted. Limitations are foreseen in the continued application, without modification, of state-space simulation techniques and similarly, in attempts, *a priori* to align biological systems' modeling in a framework of purportedly general systems theory. Instead, an evolutionary development is foreshadowed from the continued concern to adequately represent biological systems in simulation modeling format. The course of the development will be towards ecosystem theory requiring new language types and model implementation modes which will have as much the essence of the biological systems as the earlier simulation techniques had of the engineering and physical systems.

- OL042 Rogers, L. E., and R. J. Lavigne. 1972. Asilidae of the Pawnee National Grasslands, in northeastern Colorado. Agr. Exp. Sta., Sci. Monogr. 25. Univ. Wyoming, Laramie. 35 p.

Pawnee, Insects, Robber-flies, Asilidae, Insect-systematics, Insect-ecology, Food-composition, Insect-foodweb, Foodweb, Mating-behavior

This study attempts to answer questions about species composition, seasonal distribution, prey selection, behavior, and habitats of the robber flies occurring on the Pawnee National Grassland Intensive Study Site.

Some of the species were represented by small numbers of collection records so that their seasonal distribution is probably not well defined; such species include *Ospriocerus abdominalis*, *Asilus gilvipes*, *Stichopogon trifasciatus*, *Efferia varipes*, *E. pallidula*, *O. latipennis*, *Proctacanthella cacopiloga*, *Mallophorina guildiana*, *Stichopogon argenteus*, *E. bicaudata*, and *Backomyia limpidipennis*. Other species were collected so extensively that their true seasonal distribution is well represented. Such species include *Ablautus rufotibialis*, *Asilus formosus*, *Lasiopogon quadrivittatus*, *Asilus mesae*, *Proctacanthella leucopogon*, *E. staminea*, *Proctacanthus micans*, *E. helenae*, *Scleropogon picticornis*, and *Comantella falliei*.

There are seven species associated with the Owl Creek habitat. These are *A. rufotibialis*, *B. limpidipennis*, *C. falliei*, *L. quadrivittatus*, *P. cacopiloga*, *S. argenteus*, and *S. trifasciatus*. *Comantella falliei* and *B. limpidipennis* also occur around windmills and in irrigated plots, indicating the need for a moist environment. *Ablautus rufotibialis* only occurs in the bluffs along Owl Creek, and *L. quadrivittatus* was found along sand terraces adjoining Owl Creek. The other species were all found in the open rangeland habitat. *Asilus gilvipes* and *A. formosus* were found to occupy a unique microhabitat in that they are associated with animal burrows in the open rangeland habitat.

Some of the species appear to be opportunistic and take any prey of a given size range. Others are more selective and only take certain groups of prey. *Ablautus rufotibialis*, *L. quadrivittatus*, *O. abdominalis*, *O. latipennis*, *S. picticornis*, and *S. trifasciatus* were all found to be stenophagic, selecting prey from three or fewer orders, while *C. falliei*, *E. helenae*, *E. pallidula*, *E. staminea*, *P. leucopogon*, and *P. micans* appear to be euryphagic. A compilation of prey records is included with the discussion of each individual species.

Seasonal distribution, prey specificity, predator size, method of prey capture, oviposition site, foraging position, habitat, and morphological characteristics were considered as niche parameters. In every case, where

sufficient data were available, there were at least some differences that could account for the coexistence of the robber flies on the Intensive study site.

From the data presented, it would appear that the moderate grazing treatment supports greater numbers of asilids than do any of the other treatments.

- OL043 Mitchell, J. E. 1972. An analysis of the beta-attenuation technique for estimating standing crop of prairie range. J. Range Manage. 25(4):300-304.

Pawnee, Aboveground-plant-biomass, Instrumentation, Shortgrass, Beta-attenuation

The standing crop of aboveground shortgrass prairie vegetation may be quickly and accurately estimated by the beta-attenuation technique. This technique is based upon the principle that herbage absorbs or attenuates beta particles emitted by certain radioactive nuclides as a predictable function of the herbage biomass intersecting the attenuation field between emitter and detector. Two methods of measurement are correlated with standing vegetation. These tests indicate that the method can account for approximately 90% of the variation measured in the field, with the exception of quadrats dominated by plains prickly pear. In addition to being accurate, precise, and relatively inexpensive, the beta-attenuation technique is nondestructive in nature, allowing repetitive sampling of the same location.

- OL044 Kennedy, R. K. 1972. The sickledrat: A circular quadrat modification useful in grassland studies. J. Range Manage. 25(4):312-313.

Osage, Instrumentation, Sickledrat

A sickle-shaped modification of a circular quadrat has been used advantageously in tall-grass rangeland production studies in northeast Oklahoma. The main advantages of this quadrat are the reduction of the area concept bias in quadrat placement, ease of quadrat placement, reduction of perimeter decisions, and facilitation of precision clipping at various heights above the soil surface.

- OL045 Alldredge, A. W., and F. W. Whicker. 1972. A method for measuring soil erosion and deposition with beta particle attenuation. J. Range Manage. 25(5):393-398.

Pawnee, Beta-attenuation, Erosion, Texture, Grazing-influence, Soil-movement

A method utilizing beta particle attenuation was developed for measuring soil erosion and deposition in a shortgrass plains ecosystem. This method used a sealed strontium-90 source located below ground level. Soil

erosion and deposition was observed by fluctuations in detected count rates using a portable Geiger Mueller counting system. Initial results indicate that quantitative measurement of soil depth fluctuations in amounts considerably less than one millimeter and over a period of a few weeks are possible. Data are presented from application of this method in six soil series under heavy, moderate, and light summer grazing treatments.

- OL046 Innis, G. 1972. The second derivative and population modeling: Another view. Ecology 53(4):720-723.

#### Models, Modeling-concept, Differential-equation

In a paper with a similar title (see Ecology 52(4):606-613), John Clark argues for the use of second-order differential equations in population modeling. To refute his arguments, this paper (1) demonstrates the similarity of sets of higher order ordinary differential equations to sets of first-order ordinary differential equations, (2) discusses both practical and philosophical aspects of the inclusion of "historical" effects in a biological model, and (3) argues that intrinsically second-order biological or physical processes have not been observed.

- OL047 Lavigne, R. 1972. Ethology of *Ablautus rufotibialis* on the Pawnee Grasslands IBP Site. J. Kansas Entomol. Soc. 45(3):271-274.

Pawnee, Robber-flies, Insects, Predation, Feeding-habit, Food-composition, Mating-behavior

The northern distributional limit of *Ablautus rufotibialis* Back is extended to the northeastern corner of Colorado. The simple male courtship behavior is described. This is the first time male courtship behavior has been reported for the genus *Ablautus*. Females oviposit in the soil, usually in the shade of grass clumps. The majority of prey taken belong to the dipterous families Anthomyiidae, Sepsidae, and Cecidomyiidae.

- OL048 Pearson, R. L., and L. D. Miller. 1973. Remote mapping of standing crop biomass for estimation of the productivity of the shortgrass prairie, Pawnee National Grasslands, Colorado, p. 1357-1381. In Proceedings of the 8th International Symposium on Remote Sensing of the Environment. Univ. Michigan, Ann Arbor.

Pawnee, Blue-grama, Aboveground-plant-biomass, Instrumentation, Reflectivity, Remote-sensing, Plant-cover, Shortgrass, Vegetation-mapping

The US/IBP Grassland Biome Program sponsored by the National Science Foundation has undertaken an ecosystem analysis study of an entire shortgrass prairie biome using systems analysis techniques. One of the most important spatial parameters of the Grassland Biome which must be determined on an areal basis is

the amount of vegetation present on the prairie at a particular place and time. Estimates of the amount of vegetation present have traditionally been made by hand clipping plots of known area with shears and weighing the dried vegetation from the plot trimmed to determine the mass of vegetative material per unit area, its biomass and its calorie equivalent. A more efficient means of determining the amount of plant cover has been devised using remote spectral measurements of the vegetation. These measurements can be obtained from any altitude allowing small plot estimates from ground measurements or large area estimates from aerial or satellite measurements.

Small area biomass estimates have been made with a two-channel spectral ratio method using a small hand-held radiometer with a biomass estimation accuracy of greater than 95%. Large area biomass determinations have been tested on multispectral scanner data using both a channel ratio technique and multispectral pattern recognition techniques. The resulting biomass maps show correlations with several ground truth sites of from 80% and 90% between the estimated biomass values from the multispectral data of an area and biomass values taken from clipped plots in the same area.

The spectral data used in the biomass determinations are taken from wavelength regions sampled by many present and future remote sensing data gathering systems such as ERTS and SKYLAB. In addition, the channel ratio method is based on the characteristic reflectance properties of the leaves of living plants. Therefore, the method can be applied to biomass estimation in vegetation types different from the shortgrass prairie although such applications remain to be tested.

- OL049 Rogers, L., R. Lavigne, and J. L. Miller. 1972. Bioenergetics of the western harvester ant in the shortgrass plains ecosystem. Environmental Entomol. 1(6): 763-768.

Pawnee, Insects, Ant, Energy-flow, Insect-respiration, Calorimetry, Insect-density, Insect-population, Insect-biomass, Grazing-influence, Insect-production

The bioenergetics of *Pogonomyrmex occidentalis* (Cresson) was studied on the IBP grassland intensive study site in north-east Colorado. Energy flow values were determined by estimating the energy required per colony for production of ant tissue and for respiratory energy loss. Extrapolation of the energy values per colony to colony densities in the differentially grazed pastures resulted in seasonal estimates of population energy flow values for western harvester ant populations in ungrazed, lightly grazed, moderately grazed, and heavily grazed pastures.

Excavation of 11 colonies resulted in estimates of 2032 worker ants and 315 winged reproductives produced per colony each year. This resulted in an estimate of 46.81 kcal per colony required for secondary production per year.

Respiratory energy losses were estimated from measurements of CO<sub>2</sub> production in relation to field temperatures, as determined from measurements conducted on two colonies established in the laboratory. Annual energy requirements for respiration were estimated at 418.42 kcal per colony.

Energy flow values (tissue production + heat production) ranged from 1.45 kcal per m<sup>2</sup> per year in the moderately grazed pasture to 0.14 kcal per m<sup>2</sup> per year under heavy grazing pressure. The energy flow values for *P. occidentalis* are much lower than those calculated for *P. badius* (Latreille). The major area of difference occurs in estimates made of energy required for respiration.

- OL050 Wallace, J. D., D. N. Hyder, and G. M. Van Dyne. 1972. Salivary contamination of forage selected by esophageal fistulated steers grazing sandhill grassland. J. Range Manage. 25(3):184-187.

Mammals, Cattle, Steers, Fistula, Food-chemical-composition, Calorimetry, Blue-grama, Salivary-contamination

The effect of saliva contamination on chemical composition of forage collected from esophageal fistulated steers grazing sandhill grassland was studied over four different seasons. Salivary contamination of grazed forage significantly increased the ash component, but did not change other chemical constituents calculated on an organic matter basis. The increase in ash attributed to saliva varied with species of plants and season of grazing.

- OL051 Genoways, H. H., and J. K. Jones, Jr. 1972. Mammals from southwestern North Dakota. Occasional Papers No. 6. The Museum, Texas Tech Univ., Lubbock. 36 p.

Dickinson, Mammals, Mammal-checklist, Mammal-systematics, Mammal-biomass, Reproduction

Thirty-nine species of mammals were collected or observed in the course of field work in southwestern North Dakota. In this paper ecological and distributional data for each species have been summarized. It is hoped that this study, together with those by Andersen and Jones on northwestern South Dakota and one underway by Richard P. Lampe and associates on southeastern Montana, will provide a better understanding of the mammalian fauna of this important region of the Northern Great Plains.

Four general habitat types prevail in southwestern North Dakota: dry upland grassland, which is the most widespread type; mesic grasslands; woodlands, both in riparian situations and on the Killdeer Mountains; and saxicolous habitats associated with the badlands along the Little Missouri River and other rocky outcroppings. The greatest number of species appears to be more or less restricted to upland grasslands. Those taken exclusively in this habitat include *Lepus townsendii*, *Sylvilagus audubonii*, *Spermophilus*

*tridecemlineatus*, *Cynomys ludovicianus*, *Thomomys talpoides*, *Perognathus fasciatus*, *Dipodomys ordii*, *Reithrodontomys megalotis*, *Peromyscus maniculatus*, *Onychomys leucogaster*, *Lagurus curtatus*, and *Microtus ochrogaster*. Other species such as *Sorex cinereus*, *Microtus pennsylvanicus*, and *Zapus hudsonius* occasionally were taken in upland situations, but were more abundant in mesic grasslands.

Species seemingly restricted to riparian woodland or the Killdeers included *Lepus americanus*, *Sylvilagus floridanus*, *Castor canadensis*, *Peromyscus leucopus*, *Clethrionomys gapperi*, and *Erethizon dorsatum*. The introduced *Sciurus carolinensis* also is restricted to the Killdeers. *Sorex cinereus*, *Microtus pennsylvanicus*, and *Zapus hudsonius* were abundant in woodland habitats, and specimens of *Eutamias minimus* were taken in such situations. *Microtus pennsylvanicus* may have the broadest ecological tolerance of any species in southwestern North Dakota, being relatively common in all three of the above mentioned habitats.

Saxicolous species include *Eutamias minimus*, *Neotoma cinerea*, and five species of bats (*Myotis evotis*, *M. leibii*, *M. lucifugus*, *M. volans*, and *Eptesicus fuscus*). Bats utilize this habitat primarily for roosting sites, but also use man-made structures and feed elsewhere, usually in or near woodland habitats. Placement of the carnivores and artiodactyls with any one habitat type is difficult because of the high vagility of these large mammals. Our specimens of *Canis latrans*, *Vulpes vulpes*, *Mustela frenata*, and *Mephitis mephitis* were taken in upland situations. The raccoon, *Procyon lotor*, usually is associated with riparian habitats on the Great Plains. Individuals of *Odocoileus hemionus* were observed in the breaks and bluffs along the Little Missouri River and *O. virginianus* was seen in and around the woodlands of the Killdeer Mountains. The pronghorn, *Antilocapra americana*, is a species of upland grasslands.

The 37 species of mammals native to southwestern North Dakota discussed in this account are from six faunal units as described by Hoffmann and Jones. Fifteen species are widespread: *Myotis leibii*, *M. lucifugus*, *Eptesicus fuscus*, *Castor canadensis*, *Peromyscus maniculatus*, *Ondatra zibethicus*, *Erethizon dorsatum*, *Canis latrans*, *Vulpes vulpes*, *Procyon lotor*, *Mustela frenata*, *Mephitis mephitis*, *Odocoileus hemionus*, *O. virginianus*, and *Antilocapra americana*. Species (nine) with boreal or montane affinities include *Sorex cinereus*, *Myotis evotis*, *M. volans*, *Lepus americanus*, *Thomomys talpoides*, *Neotoma cinerea*, *Microtus pennsylvanicus*, *Clethrionomys gapperi*, and *Zapus hudsonius*. The steppe faunal unit is represented by *Lepus townsendii*, *Spermophilus tridecemlineatus*, *Cynomys ludovicianus*, *Perognathus fasciatus*, and *Microtus ochrogaster*. Four species (*Sylvilagus audubonii*, *Dipodomys ordii*, *Reithrodontomys megalotis*, and *Onychomys leucogaster*) have their affinities in the Southwest. The Great Basin and deciduous forest units each are represented by two species--respectively, *Eutamias minimus* and *Lagurus curtatus*, and *Sylvilagus floridanus* and *Peromyscus leucopus*. The species of the

latter unit enter the area in the riparian woodland along the larger streams and rivers. Aside from the widespread species, the mammalian fauna of southwestern North Dakota appears to represent a transitional region between steppe species and those characteristic of boreal or montane areas to the north on the one hand, and species representing faunas of the Southwest and Great Basin on the other.

- OL052 Armijo, J. D., G. A. Twitchell, R. D. Burman, and J. R. Nunn. 1972. A large, undisturbed, weighing lysimeter for grassland studies. *Amer. Soc. Agr. Eng., Trans.*, 15(5):827-830.

#### Pawnee, Lysimeter, Instrumentation

This paper deals with the task and success of isolating an undisturbed 25-ton soil core, constructing a structurally-sound retainer to accept the soil container, and constructing a long tunnel to accommodate apparatus and access-requirements which were satisfied while preserving the original surface conditions. General features of lysimetry such as minimal unnatural surface area, high sensitivity, drainage provisions, minimal air volume beneath the soil container, and apparatus to check water and temperature balance were also achieved.

The lysimeter is located in the Pawnee National Grassland of northeastern Colorado, approximately 24 miles south of Cheyenne, Wyoming.

In general, performance of the lysimeter has exceeded expectations. A sensitivity equivalent to 0.001 inch (0.025 mm) of evapotranspiration is attainable. In actual weight change, this amounts to 0.443 lb (0.20 kg), which represents approximately 1/100,000 of the total soil container weight. Repeatability, nonlinearity, hysteresis, and drift with time have not, to date, caused any problems. Effects of wind on output voltage are averaged by the continuous integration process of the recorder. Temperature changes within the tunnel are not great, occur gradually in time, and do not appear to affect the electronic apparatus.

- OL053 Grow, R. R., J. E. Lloyd, and R. Kumar. 1973. An economical CO<sub>2</sub>-powered insecticide sprayer for small experimental plots. *J. Econ. Entomol.* 66(1):252-253.

#### Insecticide-sprayer

To obtain accurate chemical dosage on small plots of range grass with a pressure-nozzle sprayer, it was necessary to apply 1-2 gal of liquid formulation to each plot and to carefully maintain constant nozzle pressure. Application of small quantities was not practical with a conventional tractor-mounted weed sprayer, and constant pressure could not be maintained with a 3-gal compressed-air sprayer. To meet these requirements a new sprayer described in this paper was constructed.

The basic components of the sprayer are the sprayer tank, the CO<sub>2</sub> cylinder with back pack, and the spray boom.

The advantages of this sprayer are effective, trouble-free operation at low cost. Costs of parts and labor were \$51.76 and \$3.00, respectively.

- OL054 Innis, G. 1972. Simulation of ill-defined systems: Some problems and progress. *Simulation Today* No. 9, p. 33-36. *In Simulation* 19(6).

#### Models, Modeling-concept, Simulation, Phosphorus-model

This paper addresses some problems and progress in the development of mathematical simulation models in which the mathematical relations are not fully understood--in particular, models of biological systems. Three types of utility of models are defined, as are sharp and fuzzy laws. With these concepts in mind, models of various sizes are discussed. Modeling is analyzed from the point of view of making concepts specific, of sharpening fuzzy laws, and of producing useful results. The practical difficulties encountered when a team of experts in different fields attempt to develop a model are considered. Finally, the question of cost is addressed vis-a-vis the benefits that can accrue as a result of modeling activity.

- OL055 Porter, D. K. 1972. Shortgrass prairie. *Amer. Birds* 26(6):975-976.

#### Pawnee, Birds, Bird-density, Nesting

The pasture has been heavily grazed in summer by a controlled number of cattle for over 30 years. It is characterized by uniform short grasses, predominantly blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloe dactyloides*) and plains prickly pear (*Opuntia polyacantha*). Shrubs are absent. Soils are primarily sandy loams with small areas of finer textures or complexes. Annual precipitation is about 12 inches. The topography is flat to slightly rolling, varying in elevation from 5390 to 5445 ft. Nesting success in the pasture was Horned Lark, 63%; McCown's Longspur, 61%; Mountain Plover, 33%; Mourning Dove, 29%. The very high success of the former two when compared to overall productivity for this area (42% and 45%, respectively) may indicate the pasture approaches their optimal habitat requirements. Ground nesting doves had less than half of the success of tree nesting doves. Horned Larks established territories and began nesting in early April. However, two snowstorms that month drove all passerines (but not Mountain Plovers) from the plot, necessitating reestablishment of territories. Therefore, coverage is given as beginning only after the last storm. Lark Buntings fed daily and occasionally sang in the plot but are not believed to have nested there. They did nest in the adjacent lightly summer grazed pasture.

- OL056 Swartzman, G. L., and G. M. Van Dyne. 1972.  
An ecologically based simulation-optimization approach to natural resource planning. *Annu. Rev. Ecol. Syst.* 3:347-398.

Models, Modeling-concept, Simulation, Optimization, Resource-model, Australian-arid-land-model

Renewable natural resource management involves simultaneous consideration of many variables. Implementation of the multiple-use concept on wild lands, if one includes the probabilistic inputs of such factors as climate and mortality, requires the consideration of a staggering array of situations. This can be done, however, using simulation and optimization models and modern computational tools and techniques.

This paper introduces a technique for aiding large-scale system decision making. The general approach in this problem was to develop a computer simulation model showing the intra-seasonal and interseasonal dynamics of important state variables of an arid-land resource system. The state variables selected for consideration were soil water at different depths, different categories of plant biomass, numbers of shrubs, biomasses and numbers of different animal age and sex groupings, and biomasses of wool.

The decision was made to introduce an optimization, or management manipulation, of the system at yearly intervals. In the optimization procedure, there is a "commons grazing area" usable by two private property owners on a cooperative basis. At times of optimization, there may be animal transfers, pest animal control, and sales of animals or animal products.

Experience with the development and operation of this model led to the following tentative conclusions:

1. Large-scale system simulation models which give realistic output can be developed and can be managed, using a series of static optimization problems, in an attempt to arrive at good management procedures.

2. There is probably no hope, in such complex large-scale systems, of using the simulation-optimization approach to arrive at "the optimal" management procedure. We must settle for a good, resilient management procedure which seems to be best for the range of contingencies considered in the simulation.

3. The testing or exercising of the model in search of the best optimization "formula" is likely to be quite expensive in terms of computer and interaction time. The present model has been carried to the point at which such experimentation can just begin. We would expect that simple manipulation of the linear programming objectives and constraints alone, and comparing them under a variety of abiotic conditions, still would not guarantee that the best solution arrived at is optimal. However, bad or unforeseeably defective management alternatives would be eliminated. Also the manager might use this approach as a "sounding

board" with which to compare his experience in decision making on large systems, or to develop a feel for decision making on newly managed systems.

4. In developing and exercising such large-scale models, a high degree of interaction is necessary between the biologist, modeler, and systems managers. This group interaction is invaluable in getting a feel for the system and the effects of changes upon the system.

5. The exercising of model parameters over ranges around the mean should show the weak points of model output and point to areas for further model development and for biological and physical research.

6. The time pattern of management suggested by the optimization approach, i.e., management at yearly or half-yearly intervals, may not be the best management approach with respect to system stability in systems with high abiotic and plant fluctuations. In hopes of preventing a system crash in drought periods we were forced to adopt a conservative approach, forcing sales at times of low herbage. This could be replaced by a more flexible event-oriented approach closely geared to indicators of potential system instability. We tried to get at this with the range condition index, but the results showed that shrub numbers, from which we calculated range condition, did not indicate but rather followed drought conditions.

7. Probably three major items need to be considered in future studies of this type: First, we must use a more responsive index or set of indices geared to the specific locale of the system studied. Second, we need to monitor on a more frequent basis. Third, we need to combine with an optimization (such as we used) a set of management alternatives geared to events forecasting potential system instability.

- OL057 Vavra, M., R. W. Rice, and R. E. Bement. 1973.  
Chemical composition of the diet, intake and gain of yearling cattle on different grazing intensities. *J. Anim. Sci.* 36(2): 411-414.

Pawnee, Fistula, Cattle, Grazing-influence, Food-chemical-composition, Ingestion, Calorimetry, Cattle-nutrition, Mammals, Food-consumption, Cattle-production, Mammal-production, Digestion

Esophageal fistulated yearling cattle were used to collect diet samples and to measure intake during the summers of 1969 and 1970. Samples were taken from 128-ha pastures grazed at heavy and light intensities.

No great differences were observed between pastures for crude protein, gross energy, acid detergent fiber, lignin, and cellulose levels in the diets. Heavy grazing resulted in somewhat lower values for dry matter digestibility and intake. The differences in intake were greater later in the season when total forage available may have become limited on the heavy grazed pasture.

Individual livestock gains reflected the greater digestibility and intake observed on the light use pasture. Gain per animal was greatest on the light use pasture. However, more gain per hectare was produced on the heavy use pasture.

- 0L058 Strong, M. A., and R. A. Ryder. 1972. Preliminary observations of avian productivity on the Pawnee Site in north central Colorado. J. Colorado-Wyoming Acad. Sci. 7(2-3):113. (Abstr.)

Pawnee, Birds, Nesting, Bird-reproduction, Bird-growth, Horned-Lark, McCown's-Longspur, Meadowlark, Lark-Bunting, Mourning-Dove, Brewer's-Sparrow

During 1970, reproductive rates, relative nesting success, growth curves of nestlings, and periods of nesting activity were estimated for Horned Lark (*Eremophila alpestris*), McCown's Longspur (*Rhynchophanes mccownii*), Western Meadowlark (*Sturnella neglecta*), Lark Bunting (*Calamospiza melanocorys*), Loggerhead Shrike (*Lanius ludovicianus*), Mourning Dove (*Zenaidura macroura*), and Brewer's Sparrow (*Spizella breweri*) on the shortgrass prairie in north central Colorado. The percent of nests successful in fledging at least one young varied from 26.2 for Horned Lark to 36.8 for Lark Bunting among strictly grouped nesters, but Mourning Doves were the most successful with 53.6%. A total of 300 nests of 21 species were observed during the nesting season of 1970. Horned Larks were the earliest nesters, but Mourning Doves had the longest nesting season and showed three peaks of nesting activity. All ground nesting passerines appeared to grow at the same rate, but data were insufficient for proper comparisons.

- 0L059 Porter, D. K. 1973. Shortgrass prairie. Amer. Birds 27(3):686.

Pawnee, Birds, Bird-density, Horned-Lark, Hawk

Shortgrass Prairie.--Location: 8 miles north-northwest of Nunn, Weld County, Colorado, on the Central Plains Experimental Range of the Agricultural Research Service, Pawnee National Grassland; 40°49'N, 104°55'W. Size: 40.5 ha = 100 acres (south block measures 60 x 20 chains, central block 20 x 10, north block 10 x 20, borders are contiguous; blocks marked with grid interval of two chains; surveyed with 2-chain tape and staff compass). Weather: Temperatures were mild for this time of year, averaging 42°F during the censuses. Winds were from a northerly direction, usually northwesterly, and averaged 8.5 mph. One-half to 2 inches of snow covered the plot on January 12 and 20. Coverage: January 12-14, 19, 20, 21. Total: 6 counts, between 0825 and 1340, and lasting approximately 75 minutes. Count: Horned Lark, 14 (35, 14); Lapland Longspur, 1 (2, 1); Rough-legged Hawk, +. Average Total: 15 birds (37 per sq. km., 15 per 100 acres). Winter distribution of birds on the study plot and the surrounding areas is highly irregular and sporadic. For example, 60% of the Horned Larks seen were encountered on the last day of the coverage. Obviously, extrapolating the

results of the study to other areas or other time periods would be of questionable validity.

- 0L060 Martl, C. D. 1973. Food consumption and pellet formation rates in four owl species. Wilson Bull. 85(2):178-181.

Birds, Feeding-habit, Food-consumption, Owl, Owl-prey, Bird-biomass, Ingestion, Egestion

Food consumption and pellet formation rates were studied for 1 year in captive Great Horned, Long-eared, Burrowing, and Barn Owls. Mean food consumption for the whole year in the Great Horned Owl was 4.7% of its body weight per day; in the Long-eared Owl, 12.7%; in the Burrowing Owl 15.9%; and in the Barn Owl, 0.1%. Average pellet rates per day for the year were 1.2 for the Great Horned Owl, 1.4 for the Long-eared Owl, 1.5 for the Burrowing Owl, and 1.7 for the Barn Owl.

- 0L061 Flinders, J. T., and R. M. Hansen. 1973. Abundance and dispersion of leporids within a shortgrass ecosystem. J. Mammal. 54(1): 287-291.

Pawnee, Jackrabbit, Cottontail, Lagomorph, Jackrabbit-density, Cottontail-density

The study reported herein provides estimates of winter population densities and dispersion of three species of adult leporids on the shortgrass prairie of northeastern Colorado. A modification of the belt or strip method of censusing was used, and the results of this research make it easier to assess the impact and importance of these mammals within the Pawnee National Grassland in northeastern Colorado.

- 0L062 Wiens, J. A. 1973. Pattern and process in grassland bird communities. Ecol. Monogr. 43(2):237-270.

Birds, Bird-pattern, Bird-density, Horned-Lark, Cottonwood, Nesting, Bird-distribution, Species-diversity, Bird-diversity, Species-association, Jornada, Pantex, Osage, Pawnee, Bridger, Bison-Site, Bird-migration, Migration, Bird-population, Bird-biomass, Intersite-comparison, Habitat, Bird-habitat, Grazing-influence, Grasshopper-Sparrow, Feeding-habit, Food-composition, Territoriality, Lark-Bunting, Dickcissel, Ingestion, Raptor, Hawk, Eagle, Golden-Eagle, Owl, Predation, Breeding-rate, Birth-rate, Bird-production, Energy-flow, Bird-energy-flow, McCown's-Longspur, Mountain-Plover, Horned-Lark, Meadowlark, Brewer's-Sparrow, McCown's-Longspur-production, Brewer's-Sparrow-production, Mountain-Plover-production, Horned-Lark-production, Lark-Bunting-production, Meadowlark-production, Clutch-size, Reproduction, Bird-reproduction, Bird-energetics

Variations in abundance and distribution of bird species and avifaunal and community organization at regional, local, and within-plot levels were studied during 1969 and 1970 at a shortgrass prairie in Colorado and during 1970 at six additional International Biological Program (IBP) grassland sites. Patterns were

generally not distinct at the regional level, although low rainfall sites tended to support fewer individuals and less biomass than more mesic sites. The dominant bird species were widely distributed, but 70% of all species recorded were present at only one of the seven sites. Local plot-to-plot differences, associated with grazing intensity, were considerably more important than the regional differences. Vegetational and avifaunal relationships of plots were determined by similarity-cluster analysis and by examination of vegetation structure. Variations in the number of breeding bird species, bird-species diversity, or equitability were unrelated to the gradient of plots from tallgrass through shortgrass to desert, but standing crop biomass generally decreased along this gradient. The plots differed in the proportions of small, medium, and large-sized species. Shortgrass sites were generally dominated by omnivorous species; plots with a greater vegetation structure supported more carnivorous forms. Only carnivorous species occurred at the desert site. The effect of grazing on bird populations varied among the treatment plots at the various sites. In the Colorado shortgrass prairie, grazing season had a greater effect on community organization than grazing intensity. Patterns of variation were much more pronounced when single species rather than breeding faunas were considered.

Grasshoppers, Lepidoptera larvae, beetles (especially curculionids, carabids, cerambycids, and scarabaeids), ants, and various seeds were the most important prey of the dominant bird species. Small sparrows and larks had generally similar diets. The diets of the larger meadowlarks and shorebirds differed from those of the former group and also differed from each other. The proportion of seeds and arthropods in the diets of Lark Buntings and Horned Larks varied considerably with time. Diurnal raptors, studied at only one site, were widely dispersed, occurring at densities and standing crops substantially less than those of small passerine populations. Owls preyed chiefly upon small mammals and insects, but the proportions of these food items in the diet differed significantly among the four species studied.

The estimated energy intake of the breeding bird populations from April through August ranged from 1.01 to 2.33 kcal/m<sup>2</sup>; thus the energy flux through avian consumers in grasslands is apparently very small. In general, seeds decreased in importance as energy sources and arthropods increased in importance along a gradient from shortgrass through mixed-grass to tallgrass plots. Secondary production estimated for six grazing-treatment plots ranged from 3.9 to 6.9 × 10<sup>-3</sup> g/m<sup>2</sup>.

The role of birds as consumers in the dynamics of grassland ecosystems is considered. It is suggested that birds may act as controllers of other elements of system function or may not be closely evolved into the functional framework of the ecosystem at all, existing on "excesses" in production.

- OL063 Knievel, D. P. 1973. Procedure for estimating ratio of live to dead root dry matter in root core samples. *Crop Sci.* 13(1):124-126.

Belowground-plant-biomass, Live-dead-root-separation, Blue-grama

Biological activity of roots from herbaceous plants was assessed using triphenyl-tetrazolium chloride (TTC) reduction techniques in an effort to establish a relatively simple method of determining the amount of living tissue in soil core samples from the field. Formazan (reduced TTC) was extracted with 95% ethanol and measured colorimetrically. Relationship between TTC reduction per gram roots and dry weight ratios of living to dead root tissue, established by simple correlation and regression analysis, was used to determine live and dead root dry weights of unknown root samples. TTC reduction per gram live root dry weight declined with plant age and, although not measured directly, probably varied with species. The procedure would accommodate large sample numbers if parts were automated.

- OL064 Rauzi, F., and F. Smith. 1973. Infiltration rates: Three soils with three grazing levels in northeastern Colorado. *J. Range Manage.* 26(2):126-129.

Pawnee, Grazing-influence, Infiltration, Infiltration-rate, Litter, Aboveground-plant-biomass

The influence of soil type, grazing level, and vegetation on infiltration rates were evaluated at the Central Plains Experimental Range near Nunn, Colorado. Total plant material was significantly correlated with infiltration rates on two of the three soil types tested. Heavy grazing significantly decreased infiltration rates on two of the soil types. Grazing influences did not reduce infiltration rates until after 20 minutes of simulated rainfall.

- OL065 Blocker, H. D. 1972. Rangeland invertebrate studies: A review and a look at the future. Third Midwest Prairie Conf. Proc. 3 p.

Insects, Insect-biomass, Osage, Instrumentation

Still needed is a method that will enable us to determine the total effect of invertebrate herbivores (considered as an ecological unit, perhaps) of rangeland. Such information, coupled with that gained from other types of studies discussed here, would give us the ability to determine whether or not invertebrates are worthy competitors of cattle and wildlife.

We will be disadvantaged so long as we dismiss the impact of invertebrates (other than grasshoppers or other noticeable pests) on rangeland. We need to know enough about their ecology and biology to better assess

their roles. Collecting methods need to be standardized (insofar as possible) so that reported data can be compared and interpreted. That can be done, in my opinion, only if objective sampling methods are used and the total invertebrate population is assessed.

Ultimate goals are to better understand invertebrate populations within various range treatments and to manipulate populations, if necessary, for maximum production for recreational and commercial purposes on our ever decreasing acreages of rangeland, while maintaining them in an ecologically sound condition.

- OL066 Tucker, C. J., L. D. Miller, and R. L. Pearson. 1973. Measurement of the combined effect of green biomass, chlorophyll, and leaf water on canopy spectrophlectance of the shortgrass prairie. Proceedings of the Second Annual Remote Sensing of Earth Resources Conference, Space Inst., Univ. Tennessee, Tullahoma. 27 p.

Spectrophlectance, Pawnee, Blue-grama, Short-grass, Reflectivity, Chlorophyll, Aboveground-plant-biomass, Biomass-meter, Instrumentation, Mapping, Biomass-mapping, Vegetation-mapping

Statistical analysis of *in situ* spectrophlectance data from sample plots of the shortgrass prairie indicates that green biomass, chlorophyll, and leaf water concentrations are directly interrelated to that composite property of the plot called the "functioning green biomass." Correlations between the reflectance and these three measures of the functioning vegetation have been calculated at 91 wavelength intervals of 0.005  $\mu\text{m}$  between 0.350 and 0.800  $\mu\text{m}$  using computer analysis. These spectrocorrelation results show the spectral regions of the optimum sensitivity for remotely estimating the green biomass, chlorophyll, and leaf water of a prairie surface and substantiate the direct interrelationship between these parameters. Comparisons between spectrocorrelation curves from two sampling periods in the growing season identify regions of the spectrum between 0.350 and 0.800  $\mu\text{m}$  that are relatively unaffected by increasing amounts of standing dead vegetation and continue to show strong consistent correlations to the amount of functioning green biomass. These basic concepts have been field validated using a hand-held radiometer-calculator system operating in two of the wavelength bands of highest correlation. This device is used in the field for rapid nondestructive estimation of the quantity of the green functioning biomass or any one of the three dependent parameters on a sample plot. Multi-spectral scanner imagery taken from an aircraft has also been reduced by automatic image processing methods to exploit these concepts and yield maps of green biomass.

- OL067 Klein, D. A., P. A. Mayeux, and S. L. Seaman. 1972. A simplified unit for evaluation of soil core respirometric activity. *Plant and Soil* 36(1):177-183.

Soil-respiration, Instrumentation

A simplified respirometer capable of measuring oxygen uptake and carbon dioxide evolution of large soil samples over extended experimental periods is described. Respirometric activity is calculated by use of conventional manometric procedures. This unit provides a combination of low cost, simplicity, and procedural validity which make it applicable to diverse experiments in soil microbiology.

- OL068 Anway, J. C. 1973. Consumer simulation model: A canonical mammal, p. 835-840. In Proceedings of the 1973 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

Models, Modeling-concept, Ecosystem-model, Simulation

This paper describes a computer simulation model designed to follow significant flows of biomass and energy, and resultant biomass changes in mammalian consumers on a shortgrass prairie ecosystem. The canonical approach here utilizes one program formulation to address mammalian types and the age classes of each type ranging from mice to cattle, whether carnivorous, omnivorous, or herbivorous.

Input variables include life tables describing the mammalian population to be simulated, available dieting material, and environmental data. Output variables include population dynamics (numbers and biomass), food intake, and animal waste products.

- OL069 Dyer, M. I. 1973. Process studies related to grassland ecosystem research, p. 669-683. In Proceedings of the 1973 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

Models, Ecosystem-model

The few materials summarized in this paper relate an overview on the major portions of the process-oriented subsystem models prepared during a series of workshops held in 1972. The subsystems are more or less discipline-oriented; thus many of the flows within these models have been obtained from literature dealing specifically with these disciplines. However, the important attribute stemming from the workshops is the thought given to connecting the subsystems; as a result, needs for interdisciplinary work in many different areas are apparent. Even though the models shown here appear to be relatively simple, there is a great deal of inherent complexity. For instance, ELM created the template for these considerations and looks quite like the units presented here. In ELM there are over 3000 parameters now coded, all of which have the potential of interacting with one another in a nonlinear fashion. One of the major objectives of the workshops was to identify critical needs in these ties. It is interesting to note that the most critical needs for information were in these subsystem ties, with one exception, that within the nutrient subsystem. These needs are cited below.

- A. Between producer and consumer subsystems
  - 1. Consumer effect on plant growth
    - a. Consumption rates by various types of consumers such as insects, small mammals, and birds
  - 2. Plant effects on consumers
    - a. Availability of labile and non-labile plant materials
    - b. Availability of reproductive parts such as flowering organs and seeds
- B. Between producer and decomposer subsystems
  - 1. Dead plant material
    - a. Roots
    - b. Litter (availability of labile and nonlabile materials in these compartments)
  - 2. Rates of root respiration
  - 3. Availability of exudate from the plant, born in roots and in tops
- C. Between consumer and decomposer subsystems
  - 1. Decomposition rates of animal excrement for large herbivores, insects, and small mammals
- D. Between producer and abiotic subsystems
  - 1. Infiltration rates of water
  - 2. Evapotranspiration indices
  - 3. Heat transfer coefficients for litter and leaf materials
  - 4. Stomatal resistance in various types of plants
- E. Between decomposer and abiotic subsystems
  - 1. Infiltration rates
  - 2. Temperature profile
  - 3. Carbon dioxide content in soil
- F. Between nutrient subsystem and producer subsystem
  - 1. Levels of nitrogen in plant and the rate of transfer throughout the plant
    - a. In roots
    - b. In tops
  - 2. The effects of temperature and water on these transfer rates

- 01070 Gustafson, J., and G. Innis. 1972. SIMCOMP: A simulation compiler for biological modeling, p. 1090-1096. In Proceedings of the 1972 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

#### Models, Computer-programs, SIMCOMP

In the development of large-scale simulation models for biological systems one often encounters the problem that, as in many other modeling activities, the programming bookkeeping and overhead far exceed the problems of describing the biological system for simulation on the computer. Yet if one goes to some of the better known simulation languages, one finds that the language lacks the power and versatility of a language like FORTRAN for the expression of some of the more complicated mechanisms of interest to the modeler. The development of this modeling technique was approached, therefore, with the specific idea in mind of retaining much of the versatility of FORTRAN while reducing, insofar as possible, the amount of nonbiological information that the modeler was required to provide. As a

starting point, a difference equation flow orientation was used. The compiler is, therefore, somewhat similar to DYNAMO yet contains a large number of restrictions which are appropriate to biological modeling and which result in a much simpler programming representation.

The compiler is implemented in FORTRAN as a two-pass system. The first pass takes the input and provides as output a FORTRAN model of the biological system. The second pass is then the compilation and execution of this FORTRAN program. This two-pass system provides some other interesting opportunities for the modeler. We have found in the development of large-scale biological models that the majority of the cost associated with these models resides in the development phase of the activity. The compiler is designed to reduce significantly the development phase while sacrificing, perhaps, efficient execution of the model. However, since the resulting model is written in FORTRAN, it is a very easy step for the modeler, once he has the version of the model that he intends to run many times, to optimize and to modify the FORTRAN model to improve its execution characteristics. This system has been extensively tested in a number of modeling activities, some of which are the topic of other papers at this conference.

- 01071 Hunt, H. W., and E. W. Huddleston. 1973. A simulation model for populations of the mosquito, *Culex tarsalis*, p. 733-738. In Proceedings of the 1973 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

#### Models, Simulation, Mosquito-population-model

A deterministic compartment model in difference equation form has been developed for populations of *C. tarsalis*. Delay lines are employed to achieve realistic age distributions. The rates of development of eggs, immatures, and adults are separately controlled by daily observations of temperature. Mortality is a function of temperature for eggs and adults and a function of temperature and the amount of breeding habitat for immatures. Breeding habitat is predicted from observations of the water level in playa lakes. The model is fit to data from light traps operated through 2 years, and validated with a third year's data from the same traps. An intermediate version of the model proved to be inadequate in that it predicted smaller populations than observed in the early summer, and larger than predicted in the fall. Several possible explanations for the departure are given. The only explanation tested--the operation of density dependence in the mortality of immatures--provides a good fit to the data. Several applications of the model to the management of *C. tarsalis* populations are proposed.

- 01072 Parton, W. J., and J. K. Marshall. 1973. MODENV: A grassland ecosystem model, p. 769-776. In Proceedings of the 1973 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

# Models, Ecosystem-model

MODENV is an ecosystem simulation model designed to study the long-term influence of environment and environmental modifications on grassland ecosystems including effects of range management practices and competition among plant species groups. The model simulates the flows of biomass, water, soil, and heat in the ecosystem, including the biomass dynamics of four plant species groups that are utilized by a consumer. Simulated results demonstrate the influence of different weather patterns and range management practices on a grassland ecosystem.

- OL073 Reuss, J. O., and C. V. Cole. 1973. Simulation of nitrogen flow in a grassland ecosystem, p. 762-768. In Proceedings of the 1973 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

## Simulation, Models, Nitrogen-model, Nutrient-model

A dynamic simulation model of nitrogen flow in a grassland ecosystem has been developed. The state variables in the present version of the model include nitrogen in the following major compartments: soil ammonium, soil nitrate, soil organic matter, live roots, dead roots, live tops, and litter. Belowground state variables are subdivided into four depths. The model may be used as a module in an ecosystem model or will operate independently in conjunction with a simple producer-decomposer submodel. Nitrogen flows, plant growth, and plant decomposition are controlled by temperature, soil water, phenological stage of plant development, and the nitrogen status of the various components of the system. The interaction of the nitrogen system with production and decomposition allows nitrogen status to act as a control variable in ecosystem processes, an important feature in a grassland model.

Initial tests indicate that the model does react in a realistic manner. Simulation of fertilization effects has been quite satisfactory and the model has been useful in identifying processes where further research is important for an understanding of the system.

- OL074 Rodell, C. F. 1973. Simulation of gene flow in *Drosophila* populations, p. 814-820. In Proceedings of the 1973 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

## Models, Simulation, Gene-flow-model, Grazing-influence, Optimization-succession

A stochastic model is developed to represent reproduction within and gene flow between adjacent breeding populations. Random procedures are used for both the process of reproduction in a finite population and to determine which genotypes migrate. The model represents the dynamics of a recessive lethal gene and its wild-type allele. Several

migration rates and population sizes are used in combination with each other and the results are compared with those predicted by a deterministic model. The results of both models are discussed in relation to field data on adjacent breeding populations of *Drosophila melanogaster*.

- OL075 Sauer, R. H. 1973. PHEN: A phenological simulation model, p. 830-834. In Proceedings of the 1973 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

## Models, Phenology-model, Phenology

A phenological simulation model (PHEN) has been developed to provide information on a daily basis on the developmental stage (phenophase) for each of the five primary producer species simulated in the US/IBP Grassland Biome model ELM.

Seven phenophases were described for PHEN: three vegetative, one vegetative to reproductive, two reproductive, and one senescent. The proportion of biomass in each phenophase is simulated. Flows between the phenophases are regulated by a series of difference equations. Phenological progression is directly proportional to the 20-day moving average of the product of daily maximum air temperature and insolation. However, soil water content has varying effects. Very wet or dry soil reduces the rate of vegetative phenological progression, while the rate of progression through the reproductive phenophases to senescence decreases with increasing soil water content. Senescence ends with cool weather and wet soil as indicated by a 20-day moving average of the product of maximum daily air temperature and the difference between maximum and currently simulated soil water contents.

Model output for years of high, average, and very low precipitation are presented. The phenological information simulated in PHEN serves as a major connection between the trophic levels of ELM by adding the dimension of quality to that of quantity in the simulation of biomass dynamics.

- OL076 Wiens, J. A., and G. S. Innis. 1973. Estimation of energy flow in bird communities. II. A simulation model of activity budgets and population bioenergetics, p. 739-752. In Proceedings of the 1973 Summer Computer Simulation Conference. Vol. II. Simulation Councils, Inc., La Jolla, California.

## Birds, Bird-energy-flow, Models, Bird-model, Bird-energetics

Bird populations normally do not act as major energy storage or transfer compartments in ecosystems, but they may at times regulate other aspects of system functioning through their patterns of predation. Here we describe a simulation model for assessing the bioenergetic demands of bird populations during the breeding season, as well as estimating changes in age class population densities and biomass. Special attention is given to modeling of

individual activity budgets, i.e., the pattern of daily time allocation among various behaviors.

In the basic model structure, field or literature values for clutch size, mortality rates, reproductive phenology, migration movements, and breeding population density are used to compute the population densities of nestling, fledgling, juvenile, and adult age classes. Given information on adult body weights, weight changes of young are obtained from a logistic function and the age class distributions within a population used to estimate biomass changes in each age class through time. Coupled with an ambient temperature function, existence energy demand functions, and considerations of energy costs of digestion, activity, molt, egg production, and growth, an area-based estimation of the daily energy requirements of each age class of a population is produced as output.

In the activity budget submodel, the costs of activity are considered in greater detail. Given input values for the proportion of a 24-hour period devoted to major activity types, i.e., foraging, flight, aggression, courtship, incubation, inactivity, at several points through the breeding cycle, and specifications for the degree to which existence energy demands are elevated by each activity, the individual daily energy requirements of each activity type for adult males and females are calculated.

The use of the model as a simulation tool is explored in two exercises. In one, the amount of time spent in aggressive behavior in a population of American Avocets was systematically increased. An eight-fold increase in aggressiveness, for example, swelled the energy demands of Avocets by 11 to 20 kcal/bird-day. In the other exercise, we examined the effects of increased grazing intensity in grasslands on populations of Horned Larks. Under the assumptions of this simulation, increasing grazing by cattle resulted in somewhat higher individual energy demands and substantially higher population energy requirements. By coupling these output estimates with information on territory sizes and dietary-composition, we project the pattern and intensity of prey consumption. In heavily grazed areas, for example, larks must obtain nearly twice as many prey individuals per unit area per hour spent foraging as birds occupying ungrazed situations.

- OL077 Innis, G. 1972. Simulation of biological systems: Some problems and progress, p. 1085-1089a. In *Proceedings of the 1972 Summer Computer Simulation Conference*. Vol. II. Simulation Councils, Inc., La Jolla, California.

#### Models, Modeling-concept, Simulation

Over the past several years modeling of biological and other systems has certainly been on the upswing. In the biological sciences there has been considerable effort to apply systems analysis and modeling

techniques to a wide variety of problems. These applications have often involved people who are not particularly trained in the use of the computers or mathematics and who may be somewhat skeptical of the potential benefits. The modelers, on the other hand, are often not particularly well-trained biologists. As a result of these mismatches, a number of different techniques have been used to establish a rapport between the experimenter and the modeler and to develop useful models of biological systems.

There are two distinct extremes to the scale problem. Small-scale models can be developed effectively with a single modeler and experimenter working together. Indeed, many times the small-scale model is developed by one individual serving in both the modeler and experimenter capacity. At the other extreme of the scale is the problem of developing large-scale models in which some of the problems associated with computing and mathematics become sufficiently important and involved that professionals in these areas are needed. In this situation teams involving modelers and experimenters are required in order to develop effective models. The establishment of rapport and working arrangements in these groups is a problem which often has not been solved to the satisfaction of either of the groups and has, on occasion, severely limited progress.

- OL078 Woodmansee, R., G., and G. S. Innis. 1973. A simulation model of forest growth and nutrient cycling, p. 697-721. In *Proceedings of the 1973 Summer Computer Simulation Conference*. Vol. II. Simulation Councils, Inc., La Jolla, California.

#### Models, Forest-growth-model, Nutrient-model

A simulation model of lodgepole pine forest growth (carbon) and potassium dynamics is discussed. The simulation model utilized the SIMCOMP computer language developed in the US/IBP Grassland Biome program at Colorado State University. The forest simulated was assumed to be a pulse-stable, fire-maintained system. The system was adjusted so inputs of nutrient via weathering and the atmosphere balanced outputs via leaching and erosion over a fire/growth cycle of 70 years, the assumed average frequency of fires.

This balanced system was then perturbed by two different clear-cutting practice simulations. One clear-cut practice simulated removal of the boles of trees and the scattering of slash which was left to decompose as litter. At the end of three cutting cycles of 210 years total biomass of plants was 13% smaller than the comparable stage in the fire-maintained system. Potassium losses from the system were 15% to 20% of the total nutrient capital.

The other clear-cut practice simulated bole removal and complete removal of slash from the system. This exercise of the model resulted in a 20% reduction in total biomass of plants and a 42% decrease in the potassium capital of the system.

- OL079 Miller, L. D., and R. L. Pearson. 1972. Areal mapping program of the IBP Grassland Biome: Remote sensing of the productivity of the shortgrass prairie as input into biosystem models, p. 165-208. In Proceedings of the 7th International Symposium on Remote Sensing of the Environment. Univ. Michigan, Ann Arbor.
- Pawnee, Shortgrass, Reflectivity, Aboveground-plant-biomass
- The IBP Grassland Biome Program is a major ecosystem analysis involving 88 principal investigators systematically describing the functioning of natural grasslands. A comprehensive remote sensing research program has been undertaken in the context of this overall experiment to determine the utility of various sensor devices in supplying input data into this biosystem model. The initial objective of this effort has been to design and test a multi-faceted approach to measure and map percent cover of areas ranging from small sample grassland plots to much larger landscapes. These maps provide the basic data from which to interpret standing crop or above-ground biomass and, in turn, the primary productivity of a grassland.
- The amount of vegetation on a prairie can be measured by its characteristic spectroradiance or spectrorreflectance. A variety of approaches to exploiting this relationship are covered in the report, including the use of airborne and satellite multispectral scanner imagery, aerial and ground photography, and ground spectrometry. Each of these approaches is explained in detail and preliminary results are presented. A description of the design, construction, and testing of the trailer-mounted, field spectrophotometer is also included. A landscape model is described which has been designed to interface the data taken by mapping remote sensors to the biosystem or hydrologic models which statistically describe the functioning of a natural grassland.
- OL080 Trlica, M. J., A. J. Dye, W. H. Moir, L. F. Brown, D. A. Jameson, and W. A. Rice. 1973. A field laboratory for gas exchange measurements of grassland swards. *Photosynthetica* 7(3):257-261.
- Instrumentation, Carbon-dioxide-exchange
- Total carbon dioxide exchange of a plot is measured with the system. A hemispherical plexiglass cuvette is the sampling device used to monitor photosynthesis and respiration of intact grassland swards. From comparisons of the carbon dioxide exchange of illuminated, darkened, and clipped plots, estimates of photosynthesis, aboveground plant dark respiration and belowground respiration can be made. Air temperature within the cuvette can be controlled to either simulate ambient conditions or be held constant at a desired temperature. The laboratory has been used successfully for measuring gas exchange of shortgrass prairie ecosystems for two consecutive growing seasons.
- OL081 Williams, G. J. III, and J. L. Markley. 1973. The photosynthetic pathway type of North American shortgrass prairie species and some ecological implications. *Photosynthetica* 7(3):262-270.
- C-3-pathway, C-4-pathway, Photosynthesis, Shortgrass, Carbon-dioxide-exchange, Carbon-14
- Dominant species of the Pawnee Grassland, International Biological Programme site in north-eastern Colorado, *Agropyron smithii*, *Bouteloua gracilis*, *Buchloe dactyloides*, *Artemisia frigida*, *Gutierrezia sarothrae*, and *Sphaeralcea coccinea* were grown in a greenhouse along with *Nicotiana tabacum*, a known C<sub>3</sub> plant, and *Zea mays*, a known C<sub>4</sub> plant. The photosynthetic pathways of the shortgrass prairie species were identified by determining the initial products of photosynthesis, CO<sub>2</sub> compensation points, and response of CO<sub>2</sub> compensation points to temperature. The experimental plants fell into two distinct groups: those which exhibited responses similar to *N. tabacum* (C<sub>3</sub>), *A. frigida*, *G. sarothrae*, *S. coccinea*, and *A. smithii*, and those whose responses were similar to *Z. mays* (C<sub>4</sub>), *B. gracilis* and *B. dactyloides*.
- OL082 Knight, D. H. 1973. Leaf area dynamics of a shortgrass prairie in Colorado. *Ecology* 54(4):891-896.
- Pawnee, Leaf-area, Leaf-area-index, Shortgrass, Blue-grama, Buffalo-grass, Plant-cover, Prickly-pear, Precipitation, Grazing-influence, Primary-production
- Leaf area changes were studied at the Pawnee Grassland in northeastern Colorado. Specific objectives were (1) to measure seasonal changes in leaf area during 1970 and 1971, (2) to estimate the influence of irrigation, irrigation plus nitrogen fertilization, and grazing on leaf area, and (3) to calculate average daily aboveground productivity per unit of leaf area during the peak of the growing season. The point-quadrat method was used for leaf area measurement. Peak leaf area was reached in mid-June of both years, with a maximum Leaf Area Index of 0.55 in 1970. Both years were drier than average, but seasonal distribution of rainfall was different with a corresponding seasonal difference in LAI. Irrigation alone increased LAI about two-thirds, and irrigation plus fertilization increased LAI approximately tenfold. Different grazing treatments had little effect on total leaf area values. Aboveground productivity per unit leaf area averaged about 5 g/day/m<sup>2</sup> of leaf area in May and about 4 g in June and July 1970.
- OL083 Singh, J. S., and P. S. Yadava. 1973. Caloric values of plant and insect species of a tropical grassland. *Oikos* 24(2):186-194.
- Calorimetry, Tropical-grassland, Plant-energetics, Insects, Insect-energetics
- The present paper deals with caloric values of important plants and insects occurring in

the grassland vegetation at Kurukshetra, India. The data indicate variations in energy content among different species and at different seasons.

- OL084 Coleman, D. C. 1973. Soil carbon balance in a successional grassland. *Oikos* 24:195-199.

#### Soil-respiration

Soil respiration was measured every 1 to 2 months for 2 years in a broomsedge old field. Measured CO<sub>2</sub> output per m<sup>2</sup> approached C of organic matter input from roots and litter. The alkali absorption technique, when used judiciously, is useful for a quantitative integrated measurement of soil secondary productivity.

- OL085 Flake, L. D. 1973. Food habits of four species of rodents on a short-grass prairie in Colorado. *J. Mammal.* 54(3):636-647.

#### Pawnee, Mammals, Rodent, Food-composition, Feeding-habit

Food habits of four rodents (*Dipodomys ordii*, *Onychomys leucogaster*, *Peromyscus maniculatus*, and *Spermophilus tridecemlineatus*) of a shortgrass prairie ecosystem in northeastern Colorado were studied in 1969 and 1970 through microscopic analysis of stomach contents. Mean percent volumes of animal matter in diets of these rodents over the entire study were: *D. ordii*, 4.4%; *O. leucogaster*, 73.9%; *P. maniculatus*, 39.0%; and *S. tridecemlineatus*, 44.0%. The greatest amount of seasonal variation in percent volume animal matter in the diet was in *P. maniculatus*. Animal matter in diets of all four species was composed almost entirely of arthropods and a few parts of vertebrates. The most common arthropods included adult and larval Coleoptera, larval Lepidoptera, and grasshoppers (except in *D. ordii*). Plant matter in the diets of all species included leaves, stems, and flowering parts of various species of grasses, sedges, forbs, and shrubs, seeds (unidentified), and tissues of mosses, lichens, and fungi. Seeds were the most common type of plant matter in diets of *D. ordii* and *P. maniculatus*, whereas plant matter in *S. tridecemlineatus* and *O. leucogaster* was more equally divided between seeds and nonseed parts of grasses (and sedges) and forbs. Much seasonal variation in types and relative amounts of different kinds of plant and animal matter was noted.

- OL086 Donoho, H. S. 1972. Buggin' the bunnies. *Colorado Outdoors* 21(2):4-8.

#### Mammals, Jackrabbit, Pawnee, Jackrabbit-activity, Jackrabbit-homerange

Each jackrabbit is instrumented with a radio tuned to a different frequency so that individual hares can be identified. The transmitters emit a beep, and the number of beeps per minute is related to temperature. Hence, frequency of beeps increases or decreases depending on whether the jackrabbit is active, inactive, or dead.

Jackrabbits are active during twilight hours and at night. They rest during daylight hours, lying in shallow excavations which make them inconspicuous on the shortgrass prairie. Whitetails cover about twice the area that blacktails do in one night. Night activity areas also vary in size with age and sex. Adults and males range over larger areas than juveniles and females, respectively. The average rate of movement of a jackrabbit on a winter night is 0.3 mph and 0.9 mph on a summer night. Jackrabbits are about three times as active in summer as in winter.

Avian predators (Golden Eagles, Rough-legged Hawks, Marsh Hawks, and other large hawks and owls) seem to account for most of the depredation (about 45%). Coyotes take the next highest toll (about 35%); and hunters, automobiles, and unknown causes account for the remainder (about 20%).

- OL087 Ryder, R. A., and M. A. Strong. 1971. Censuses of avian populations at the Pawnee Site, Colorado, under the International Biological Program, p. 363-377. In 51st Annu. Conf. Western Ass. State Game and Fish Comm., Proc.

Pawnee, Birds, Bird-biomass, Nesting, Clutch-size, Bird-density, Horned-Lark, McCown's Longspur, Meadowlark, Lark-Bunting, Brewer's Sparrow, Mountain-Plover, Mourning-Dove.

Birds are being studied on the shortgrass prairie in northeastern Colorado as part of an analysis of the Grassland Biome under IBP.

The plot-count is believed to give better data on total bird densities and production of the smaller birds whereas the road-count is believed to give better information on migration and seasons of occupancy for all species. A large area must be searched for active nests in order to estimate raptor breeding populations and productivity.

Plots heavily grazed by cattle received the greatest use by birds for nesting and foraging; lightly grazed plots received the least use. There were definite species preferences for area grazed at different intensities, most likely due to the different vegetation that resulted. Horned Larks, McCown's Longspurs, and Mountain Plovers nested mainly in heavily grazed shortgrass, whereas Lark Buntings, Chestnut-collared Longspurs, and Western Meadowlarks preferred moderately to only slightly grazed areas with taller grasses and more forbs. Brewer's Sparrows were confined to areas of four-wing saltbush (*Atriplex canescens*). Golden Eagles (mainly) and Prairie Falcons (entirely) nested on cliffs north of the main grassland study areas whereas Swainson's Hawks, Ferruginous Hawks, and Great Horned Owls were rather widely dispersed in the grasslands wherever suitable nesting trees were available. Ferruginous Hawks also nested on the ground and one on an abandoned chimney.

Considerably more species utilize the shortgrass prairie of northeastern Colorado for resting while in migration than either for nesting or wintering.

- OL088 Thorsteinsson, I., G. Olafsson, and G. M. Van Dyne. 1971. Range resources of Iceland. *J. Range Manage.* 24(2):86-93.

Iceland, Climate, Range-conditions, Vegetation-types, Carrying-capacity, Grazing-influence

Animal agriculture in Iceland is second only to fisheries. At least half the forage consumed by large herbivorous animals comes from rangelands. During the period June to September most of the sheep and large numbers of unbroken horses graze on mountain ranges where they roam freely in large grazing districts or commons. There is urgent need for land reclamation and range improvement. Only 25% of the country is covered with vegetation, much of which does not provide adequate protection against soil erosion and has low carrying capacity. With increasing population and demands upon rangelands for food production, an aggressive program of rangeland improvement and management, supported by adequate research, is essential.

- OL089 Wright, R. G., Jr. 1972. Land use and the Front Range. *Colorado Outdoors* 21(2): 32-35.

Urban-development

The population increase currently being experienced in Colorado, particularly in the Front Range corridor--the area generally considered to extend from Fort Collins on the north to Pueblo on the south, paralleling the foothills of the Rocky Mountains--is having a profound impact on land use and development in the region. This article briefly examines the projected changes in land settlement patterns, the effect this will have on our society, and what can be done to ameliorate some of the problems inherent in these changes.

- OL090 Wright, R. G., Jr. 1972. Computer processing of chart quadrat maps and their use in plant demographic studies. *J. Range Manage.* 25(6):476-478.

Jornada, Field-data-procedures, Data-processing, Plant-cover, Plant-demography

Chart quadrat maps offer a unique source of data on long-term trends in grasslands. Through the use of film scanning computer systems, this information can be more easily processed and used in plant demographic studies.

- OL091 Hansen, R. M., D. G. Peden, and R. W. Rice. 1973. Discerned fragments in feces indicates diet overlap. *J. Range Manage.* 26(2):103-105.

Mammals, Cattle, Sheep, Bison, Plant-fragment-identification, Fistula, Food-composition, Egestion

A mean dissimilarity index was used to measure the degree of dietary overlap of appropriately paired diet and fecal samples of cows, bison, and sheep. When botanical composition is determined by the microscope technique for plant fragments identified in the feces of different kinds of herbivores (cattle, sheep, and bison), the estimated degree of dietary overlap is approximately the same as if diet samples had been used to estimate dietary overlap.

- OL092 Van Dyne, G. M. 1972. Organization and management of an integrated ecological research program--with special emphasis on systems analysis, universities, and scientific cooperation, p. 111-172. In J. N. R. Jeffers [ed.] *Mathematical models in ecology*. Blackwell Sci. Pub., Oxford, England.

Models, Modeling-concept, Ecosystem-model, Biome-objectives, Integrated-research-needs

This paper reviews a large-scale, long-term, interdisciplinary, integrated, ecological research program. The magnitude of these studies is indicated by the example that the grassland study now has more than 90 senior scientists involved, representing about 30 academic institutions and federal agency groups, and an annual budget of near \$2.0 million is spent in field, laboratory, and armchair research. We are using results obtained from field and laboratory ecological experiments, analysis of the literature, and natural resource data as a major source of inputs to our programs. Our programs attempt to integrate these data and information sources through a systems analysis approach. The output will be comparative analyses, implemented through use of simulation, optimization, and structural models. We feel there will be a payoff from these studies toward the development of a new ecological theory and toward development of resource management principles.

Specific attention is directed in this paper not to the large volume of data generated in these studies, but instead to discussion and analysis of some of the developmental characteristics of the programs. I have also attempted to provide suggestions for this type of study, on a national and international basis, as they carry forward during and following the life of the IBP. Some approaches in mathematical modeling and analysis are discussed with special emphasis on simulation models. The use of the state variable approach involving systems of differential equations is referred to and generalized modifications are included to allow the inclusion of the real-life complexities of ecological systems.

The paper flows in a generally chronological sequence: introduction and discussion of integrated research, the first 15-month research segment, the next 16-month grant, and general discussion of problems and needs.

