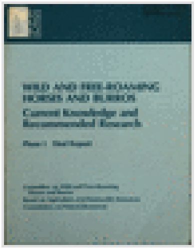

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WILD AND FREE-ROAMING HORSES AND BURROS:
Current Knowledge and Recommended Research

Phase I Final Report of the

Committee on Wild and Free-Roaming Horses and Burros

Board on Agriculture and Renewable Resources

Commission on Natural Resources

National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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CONTENTS

PREFACE

The Public Rangelands Improvement Act of 1978 directs in part that the Bureau of Land Management and the National Academy of Sciences contract for performance of a research study on wild horses and burros. This report, which is submitted in partial compliance with the Act, is the final report on Phase I. It assesses the current state of our relevant knowledge and sets forth in detail the kind of research effort that could provide information now lacking but essential to sound management of wild and free-roaming horses and burros. Phase II of the study is now under way, and a final report from the Academy will be submitted to the Bureau in 1981 (see Chapter 1 for a more detailed discussion of the study).

ACKNOWLEDGMENTS

Several people contributed time and effort to the work of the committee. Maureen J. Seidman, Executive Secretary at Utah State University, typed, edited, collated, and supervised the printing of the drafts of the interim and final reports. She also organized travel and meeting arrangements for the Committee and conducted correspondence and telephone communications.

David R. Anderson, Leader of the Cooperative Wildlife Research Unit at Utah State University, provided critical advice on parts of the final report, assisted in formulating the RFP on census research, and helped review the resulting proposals.

Milton Frei of the BLM in California attended two meetings of the Committee at its request, and accompanied Walter Conley to a number of BLM offices around the West to obtain some of the horse and burro data analyzed in the report.

Montague Demment of the University of Wisconsin acted as consultant to the Committee on horse nutrition and wrote Appendix A.

Other individuals of the University of California, Davis, New Mexico State University, and Utah State University, who assisted with data analyses, library searches, and literature reviews, were Jeri Aamodt, Martha Bryant, William B. Collins, Micheline Devaws, Margot Garcia, Allen Kraus, Jennifer Lewis, Cindy Rebar, Paul Smyth, Everett Springer, Janice Stevenson, Gwen Thomas, Thomas Thompson, Raul Valdez, Thomas Watts, and Glenn Yost.

EXECUTIVE SUMMARY

BACKGROUND OF THE REPORT

The Public Rangelands Improvement Act of 1978 (PL 95-514) and contract AA 551-CT9-16 between the Bureau of Land Managment (BLM) and the National Academy of Sciences (NAS) direct NAS to impanel a committee to assess the state of knowledge on wild horses and burros, recommend research to fill gaps in knowledge, oversee the research during its conduct, and compile all relevant information at the end of a 2-year research effort. The state-of-knowledge assessment and the research design were designated Phase I of the total undertaking, and this document is the final report of Phase I. It reviews knowledge about a wide array of topics, recommends 18 research projects, and discusses information relative to policy questions without, itself, advocating policy.

The Committee on Wild and Free-Roaming Horses and Burros was impaneled in June 1979. It divided its task among three subcommittees with responsibility for horse and burro biology, effects on other ecosystem components, and sociopolitical and economic considerations. Following the introductory statement in Chapter 1, the main body of this report is divided into four major sections. Chapters 2, 3, and 4 correspond to the subject matter investigated by the three subcommittees, and Chapter 5 is concerned with research and management methodology. There are also three appendixes.

BIOLOGY OF HORSES AND BURROS

History and Paleontology of Equids in North America

The mainstream of equid evolution occurred in North America. Fossil evidence shows the presence of a large horse and an ass, structurally indistinguishable from the modern horse and donkey, as recently as 11,000 years ago. Their extinction occurred at that time along with the demise of a number of other species of large mammals. Modern wild horses and asses were reintroduced into North America by the Spaniards in the late 15th century. Some observers believe that the vegetation in the West was vulnerable to the introduction of domestic herbivores because it had experienced little grazing pressure since the late Pleistocene period. These observers consider equids to be particularly disruptive to the ecosystem because they are alien to the region. However, the view may need to be tempered by a knowledge of the paleohistory of equids in North America. The possibility exists that there are vacant niches into which these animals could fit.

Social Organization

Two types of social organization have been reported in wild equids: (1) the harem or stable family group, with a dominant male; and (2) the territorial form, in which stable bonds occur only between mother and offspring. These may constitute the extremes of a continuum along which different species--and different populations within a species--occur, depending on environmental, social, and population factors. For example, feral asses (burros) in the arid southwestern United States have little social structure except for the mother-young relationship, exist at low densities, and display considerable aggressive behavior. In constrast, asses on humid Ossabaw Island, Georgia form stable groups and display little aggressive behavior.

Under conditions of dry-season water stress in arid areas, asses concentrate within 3 km of water sources, and lactating females commonly threaten and reject their own young when they attempt to nurse. Concentration of the animals around watering areas has a heavy impact on local vegetation. Arid-land burros are browsers and may spend up to half their time feeding. On Ossabaw Island, however, burros are grazers and spend only about a third of their time feeding. Male asses in the Southwest display greeting behavior among themselves, but rarely are social grooming or social play seen among the young. Ossabaw Island animals exhibit the reverse of these patterns.

The basic social organization among wild horses is that of a family group with a dominant male, subdominant males, and females and their young, but some variations on this pattern occur, as do exchanges between groups. In arid areas, distribution of horses is oriented around water during the dry season, but in areas more to the north, distribution seems to be oriented around availability of forage.

Equid Demography

Horses

Although confined domestic fillies begin ovulating and breeding at 1 year of age, only one 2-year-old mare has been observed to bear a foal in seven wild horse studies spanning 1 to 5 years' duration. A small percentage (mean of 13 in the studied herds) breed at 2 and foal at 3 each year (gestation period is about 11 months). Evidence suggests an increasing percentage of mares foaling in each older age class, as occurs in domestic horses, with around two-thirds of 5-year-old and older animals bearing young. Whether the percentage declines after ages 10 to 12, as in domestics, is not known. Wild horse breeding is highly seasonal, with most foals born from April to June.

Only crude approximations exist of first-year survival rates in wild horses; the available values range from 50 to 86 percent. Mean annual adult survival rates are also poorly known, but most estimates fall between 75 to 95 percent. Age compositions of 8,764 animals rounded up during herd reductions show that the greatest numbers are in the youngest age classes (40 to 45 percent of all animals are in the foal through 2-year-old classes), with progressively fewer in each older age group. Males slightly outnumber females at birth, decline to 39 percent of animals at 4 to 6 years of age, and then may increase again slightly in the older age classes. Total herd sex ratios approximate 55 percent female.

Population increase rates calculated from BLM and U.S. Forest Service (USFS) census data average 15 to 20 percent annually for western U.S. horse herds, rates similar to those quoted by these agencies and cited in a number of earlier publications. In some cases, these may be magnified by (a) increasing commitment to and proficiency at censusing, (b) increasing visibility as herd sizes increase, and (c) change from fixed-wing to helicopter censuses in the 1970s. But in others, the experience of observers, low-stature vegetation and moderate topography, and fencing which prevents ingress or egress would seem to preclude these biases.

In contrast, two authors have projected increase rates with population models that incorporate birth and death rates similar to those published for several herds, and concluded that annual herd increase rates well below 10 percent are probable. Similar calculations with life tables in this report indicate that 15 to 20 percent increase rates can only occur in populations with geometric age distributions with (a) very high reproductive rates, and (b) virtually no mortality. Such demographic conservatism is produced in populations with half their numbers in pre-breeding or low-breeding (3-year) age classes, only about two-thirds of older mares foaling each year on the average, and some mortality.

The question of increase rates is central to horse management, and the disagreement cannot be resolved with presently available information. Research is needed to settle the question.

Burros

A small percentage of 2-year-old burros foal 1 year earlier than horses. The percentage of 2-year-old and older jennies foaling exceeds 60 percent per year, on average, with the 2-, 3-, and 4-year-old percentages probably exceeding those for horses of the same ages.

Some populations breed year-round, albeit with spring-summer emphasis in some. Survival rates are less well known in burros than in horses, but some evidence suggests high first-year loss in some areas and years, low in others. Age compositions are roughly similar in the two species, but some burro populations have higher percentages of foals. The earlier breeding and higher fertility rates potentially enable burro populations to increase faster than horses, but reported rates of 20 percent per year and higher press the biotic potential of the species, given geometric age distributions. Some populations have been reported to increase very slowly or not at all, as in the case of several Death Valley populations. In general, burro demography appears more variable than that of horses, suggesting some sensitivity to density and the plasticity of a species adapted to the desert.

Fecundity rates of females rounded up during herd reduction could be determined readily through rectal palpation.

Genetic Polymorphism

A knowledge of genetic polymorphism in horses and burros could give some idea of the minimum herd size needed to survive through periods of environmental change, and could delineate the racial lineage of wild horses, including their relationship to Spanish mustangs. While some work has been done on the genetics of domestic horses, none has been done on wild animals. Modern techniques of blood-group genetics provide a powerful tool for addressing these two biological questions.

Nutrition

While burros apparently prefer green grasses and forbs, they are highly opportunistic, broad-spectrum feeders, and are capable of surviving on high-fiber, low-nitrogen diets, including coarse shrub branches, yucca, and cholla cacti. Studies conducted so far show grasses ranging from 0 to 79.6 percent, forbs from 8.0 to 77.4 percent, and browse from 5.7 to 83.8 percent of burro diets at different seasons and in different areas. Horses are much more selective feeders. Some use of forbs and browse has been reported, but in 29 published diet analyses, consumption of grasses ranged from 36 to 100 percent of total diet, averaged 89.4, and made up 85 percent or more in 24 of the studies. This dietary preference coincides closely with that of cattle, and overlaps to some degree and in some seasons with those of elk, bighorn sheep, bison, and pronghorn antelope. Most dietary studies have not related animal data to vegetation composition, nor have they described spatial and habitat overlap with sympatric ungulates or lack thereof.

There is some reason to believe that equids have higher forage intake rates per unit of body weight than ruminants because food can pass more rapidly through the equid's cecal digestive system. The ruminant is limited in its throughput rate by the capacity of the rumen and the fermentation rate that occurs there. As a result, the equid may have an advantage when only high-fiber forages are available, since it can compensate for the low nutrient content by increasing its intake.

Essentially no data exist on the nutritional responses of free-ranging equids in western North America to the well-studied and well-documented seasonal changes in nutritional content of vegetation. In the Southwest, forage quality is highest in late winter and early spring in the Mojave Desert, with its winter rainfall season; in late summer and fall in the Chihuahuan Desert, with its late-summer season; and at both times in the Sonoran Desert, with its bimodal rainfall pattern. In the Great-Basin-Intermountain region, forage quality is highest in spring and early summer. If equids can compensate for low-quality forage by increasing intake, then quantity rather than quality may be the factor that limits food; thus equids may be less subject to seasonal nutritional stress than are ruminants.

Habitat Preferences

Understanding habitat preferences and uses is important to detecting competition between equids and other herbivores, wild or domestic; to making forage-allocation decisions; and to establishing site-suitability criteria for equids, domestic animals, and wildlife. Competition occurs when two species use a common resource and reduce it to the point where the numbers of one or both species are limited. If the resource is not reduced to this point, the two species can both use it without competing. It is conceivable that two or more species of herbivores (a) may choose and occupy different habitats and thus not compete; (b) may have overlapping habitat preferences but segregate through behavioral interaction, thus competing only if food becomes limiting; (c) may occur in the same habitat but eat different foods, in which case they will not compete; and (d) may co-occur and eat similar foods, competing only when food becomes limiting.

Recommended Research

Seven research projects on the biology of horses and burros are recommended:

- Project 1: Habitat Preference and Use
- Project 2: Food Consumption Rates and Nutrition
- Project 3: Nutritional Plane, Condition Measures, and Reproductive Performance
- Project 4: Blood Assays
- Project 5: Demography
- Project 6: Social Structure, Feeding Ecology, and Population Dynamics

- Project 7: Genetic Polymorphism.

The projected 2-year span for the research is unrealistic. Because of the extreme year-to-year variability of environmental conditions and equid performance, no comprehensive picture can be developed in less then 6 to 10 years. Project 1 should be conducted in areas not less than 5 to 6 square miles per experimental treatment. Projects 2--and 8 and 9 to be listed later--can be carried out in paddocks of 100 to 300 acres. All experiments should be conducted in treatments involving horses only, cattle only, and horses and cattle, each at moderate and heavy grazing intensities. Horses and cattle are emphasized here because the possibility of their competition, both for space and for food, seems to be greatest. If funds permit, the research could be repeated with burros and with domestic sheep. Projects 2 and 9 should contain control areas without grazing.

EFFECTS OF EQUIDS ON OTHER ECOSYSTEM COMPONENTS

Impacts on Rangeland

Although it is widely alleged that horses and burros have severe grazing impacts on western rangelands, there are few published studies about the nature and extent of these impacts. Most of the existing studies are on grazing effects of burros. Studies along the lower Colorado River and in Death Valley National Monument showed heavy impacts on vegetation from grazing burros within a radius of 2 to 2.5 km from water areas. Studies in the Grand Canyon National Park showed heavy impacts at the Colorado River elevation and moderate to light effects at progressively higher elevations. Range in Bandelier National Monument was degraded over 4,000 ha by 107 to 120 burros. A study in the Lake Mead National Recreation Area, however, revealed no major impacts. Little controlled research has been done on impacts of grazing horses; the extensive management of horse range apparently proceeds largely from management-level inventories, experience, and judgment.

The range-ecology conceptual framework used in livestock management can at least be used as a starting hypothesis for, if it cannot be applied directly to, equid management. In this scheme, plant-community successional trends are roughly proportional to grazing intensity. Properly managed grazing--which takes into account the species, number of animals, season, and distribution of grazing--can be harmonious with most resource needs and values. The specifics of managing range vegetation vary geographically and seasonally with climate and vegetational type. Year-to-year variation in precipitation can be a more influential factor in altering plant-community composition than season and intensity of grazing. Annual forage production is strongly correlated with that same variation, and herbivore numbers properly should be adjusted to the changes.

Interspecies Competition

Because competition only exists where a population is limited to some degree, it is best demonstrated experimentally by manipulating the numbers of one suspected competitor and observing whether or not the other responds. If the population cannot be manipulated, a preliminary indication can be gained by calculating the resource need of each species, measuring the amount of resource available, and determining whether the need exceeds that available. Ideally, such calculations should be combined with population-limitation experiments.

Burros are widely claimed to compete with desert bighorn sheep for water, forage, and space. Reports on water are conflicting and may depend on abundance. Competition for forage could occur near water holes. Two authors indicate that sheep avoid areas occupied by burros. While all of this evidence is equivocal, several authors point to negative correlations between burro and bighorn distribution in space and time. The possibility of burro competition with mule deer has been reported for Bandelier National Monument, and there is evidence of competition with small mammals in Grand Canyon, Death Valley, and Bandelier.

Less work has been done on horse competition. Dietary overlap has been reported for some seasons and some areas between horses, cattle, elk, mule deer, pronghorn antelope, and bighorn sheep, with joint occupation of the same habitat in some cases.

Effects of Equids on Soils

There are numerous anecdotal or localized reports of equids, mostly burros, compacting soil surface, forming trails in steep terrain that accelerate erosion, and polluting water holes. Equids are potentially capable of the same types of impacts as are created by livestock. The latter have been thoroughly studied.

Overgrazing (a) reduces protective cover and increases the impact of raindrops, (b) reduces soil organic matter and soil aggregates, (c) increases surface vesicular crusts, (d) reduces infiltration rates, and (e) increases erosion. Overgrazing reduces vegetation mulch, increases the proportion of bare ground and rock cover, increases soil bulk density, and reduces moisture infiltration rates.

Heavy grazing increases the sediment load of watershed runoff, an effect caused mostly by vegetative reduction, but also partly by trampling. Serious problems of sediment production in the riparian zone are often associated with bank instability. Total and fecal coliform counts generally increase with the presence of livestock, especially during runoffs. In some cases, bacteria are stored in the bottoms and banks of streams.

Recommended Research

The following research projects are recommended:

- Project 8: Grazing Impacts on Range-Plant Communities
- Project 9: Hydrologic Impacts
- Project 10: Riparian-Zone Impacts

Horse-cattle studies are again accorded priority because horses are more widespread than burros, potentially more serious competitors with livestock, and more likely to compete with cattle than with sheep. Horse-sheep studies should be initiated if resources permit.

Studies of equids in relation to wildlife are not recommended at this time because the possible combinations (horse-elk, horse-deer, horse-antelope, horse-bighorn, burro-desert bighorn) are so numerous, and because controlled experiments with wild ungulates are so difficult. But we urge that federal and state agencies watch for opportunities to take before-and-after censuses of wildlife populations in areas slated for horse or burro herd reductions. Censusing 1 or 2 years before and several years after herd reductions could give clues to the existence of competition, especially if censusing were replicated in several areas. If nearby populations in areas with no equid reductions could also be censused in the same years, the results could be compared to create a roughly controlled experiment.

SOCIOECONOMIC AND POLITICAL ISSUES

In the Committee's opinion, several kinds of socioeconomic and political information are needed to facilitate decision making in horse and burro management. While there is abundant information on range and ranch economics in the western United States, there is little economic literature specific to wild, free-roaming horses and burros, and development of market and nonmarket valuation techniques is limited. Areas in which inquiry is needed include: (a) the value of and demand for wild horses and burros; (b) evaluation of adoption procedures; (c) evaluation of control and managment techniques; (d) analysis of optimal numbers for wild equids and management alternatives; and (e) evaluation of the costs of existing legal regulations and restrictions.

The legal-political literature on wild horse and burro matters is extensive, particularly in terms of providing a perspective on the public agencies' overall land-management responsibilities--the context in which policies concerning wild horses and burros should be considered. Review of civil cases under the Wild and Free-roaming Horse and Burro Act of 1971 shows that most lawsuits fall into two categories: (1) those challenging the need for roundups, and (2) those questioning the adequacy of the environmental impact statements relied upon both by the government and by those challenging federal--as opposed to state--government authority over the animals. Concern has been expressed over protection of the animals, preservation of state control, impacts on rangeland, and the validity of information and views on population characteristics and impacts on other wildlife as well as the range resources.

There are almost no data on sociological aspects of the wild horse and burro issue.

Recommended Research

Six research projects, one of which is designed at three levels of intensity, are recommended. They will provide a base of socioeconomic and political data that will facilitate decision making in equid management. The projects are organized into three groups in descending priority in terms of importance of information and urgency of funding:

Group 1 includes:

- Project 11A: Taxonomy of Values and Benefits
- Project 13: Management Costs of Alternatives
- Project 14: Economic Considerations for Management Alternatives Drawn from Proposed Research Programs

Group 2 includes:

- Project 11B: Public Preferences for Alternative Management and Control Strategies
- Project 12: Analysis and Evaluation of Demands for Excess Wild Equids
- Project 15: Nonmarket Values

Group 3 includes Groups 1 and 2 and adds the following investigations to provide socioeconomic data necessary to a systems-level understanding of wild-equid management:

- Project 11C: Public Attitudes, Preferences, and Knowledge
- Project 16: Conceptual Development of Public Rangeland Management Models

RESEARCH AND MANAGEMENT METHODOLOGY

Methodology for censusing animal populations falls into three basic categories: (1) indices, (2) complete counts, and (3) various kinds of estimates based on sampling. Indices do not appear to have much potential in equid census, because they do not provide the estimates of actual numbers needed for forage allocation unless calibrated to total numbers. Current agency census efforts attempt complete counts from the air. The completeness of these--as well as the effects of such factors as vegetation type, topography, airspeed, altitude, type of aircraft, and observer experience--remain largely unstudied. One study showed experienced observers to be more efficient at spotting horses than inexperienced ones.

The accuracy of existing censuses must be tested and correction factors devised for deviations from total accuracy. Several approaches can be taken. Complete counts are most likely to err on the conservative side, but the Committee's impression is that current horse censuses, especially in open terrain, are reasonably accurate. On the other hand, one test of accuracy of a burro census in Arizona showed that only about a third of the burros had been counted. Some estimation techniques--especially mark-resight methods--may be useful with burros, and plot sampling may be possible for horses. These methods should be coupled with others, preferably complete counts, so that accuracy can be checked. Accuracy of an equid census can be affected by relative visibility, which may increase as group size increases; by observers' experience, as mentioned above; and by certain approaches to random sampling.

Preliminary analysis of BLM and USFS census data showed: (a) a failure to standardize the season of census, which raised the problem of a seasonal change in numbers due to foaling; (b) an abrupt 88 percent mean increase in horse numbers in the years when helicopter census replaced fixed-wing-aircraft census; and (c) less variability in the helicopter counts.

The "Soil-Vegetation Inventory Method" is commonly used in contemporary range-survey work and for a number of other purposes, including compliance with the wild horse and burro mandates of recent legislation. The Committee reviewed 10 BLM and joint BLM/USFS wild horse capture plans with their accompanying environmental analysis reports (EARs). Eight reductions were proposed because of problems perceived in range conditions. However, few provided much information on range condition and the techniques used to determine it, or on which herbivores (horses, cattle, wildlife) caused the problem. The most recent EAR provided detailed supporting data. The Committee concluded that, while range studies have not always been properly used to support adjustments in numbers of wild equids, the technology exists and appears adequate.

Fecal analysis, the most widely used technique for analyzing diets, is currently subject to question in ungulate studies. Not only do some consumed plant species fail to appear in feces, but the proportions of food items consumed and those showing up in fecal remains differ. The equid digestive tract may be less subject to these problems, a possibility that is supported by studies on zebra diets. However, conclusions based on equid fecal analysis should be drawn with caution until the method has undergone further study, preferably with the use of fistulation.

A more intractable problem is that of the time lag between consumption of forage and fecal deposition in highly mobile species such as equids. Defecation may not occur until 37 hours after ingestion, making it difficult to relate diets to the vegetation and habitat from which they were taken. Statistical problems and lack of microhistological reference material may pose other difficulties.

The in-vitro techniques widely used for studying ruminant nutrition should not be relied upon until they have been proven for equids. In-vivo comparisons, the use of indicators, and regression procedures should all be tried.

Assays of a number of chemical constituents in the blood may have potential for (a) evaluating nutritional condition of individual animals, and (b) using an animal's condition to indicate the nutritional adequacy of the range it occupies. Blood samples could be taken easily from horses and burros brought in from herd roundups, and from animals used in the research projects.

A number of the research projects outlined in this report can use confined animals, domestic ones, or both. Questions will arise as to the degree to which the results from the two categories can be extrapolated to wild and free-roaming animals. Observations of the behavior of the two former groups and of wild and free-roaming animals can be used to assess the comparability of results and to facilitate extrapolation from one group to another.

A set of observations of behavior is set forth to assist in cross comparisons. The set includes considerations in selecting the animals to be observed, statistical aspects, behaviors to be recorded, and schedules of observation. In addition, recommendations are set forth for observations of behavior to be made within the specific research projects outlined in this report, including an extensive repertoire of social and maintenance behavior. The rationale for each recommendation is included.

If fertility control is deemed a desirable method for limiting population, a range of contraceptive agents is available that could be implanted and might be effective for up to 5 years. Considerations of population and behavior point to attempts at reducing fertility in mares rather than stallions. The technique needs to be researched, however, initially in captive animals.

Chemical immobilization is not deemed an efficient primary capture technique for wild horses, but it can be used to quiet captured animals for purposes of research and handling. The preferred drug for this use is etorphine (also known as M99 or Immobilon).

Two methodological research projects are recommended:

- Project 17: Census Methods
- Project 18: Contraception Studies

Project 17 should investigate the validity of two or three alternative census techniques, including "complete" counts. The project should begin with a pilot effort on horses, later extended to burros. Project 18 should evaluate contraceptive methods.

CHAPTER 1

INTRODUCTION

THE COMMITTEE'S CHARGE

This report is submitted in partial compliance with the Public Rangelands Improvement Act of 1978 (PL 95-514), which directs in Section 14 (b)(3) that:

> For the purpose of furthering knowledge of wild horse and burro population dynamics and their interrelationship with wildlife, forage and water resources, and assisting him in making his determination as to what constitutes excess animals, the Secretary shall contract for a research study of such animals with such individuals independent of Federal and State government as may be recommended by the National Academy of Sciences. The terms and outlines of such research study shall be determined by a research design panel to be appointed by the President of the National Academy of Sciences.

The first step in carrying out these provisions was the creation of a contract in May 1979 between the Bureau of Land Management (BLM) and the National Academy of Sciences (NAS). The contract charged the Academy with the responsibility to develop a research program that would:

A. Develop data on the biology of wild horses and burros, including the population dynamics of wild horse and burro herds;

B. Identify principles and procedures for managing populations of wild horses and burros in accordance with the policies and objectives of this Act;

C. Develop information concerning the availability and use of forage and water resources, dietary and habitat overlaps, and other factors relevant to the determination of the number of wild freeroaming horses and burros that a herd area can sustain; and

D. Provide the Secretaries of Interior and Agriculture with scientific information upon which to make the determination as to excess animals required by this Act.

Both the Act and the contract direct NAS to impanel a committee to assess the state of knowledge relevant to the management of wild and free-roaming horses and burros, to design a research program that will provide information now lacking but essential to guide sound management, to review and oversee the 2-year research effort, and then to prepare a final report summarizing knowledge relevant to a sound management program for wild and free-roaming horses and burros. The NAS Committee on Wild and Free-roaming Horses and Burros (WFRHB) was impaneled in June 1979.

Phase I of the total undertaking involved the initial state-of-knowledge assessment and research design. The present document is the final report for Phase I. The state-of-knowledge assessment is a compilation of information in four general categories: (1) equid biology, (2) the effects of equids on various ecosystem components, (3) socioeconomic aspects of the subject, and (4) research and management methodology. The research program consists of 18 projects designed to enhance knowledge in these four subject areas. While the report discusses information in terms of its relevance and adequacy with regard to various policy questions, the Committee has taken an analytical approach without advocating policy on any issues. PL 95-514 makes it clear that the role of the Committee and the research it recommends is to provide information to help the Secretaries of Interior and Agriculture arrive at management decisions.

The Committee is now moving into Phase II by offering its services, as needed, to the BLM and the Forest Service (USFS) in the contracting procedures needed to bring the research program into operation. Once contracts are let and the research is under way, the Committee will assume its advisory responsibility on the research.

SUBDIVISION AND TIMING OF THE TASK

The BLM/NAS contract specifies the areas of knowledge considered important to the development of a sound horse-and-burro management program. Consideration of these areas was also vital in preparing the state-of-knowledge assessment and the research design. The contract identifies them as follows:

a. Inventory--population estimates, techniques, indexes.

b. Wild horse and burro population dynamics--herd size, sex and age classes, reproduction rates, survival mortality for adults and foals, natural controls, and other population controls.

c. Forage requirements--comparisons to wildlife and livestock.

d. Impact of wild horses and burros on the public rangelands--interrelationships of wild horses and burros with other resource uses and activities, habitat, fish, wildlife, recreation, water and soil conservation, and domestic livestock grazing.

e. Socio-economic relationships of population control and management.

At its first meeting in Salt Lake City on June 28-29, 1979, the Committee outlined subtopics encompassed by the four subject areas described in the previous section. The subtopics fell into three general categories:

1. Biology of horses and burros, with primary attention to demography, behavior, genetics, nutrition, and physiology, and to environmental influences, both physical and biotic, that affect these equids.

2. Effects of horses and burros on various components of the ecosystems of which they are a part, especially vegetation, domestic animals, wildlife, and watersheds.

3. Legal, economic, and sociopolitical issues surrounding horse and burro management.

These three categories were assigned as the purview of the three following subcommittees, respectively: Subcommittee 1: Walter Conley (Chairman), Francisco Ayala, Lee Eberhardt, Patricia Moehlman, and Ulysses Seal; Subcommittee 2: John Malechek (Chairman), John Artz, Wilbert Blackburn, Gerald Gifford, J.W. Swan, and Frederic H. Wagner (Gifford served on the Committee from September to December 1979, and when he resigned, Blackburn took his place); Subcommittee 3: Walter Johnston (Chairman), Gail Achterman, Sally Fairfax (NAS Board on Agriculture and Renewable Resources Liaison to the Committee), and Stephen Kellert.

Each subcommittee then set about the task of gathering state-of-knowledge information from a variety of sources and designing the needed research.

The entire Committee met five times:

June 28-29, 1979 at Salt Lake City, Utah

July 6-7, 1979 (including a 1-day public hearing) at Reno, Nevada

September 6-8, 1979 (including attendance at A Symposium: The Ecology and Behavior of Feral Equids, conducted at Laramie, Wyoming)

October 27-28, 1979 at Las Cruces, New Mexico

January 26-27, 1980 at Davis, California

In addition, several subcommittee or partial subcommittee meetings were held at various sites. On December 6, 1979, the Committee Chairman and representatives of Subcommittees 1 and 2 met with BLM and USFS officials in Logan, Utah to begin developing requests for proposals (RFPs) on census research and on projects to study equid habitat selection, food preferences and consumption rates, vegetation and watershed impacts, and blood assays as nutritional indices. On April 7, the Chairman and two other Committee members met with BLM and USFS officials in Denver to review proposals generated by the RFPs.

The Phase I tasks were to be completed by October 31, 1979. In July, the Committee requested an extension of the due date specified in the contract. It proposed to submit an interim state-of-knowledge assessment on October 31 along with the design of that portion of the research that must span two horse-breeding seasons, and a completed Phase I report on December 31, 1979. NAS granted the extension. The interim report was duly submitted and has been reproduced and distributed by NAS.

By December 1979, it was clear that still more time was needed to prepare the final report, and another extension was requested and granted. As noted above, this report is the culmination of Phase I.

STRUCTURE AND BASIS OF THE REPORT

The report consists of four major chapters and three appendixes. Following this introductory discussion, Chapters 2, 3, and 4 describe essentially the subject matter of the three subcommittees. Chapter 5, on research and management methodology, is a joint effort of Subcommittees 1 and 2. Appendix A is a lengthy review of equine cecal digestion; Appendixes B and C are annotated bibliographies on grazing hydrology and economic and sociopolitical issues, respectively.

Each of the four major chapters is divided into two parts. The first is a state-of-knowledge assessment. The second is a description of research projects that are needed both to fill gaps in knowledge revealed by the state-of-knowledge assessment and to provide a data base for a sound management program. The state-of-knowledge assessment surveyed the published literature thoroughly. Mimeographed material, intradepartmental and other unpublished reports, as well as theses and dissertations were reviewed, but less completely. The great store of unanalyzed, unpublished data in the files of agencies, organizations, and individual observers was consulted to some degree, but the Committee thus far has not had enough time to make thorough or far-reaching analyses and interpretations of them. Still another considerable store of knowledge lies in the unrecorded experience of hundreds of range managers, wildlife ecologists, and lay devotees of horses and burros. This source has hardly been tapped by the Committee, again because of time limitations.

It is the scientist's responsibility to gather and weigh evidence, regardless of its source, and to asses both its quality and the manner in which it was procured. The current review could not avoid a heavy concentration on the published literature and a less thorough treatment of raw data and information based on experience. Published literature tends to lag behind the accumulated store of knowledge, and heavy reliance upon publications may produce inadequate or biased understanding. The state of the art will not be fully assessed until the Committee has an opportunity to go afield with range managers, wildlife biologists, and amateur horse and burro observers. The members began to do this in the summer of 1980, but until that work is completed, the Committee must continue to rely heavily on the published literature.

The 18 recommended research projects are listed below in an order that deviates somewhat from that in the interim report.

1. Habitat Preference and Use by Co-occurring and Separately Occurring Feral Equids and Cattle

2. Food Consumption Rates and Nutrition of Wild and Free-Roaming Horses and Burros and Their Associated Species

3. Nutritional Plane, Condition Measures, and Reproductive Performance in Domestic Mares

4. Blood Assay of Experimental Equids and Livestock in Projects 1, 2, 3, 5, and 8

5. Demography of Wild Horses and Burros

6. Social Structure, Feeding Ecology, and Population Dynamics of Wild and Free-Roaming Horses and Burros

7. Genetic Polymorphism

8. Grazing Impacts of Equids and Cattle on Range-Plant Communities

9. Hydrologic Impacts

10. Riparian-Zone Impacts

11. Public Attitudes

12. Analysis and Evaluation of Demands for Excess WFRHB

13. Management Costs of WFRHB Alternatives

14. Economic Considerations for Management Alternatives Drawn from Proposed Research Programs

15. Nonmarket Values for WFRHB

16. Conceptual Development of Public Rangeland Management Models

17. Census Methods for Wild Horses and Burros

18. Contraception Studies

The projects are discussed more fully in the following chapters of this report.

CHAPTER 2

BIOLOGY OF HORSES AND BURROS

INFORMATION NEEDS

The passages quoted from PL 95-514 and the BLM/NAS contract in Chapter 1 itemize in some detail the categories of desired information on horse and burro biology: population dynamics, food and habitat requirements, use of forage and water resources, and population controls. PL 95-514 states further, in Section 14 (b)(1), that:

> The Secretary shall maintain a current inventory of wild free-roaming horses and burros on given areas of the public lands. The purpose of such inventory shall be to: make determinations as to whether and where an overpopulation exists and whether action should be taken to remove excess animals; determine appropriate management levels of wild free-roaming horses and burros on these areas of the public lands; and determine whether appropriate management levels should be achieved by the removal or destruction of excess animals, or other options (such as sterilization, or natural controls on population levels).... Where the Secretary determines ... that an overpopulation exists on a given area of the public lands, and that action is necessary to remove excess animals, he shall immediately remove excess animals from the range so as to achieve appropriate management levels ....

This heavy emphasis on the definition of "excess" animals, and the fact that the Committee was invested with the responsibility for helping the Secretaries of Interior and Agriculture make that determination, necessitate a clarification of the term "excess," and of its implications for informational needs.

The term has at least three connotations: "excess" can have the sense that (1) the number of animals is detrimental to their own condition and welfare, (2) the number of equids adversely affects the condition and welfare of the other components of their ecosystems, and (3) the number of equids interferes with other management objectives for the public rangelands. The latter two connotations will be considered in Chapters 3 and 4; the first is addressed in this section.

An excess of animals threatening to their own welfare will occur when a population has risen to densities at which its members' behavior, demography, and state of health fall below some specified levels or standards. Establishment of such standards, and hence the determination of "excess," requires knowledge of the animals' social- and maintenance-behavior repertoire, their demographic characteristics, and facts about their nutrition and other health conditions. It must be determined how these vary with population size, adequacy of forage, weather conditions, competitors, and other environmental variables. Physiology, as well as food preferences and consumption, must also be understood. The sections that follow explore what is known about these subjects.

STATE OF KNOWLEDGE

Information Sources

Committee members conducted preliminary literature searches by examining published research reports, unpublished theses, impact statements, and the popular literature. Bibliographies in these documents were then traced and cross-referenced. The information available on the biology of wild equids was found to be incomplete and superficial in some subject areas, irrelevant to the Committee's purpose in some aspects, and quite complete in others.

Wildlife Review (from 1936 to the present), the Denver Library (in cooperation with the U.S. Fish and Wildlife Service), and BIOSIS (Biological Abstracts) were also consulted. BIOSIS alone produced over 15,000 citations and associated codes (1969 to 1979) that were flagged on the single keyword "Equidae." These citations were obtained and screened. (Broad subject categories were created and all citations were placed in appropriate sections. These files are available at New Mexico State University.) Other computer-based reference sources that were searched included Medline (Index Medicus) and Dialog (through the Lockheed system). Science Citation Index and the bibliographies of individual articles were also consulted.

Since BLM and USFS files contain considerable amounts of field data, representative samples were sought by attempting to identify management units that: (a) had a history of intense horse and/or burro activity, and (b) contained information concerning economic and social considerations. Other factors applied to the selection of units included the existence of regional collection corrals, intense public interest, general completeness of available records, duration of available records, history of research programs, adequacy of land-use plans, etc.

Management units thus identified were visited, appropriate personnel were interviewed, and available records were copied and centralized for cataloging and evaluation. These units included: Phoenix, Arizona (BLM); Palomino, Nevada (BLM); Susanville, California (BLM); Vale, Oregon (BLM); Lakeview, Oregon (BLM); Burns, Oregon (BLM); Salt Lake City, Utah (BLM); Pryor Mountains, Montana (BLM); Rock Springs, Wyoming (BLM); Modoc, California (USFS); and Jicarilla, New Mexico (USFS). Interviews were conducted during late August and early September 1979. Because Committee member Walter Conley conducted a 2-year research project from 1976 to 1978 at Jicarilla and the records were already complete, no interviews were required there. In addition, the entire records file of the BLM (previously located at the Denver Center) was obtained, reviewed, copied where pertinent, and returned. Data from this review are filed at New Mexico State University.

Personal contacts were made with three recognized authorities in the field of equine nutrition: Drs. P. V. Fonnesbeck and L. M. Slade of Utah State University and Dr. H. F. Hintz of Cornell University. They were asked for ideas and sources of information. Mr. Montague Demment, University of Wisconsin Zoology Department, prepared the detailed review included as Appendix A.

History and Paleontology of Equids in North America

The horse (Equus caballus) and the African ass (E. asinus) were introduced to North America by the Spanish in 1495 during Columbus' second expedition to the New World (Denhardt 1951, Brookshire 1974). Horses and asses were an integral part of Spanish exploration and colonization and feral populations took hold throughout the Southwest in the 16th and 17th centuries. Native Americans incorporated equids into their cultures and horse and ass populations--both wild and domesticated--spread rapidly throughout the western states. Feral populations increased when animals escaped and were released from ranching and mining activities in the 19th and 20th centuries. Thus horses and asses have a long history in North America and may have been feral in the western United States since the 1600s (McKnight 1957, 1958).

The mainstream of equid evolution occurred in North America; only a few types wandered into the Old World in the Tertiary (Romer 1966). Native equids were present from the lower Eocene, 55 million years ago (Colbert 1969), and remained abundant until 11,000 years ago. Late Pleistocene mammal sites in Arizona (Lindsay and Tessman 1974) reveal that Equus was second in abundance only to Mammuthus and was twice as abundant as Bison.

The disappearance of equids 11,000 years ago coincided with the extinction of three genera of large mammals, and the immigration of a new predator, Paleolithic man. Martin (1973) has formulated a blitzkrieg model that postulates a spread of Paleolithic hunters so rapid that it resulted in the mass extinction of large mammals within 1,000 years.

Dating of fossil remains of type Equus (large), as well as other Equus species including E. asinus, has established their ages at between 11,000 ± 100 and 13,310 ± 210. These remains came from sites in Nevada, Arizona, and California (Haynes 1967, Mawby 1967, Hemmings 1970, Havry 1975, Cole and others 1979).

Skinner (1972) maintains that certain species groups of Equus have existed for 3 to 5 million years. He presents evidence that there is a high degree of similarity between extinct Pleistocene and living equids. Skinner lists the type species of the subgenus *Dolichohippus* as being *Equus grevyi* Oustalet, 1882, distributed as follows: "extinct in Pleistocene, North America; living, Ethiopia and Northern Kenya." He describes the type species of subgenus *Equus* (*Heminous*) as being *Equus hemionus* Pallas, 1775, with the following distribution: "Pleistocene, North America, and living, Asia." Pleistocene deposits show specimens ranging from Texas to Alaska, and Kansas to Arizona. Specimens referred to as *Equus* (*Asinus*) *cumminsii* Cope were found in Pleistocene deposits at Blanco, Texas and Deer Park, Kansas. Equid fossil remains are rarely identified to the species level. However there were ass, horse, and zebra types present in Pleistocene North America, and the skeletal morphologies of the fossil and the reintroduced equids are anatomically indistinguishable (Cole and others 1979).

Thus although feral horses and asses are considered alien or 'exotic' today, they represent lineages that have a long paleohistory in North America. This is particularly important to the interpretation of their role in modern ecosystems. The concern on the part of some people that feral horses and asses are detrimental to their habitat is partially based on the assumption that since they are exotic they are particularly disruptive to vegetational communities with which they have not coevolved. However, modern-day equids in North America are not typical exotics. A long period of coevolution between their evolutionary predecessors and the vegetation was broken for 11,000 years, which is a brief interval in geologic time.

Whether or not the vegetation today retains the same antiherbivore adaptations it had developed by the time equids became extinct at the end of the Pleistocene is a moot question. Paleobotanical evidence shows distributional changes in the vegetational zones, which were depressed from 600 to 1,000 m (Martin and Mehringer 1965, Van Devender and Spaulding 1979). But to our knowledge, no one has produced any evidence that native plant species have lost adaptations to grazing and/or browsing pressures (e.g., oily foliage, spiny or thorny branches, siliceous stems, or toxic alkaloids) that are the result of selective pressure exerted during millions of years of coevolution with equids.

However, several authors (Young and others 1976, 1979) have postulated that the marked changes in vegetation structure in the Great Basin following the 19th-century introduction of sheep and cattle were due to the lack of heavy, post-Pleistocene pressure from large herbivores. Without such pressures the vegetation had lost defenses, according to this theory, and was vulnerable to the introduction. Some plant species are known to be highly plastic, and to respond to selective pressures in short periods of time (Dyer 1968), including grazing (Stapledon 1928, Lodge 1962). If species optimize traits over an array of selective pressures, as modern evolutionary theory holds, then it is reasonable to postulate that some species may have evolved away from antiherbivore defenses in the absence of grazing pressures.

Of course, there is no way to determine differences and/or similarities in behavioral ecology between the equids present in North

America 11,000 years ago and the recently introduced species. However, it is an oversimplification simply to dismiss feral asses and horses as "exotics." The possibility of their filling an "open niche" remains (Martin 1970).

Behavioral Ecology of Equids

Genus Equus contains six living species. They are Equus caballus (horse), E. burchelli (plains zebra), E. zebra (Hartman's or mountain zebra), E. asinus (African ass), E. hemionus (Asian ass), and E. grevyi (Grevy's zebra). The genus is characterized by two distinct types of social organization. The harem or stable family group with a dominant male has been described for the plains zebra (Klingel 1967, 1972), Hartman's zebra (Lingel 1968; Joubert 1972a, b), and the feral horse (Feist and McCullough 1975, 1976; Green and Green 1977). The territorial form of social organization, in which stable bonds occur only between mother and offspring, has been described for Grevy's zebra (Klingel 1969), the Asian ass (Klingel 1977), the African ass (Klingel 1972, 1977), and the feral ass (E. asinus) in North America (Moehlman 1974, 1979; Woodward 1976, 1979). These two types of social organization appear to be the extremes of a continuum that ranges from a system in which territoriality plays an important role and social bonding is limited, to the more socially organized and cohesive family groups.

The interrelationship of social organization and environmental parameters has been the focus of review and interpretation by Crook (1970), Jarman (1974), Kaufman (1974), Klingel (1974), and Fisler (1979). Many factors appear to be important in the establishment and/or reinforcement of a social system. In particular, resource availability, feeding ecology, daily activity patterns, and demography are critical in determining social behavior, social bonding, and the type of social organization maintained. Most reviews of social organization and ecology have been on the interspecies level. However, an examination of available data on feral equids does reveal intraspecific behavioral plasticity.

Feral Asses

Since the early 1970s, field studies have been done on several feral ass populations in the southwestern United States. Table 2.1 lists the study populations, researchers, and some pertinent facts from each study.

The basic pattern of social organization and demography was the same in all southwestern study sites. The only stable unit was mother and offspring. Some typical temporary groups were females and offspring, bachelor males, and mixed groups. Adult males were often solitary. Statistical treatment of group size and composition is only available for two studies (Moehlman 1974, Woodward 1979a). There was evidence of territoriality by a small percentage of the males on all

TABLE 2.1 Feral Ass Field Studies

Study Site	Study Period	Study	Study Area	Peak Pop.	Territory Males Present	Home Range X	Sex Ratio M:F
California							
Death Valley	1970-74	Moehlman (1974)	310 km^2	≅178	x	10.8	1:1
Nat'l. Monument	1975-76	Norment & Douglas (1977)	600 km^2	≅131	x	68.1	2.1:1
Chemehuevi Mts.	1974-75	Woodward & Ohmart (1976)	150 km^2	≅ 83	x	32.0	1:1
Arizona							
Bill Williams Mts.	1974-75	Seegmiller & Ohmart (1976)	90 km^2	≅ 92	x	19.2	1:1
Black Mts.	1976-77	Walker & Ohmart (1978)	165 km^2	450	---	---	---
Lake Mead Nat'l Recreation Area	1977-78	O'Farrell (1978)	178 km^2	115	---	---	---
Alamo Lake State Park	1972-73	Farrell (1973)	19 km^2	---	---	---	---
Grand Canyon	1974-75	Carother & coworkers (1976)	---	≅ 300	---	---	---
Havasu Resource Area	1974-75	Hanley & Brady (1977)	---	≅ 50	---	---	---
New Mexico							
Bandelier Nat'l Monument		Morgart (1978)	72.8 km^2	≅ 140	x	2.86	---
Georgia							
Ossabaw Island	1973	Moehlman (1974)	---	---	---	---	---
	1978-79	McCort (1979), Johanos	---	---	---	---	---

study sites, but only the Wildrose population in Death Valley (1970 to 1974) and the Bandelier population exhibited strongly expressed territoriality. There appears to be some confusion in Woodward's (1979a) discussion of territoriality. Territorial behavior in both Grevy's zebra and the African ass (Moehlman 1974, Klingel 1979) does not involve boundary marking and defense against all conspecifics, but rather the domination of a particular area by a single male who has sole access to estrous females within that territory.

Short-term observations (1 month) were made on a population of feral asses in a very different habitat: Ossabaw Island, Georgia (Moehlman 1979). This island is characterized by lush vegetation and a warm, humid climate. There were approximately 40 feral asses on the island, with a density greater than 1/km². Although the Ossabaw observations were limited, they do illustrate the plasticity possible in the social behavior and organization of feral asses. Contrary to the situation in Death Valley, stable groups existed. At the south end of the island there was a stable group that exhibited all the characteristics of a harem. A group of 13 asses at the north end of the island were associated in 63.6 percent of the observations. In this group the dominant male did all the courting and copulating. These observations have since been substantiated by McCort (1979).

Feral asses have potentially large home ranges over which they move in a seasonal pattern. Recorded individual home ranges, which probably reflect a minimum, range in mean size per population from 2.86 to 68.1 km². The largest home range observed was 103.6 km² in Death Valley National Monument. Except for the stable group of mother-offspring ($\bar{X} = 2$) all groups are temporary and their composition can be as follows: (a) all male, (b) two or more females and offspring, (c) mixed adult males and females and subadults, and (d) yearlings. Males are often solitary, and in the Death Valley study (Moehlman 1974, 1979) 23.9 percent of the observations (N = 1,158) on population grouping patterns involved solitary males. The general trend was toward small groups, and 57.8 percent of the groups contained 2 to 4 individuals. Large aggregations (8 to 21) occurred rarely (3.3 percent) and were associated with scarce resources such as water and/or estrous females. The Chemehuevi population followed this general pattern (Woodward 1976, 1979a). Data for group sizes are not available from the other studies.

Information on spacing between individuals is available from Death Valley (Moehlman 1974). Data taken at 5-minute intervals (N = 2,915) revealed that adults (male and/or female) spent most of their time separated by distances greater than 10 m. Individuals that spent most of their time within 4 m of one another were usually genetically related. However, adult females allowed the yearling offspring of other females to come closer to them than they would permit their own yearlings. Thus, an observer lacking knowledge of individual relatedness could easily misinterpret how many offspring a female had and how often she was reproducing. This presents obvious problems in present census techniques. Distances between males and females decreased only when the female was in estrus.

During the hot summer months asses tend to drink once every 24 hours and water is a critical factor in their distribution. In most study areas, asses were concentrated within 3 km of water sources during the summer months. From September through the winter months, they were less dependent on water and were found 8.0 to 9.6 km away from it. Animals also moved to lower elevations during the winter months.

Asses are physiologically well adapted to life in an arid habitat. They can sustain a water loss of up to 30 percent body weight and can drink enough water in 2 to 5 minutes to restore fluid loss (Maloiy 1970, Maloiy and Boarer 1971). A recent study (Tomkiewicz 1979) on heterothermy and water turnover using temperature-sensitive implants revealed that body temperature could vary from 34.0 to 41.6°C and was dependent on air temperature. In the summer males had a lower mean body temperature (36.5°C) than females (38.2°C).

Mother asses in Death Valley (Moehlman 1974) showed a high threat and rejection rate when foals attempted to nurse, presumably because of fluid stress. Nursing rejections began on the first day and increased in intensity as the foal grew older. Rarely did a foal attempt to nurse without being threatened by its mother. Until the foal was a month old its nursing success, calculated by observing each attempt, was 82 percent. By the time it was 3 to 4 months old the success rate had diminished to 35 percent. This rejection is similar to weaning behavior in other equids; it differs mainly in that it commenced when the foal was so young.

Lactating females are under more severe fluid stress than other adults in the population. These animals watered more frequently during the hot months (2 to 3 times per day, in comparison with once a day for other adults). Foals ate vegetation, but they did not drink water until they were about 3 months old; the mother provided her foal with most of its fluid intake during that period. Nursing provides certain safeguards for the foal, since it does not have to compete for water at the springs. However, it may increase the fluid stress on the female in what is already an arid and difficult environment. Thus, the female may need to regulate the interval of nursing so as to moderate fluid stress. This physiologically based behavior might in turn stimulate independent and aggressive behavior on the part of the foals, and the entire mechanism may contribute to the lack of bonding between adults in this population. Two-day-old foals were already threatening conspecifics, particularly when they saw their mothers being approached by others.

In all populations studied in the Southwest, asses tended to congregate near scarce water sources during the hot months (June through August). Such a high density during one portion of the year results in a more severe impact on the vegetation in the immediate vicinity of the water source (Fisher and others 1973, Hanley and Brady 1977, Woodward and Ohmart 1976, Norment and Douglas 1977). This phenomenon will be discussed in greater detail under "Range-Plant-Community Impacts" in Chapter 3.

Hanley and Brady (1977) studied precipitation, soil texture, soil moisture, and browse utilization patterns on sites at increasing distances from the water source. They found that: "Browse utilization ranged from heavy to light with increasing distance from the Colorado River. Overgrazing occurred near the Colorado River but decreased to light or moderate use at distances greater than 2.5 km from water." Burro impact was greatest in the secondary wash communities (Cercidium-Larrea). Apparently no species were acting as increasers or invaders under heavy burro utilization pressure in this locale. There is no information in this study on burro densities. Hanley and Brady also point out that assessment of impact is complicated by the need for data concerning the amount of time and the burro densities required to modify the community structure.

The same general trend of heavy impact near water sources in the Panamint Range was evident in a report by Fisher and others (1973). However, at an exclosure approximately 2 km from the water source, measurement of vegetative species density and volume showed higher biomass outside than inside the exclosure. Annual densities and species diversity were higher outside the exclosure, but a bunch grass, Stipa sp., was more abundant inside the exclosure. Secondary production was higher in the area used by feral asses.

Two studies in the Grand Canyon (Carothers and coworkers 1976, Cole 1979) analyzed canopy cover of predominant species. However, their results disagree and have different implications. Cole suggested that the degree of burro impact on vegetation is complicated and changes over short distances on the same slope and substrate. Neither study indicated distances from water or ass densities.

O'Farrell (1978), studying feral asses in the Lake Mead National Recreation Area, also described the general trend of ass populations to clump near water during the hot summer months. Maximum density values were $X = 0.93$ per km^2, and the greatest effect on vegetation was observed within a quarter mile of the water source.

All of these studies provide interesting information on modification of vegetation by asses. However, all of the data were generated by indirect methodology. There is a distinct need for direct observations of ass feeding ecology and species utilization as they are related to availability, terrain, season, and climatic conditions.

The movement of ass populations is restricted in the hot summer months because water is limited. Their seasonal movements and rotational utilization of vegetation within their home ranges has not been examined directly. Carrying-capacity figures alone are insufficient for assessing the relationship of ass populations to the vegetational community.

Information on daily activity patterns is available from two studies: one conducted at Death Valley, California and the other at Ossabaw Island, Georgia (Moehlman 1974, 1979). Death Valley is characterized by a hot, dry climate with low and sporadic rainfall. The vegetation in the study areas was primarily browse. Death Valley offered a relatively unstable habitat in which water sources were of prime importance during the summer months. The feral asses combined in small groups, had large home ranges, were distributed for most of the year at a low density, and characterically exhibited territoriality and a low degree of sociability. In hot weather the population tended to clump around water sources. At these times territorial males resided next to the water source, thus enhancing their chances of copulating with estrous females.

On hot, humid Ossabaw Island, vegetation is lush and water supplies plentiful. The population was denser, had a smaller home range, and exhibited greater sociability and group cohesion. One group of five interrelated as a harem.

A basic element of the daily activity pattern--percentage of time spent feeding--was quite different in the two populations. The Death Valley asses were primarily browsers and spent 51.0 percent of their time feeding; Ossabaw Island asses were primarily grazers and spent 38.1 percent of their time feeding. Jarman has emphasized the importance of feeding ecology in the determination of ungulate social organization. Browsing species tend to be less sociable, and grazers occupy the more social end of the continuum (Jarman 1974). Determining factors in this trend may be the proportion of time required for feeding and the quality of forage.

The Ossabaw Island population exhibited almost no aggressive behavior. In particular, females rarely threatened their foals, whose nursing success rate was much higher than that of their Death Valley counterparts (88 percent at 3 to 4 months). This lack of rejection was probably directly related to the fact that lactating females experience little water stress in the Georgian environment.

Three categories of behavioral interactions that might affect social bonding and grouping in the two areas are greeting, mutual grooming, and social play. In Death Valley, greeting behavior occurred mainly between adult males (60.2 percent) and often (i.e., 63.3 percent of the time) involved aggressive behavior. Female-to-female greetings were rare (1.7 percent). Foals were involved in 34.0 percent of the greetings, of which they initiated 15.6 percent. Greeting behavior was rare on Ossabaw Island, which may simply be another indication that individuals were well known to each other and relationships were clearly established.

Social grooming is usually considered to be important for group cohesion (Sparks 1967). In Death Valley the general pattern of low sociability was also reflected in the rarity of mutual grooming (0.3 observation per hour). Ossabaw Island asses performed grooming much more frequently (1.5 observations per hour). Furthermore, three categories of grooming partners were seen in Georgia that were not observed in Death Valley, namely: male-female, female-nonoffspring foal, male-foal. This behavior is consistent with the general pattern of a cohesive group, relatively close spacing of individuals, and a low level of agressive behavior.

Social play is the third behavioral category that may influence social bonding. This type of interaction was not observed between foals in the Death Valley population. These foals only exhibited solitary play, which consisted of such activities as using the mouth to pick up and drop objects, running in spurts, stopping quickly in front of adults, pivoting and running away, and biting and mounting their mothers. In a more social equid population, i.e., New Forest ponies (Tyler 1972), 3-week-old foals were observed with other foals and/or yearlings, and by the time they were 6 weeks old, social play constituted 55 percent of their play. On Ossabaw Island two male foals spent many hours engaged in social play, which usually consisted of play-fighting. These foals were the same age and associated regularly.

There appears to be an upper limit on the size of an equid group in which individuals can express and maintain stable relationships and bonds. The maximum size of permanent groups in Hartmann's zebra (Joubert 1972 a,b) is about 13; 65.2 percent of the groups have between 4 and 7 animals. Klingel (1967) reported an average group size of 4.5 to 7.5 for this zebra. The average size of a feral horse harem (Feist 1971) is 5, with a maximum of 21. Thus, when feral asses did form permanent groups they followed the pattern for Equidae.

Behavioral and ecological information on the two feral populations of asses indicates that although *Equus asinus* normally displays low sociability, this species does have the behavioral plasticity, given a favorable environment, to form highly social and stable harem groups.

Feral Horses

Feral horse field studies have been conducted in Nevada, Arizona, New Mexico, Montana, and Wyoming. Comparative studies are also available from Canada and islands off eastern North America. Table 2.2 lists field studies for which information was available.

The basic pattern of social organization is a family group composed of a dominant male, subordinate adult males, females, and their offspring (Feist 1971, Pelligrini 1971, Feist and McCullough 1975, Hall and Kirkpatrick 1975, Welsh 1975, Clutton-Brock and others 1976, Keiper 1976 a, Berger 1977, Green and Green 1977, Rubenstein 1978, Salter 1978, Nelson 1979). Some family bands are single-male harems, but several authors report multi-male groups (Feist 1971, Keiper 1976 a, Green and Green 1977, Miller 1979, Nelson 1979). Klingel (1967) described a dominant male in a plains zebra family group who actively searched for a 4-year-old male member that had wandered off. Joubert (1972a) experimented with the effect of removing the dominant male from a band. The females appeared to be very closely bonded and actively searched for the missing male. They rejoined him when he was released a month later. The basic pattern of strong bonding between females persists in semi-feral situations where adult males are removed (Imanishi 1950, Tyler 1972).

However, bands are not completely stable and changes do occur. Feist (1971) found that immature females accounted for most of the changes between bands, and that these occurred during the breeding season. Klingel's (1969b) study of plains zebras recorded that young females undergoing estrus for the first time had a different and more distinctive standing posture than older females. He felt that this served as a strong advertisement of their reproductive status and

TABLE 2.2 Feral Horse Field Studies

Study Site	Study Period	Study	Study Area	Population	Density	Band Size	Home Range $\bar{X}$	Foaling	Sex Ratio M:F
Montana-Wyoming									
Pryor Mts.	May-Nov 1970	Feist (1971)	132 km^2	225-270	2.0/km^2	2-21 X=5	~25 km^2	Apr-June	1:1
	1971-72	Hall & Kirkpatrick (1975)	---	130	1.0/km^2	$\bar{X}$=3.4	---	Mar-July	~3:2
Wyoming									
Red Desert	1978-79	Miller & Denniston (1979), Boyd (1979)	620 km^2	~450	0.7/km^2	2-16 $\bar{X}$=8	---	Apr-June	---
Nevada									
Stone Cabin Valley	1975-76	Green & Green (1977)	1378 km^2	538-786	0.6/km^2	---	11-78.5 km^2	Mar-June	1:1
Wassuk Range	1969-70	Pelligrini (1971)	---	---	---	---	---	---	---
New Mexico									
Carson Nat'l. Forest	1976-77	Nelson (1979)	142 km^2	~226	1.6/km^2	1-15 $\bar{X}$=6.8	---	Apr-Aug	0.4:1
Arizona									
Grand Canyon Nat'l. Park	Mar-Aug 1974	Berger (1977)	390 km^2	~78	0.2/km^2	3-6 $\bar{X}$=4.5	~20 km^2	---	---
North Carolina									
Shakleford Island		Rubenstein (1978)	---	---	11.0/km^2	---	6 km^2*	---	---
Maryland-Virginia									
Assateague Island	1975-79	Keiper, Zervanos (1979)	---	~200	---	3-26 $\bar{X}$=11.6	4.3-6.5 km^2	---	---
Nova Scotia									
Sable Island	1970-72	Welsh (1975)	50 km^2	150-300	6-27.7/km^2	2-20 $\bar{X}$=5.5		Peak in Apr-June	1:1
Canada									
Western Alberta	1975-77	Salter, Hudson (1978)	200 km^2	~206	---	$\bar{X}$=7.7	15 km^2	Apr-June	---

*Territories = 3 km^2

increased the possibility of their abduction from the family band. Nelson (1979) observed that 61 percent of the females moved away from their primary band. Mature females accounted for 78 percent of these movements.

When strange individuals attempt to join a band, not only the dominant male, but also subordinant males and females will drive them away.

All-male (bachelor) groups commonly occur, but tend to be unstable in composition. Adult males are rarely solitary. Dominance hierarchies have been recorded in bachelor groups (Feist 1971, Feist and McCullough 1975) and appear to be important in determining which males are most likely to acquire females.

Miller and Denniston (1979) have reported a further level of social organization in horses. By analyzing 122 encounters among 16 bands, they found a nearly linear interband dominance hierarchy in terms of access to a scarce resource--water. Berger (1977) reported a similar hierarchy among four bands in his study in Grand Canyon. Miller and Denniston propose the designation of the term "herd" for a structured social unit of bands that recognize each other and form a dominance hierarchy.

Although horses have a typical social organization characterized by a lack of territorial behavior, this pattern can change under unusual environmental conditions. Rubenstein's (1978) study of the Shakleford Banks horses clearly illustrates this point. Two-thirds of the harems maintain clearly defined and stable territories. The island is narrow and visibility is good, so the energetic costs of defending a territory are correspondingly low. In addition, water and vegetation zones are evenly distributed along the island. Territorial harems are larger than those harems that utilize overlapping home ranges. Thus the structure of the island and the pattern of available resources has clearly influenced social organization in this population. The only other report of territorial behavior is for a feral population in the Wassuk Range, Nevada (Pelligrini 1971). However, territorial behavior in that report was not adequately documented.

In hotter, drier habitats, both water and forage availability are major determinants of horse movements (Berger 1977, Green and Green 1977). During the summer months the animals tend to concentrate their activities within 3 to 7 miles of available water. In Grand Canyon, Berger (1977) found that home-range size decreased in successive warm months and that the time spent in drinking and resting increased, while feeding time decreased. Time spent feeding varied from approximately 50 percent to 30 percent. Green and Green (1977) observed seasonal migrations by part of the population from Stone Cabin Valley south to the Tonopah Nuclear Test Range. The plains zebra in the Serengeti will migrate up to 150 km to get to dry-season foraging ranges (Klingel 1972). Feral horses might also be capable of such long-range movements, but are probably restricted by topography and fencing. Anecdotal accounts of Asiatic wild horses (Mohr 1971) suggest that their home ranges are centered around water sources during spring foaling and the summer dry season, but that they greatly increase their range during the winter when snow is available.

Studies in Alberta (Salter 1978; Salter and Hudson 1978, 1979) and British Columbia (Storrar and others 1977) found that habitat utilization was determined primarily by forage availability and that other factors were of secondary importance. Horses spent 75 percent of their daylight hours feeding in winter, and the authors suggested that there was a decrease in diurnal feeding during the summer. Diet quality peaked in June and was low in January. Meadow and shrubland habitats were mainly utilized in spring, with a shift to forested habitats in summer and fall-early winter. Compared with deer, moose, and elk, horses were more ubiquitously distributed.

Skelton (1978), using fecal-sample analysis of horses in the Camargue, found differences in diets according to season, age class, and herd membership. This last factor appeared to be important to the survival of Sable Island horses (Welsh 1975). Bands that lost their stallion in the winter of 1972 and were taken over by another and presumably less experienced male had the highest mortality. This outcome was attributed to bands moving to areas with poor shelter or food resources during a storm.

Studies of feral horses on Assateague Island (Keiper 1976a, 1977b; Zervanos and Keiper 1979) investigated social organization, activity patterns, and feeding behavior. These are the only studies that directly examined vegetation consumption by individuals in terms of time spent grazing per plant species. Watching different bands during summer and winter months, the authors determined that utilization of standing crop biomass by bands ranged from 5.1 to 20.1 percent in summer, and from 2.6 to 31.0 percent in winter. These figures do relate to differences in band size. The observers also recorded seasonal differences in home range size (summer, 6.48 km^2; winter, 4.32 km^2). Horses remained active throughout the night, spending 49.7 percent of the nocturnal hours feeding.

Seasonal distribution of Sable Island horses (Welsh 1975) was affected by plant-community type, shelter, and surface water. Welsh calculated that 300 horses (peak population) would eat 13 percent of the annual forage production.

In spite of all these studies, there is still a dearth of critical information specifically examining horse energetics and feeding ecology. It is readily apparent that horses are selective feeders but that they can still get by on low-quality forage. However, there are no data on the diversity and abundance of vegetational species or on what type of forage is being selected seasonally by horses per sex and age class. Such data are critical to understanding reproductive potential (Clegg and Ganong 1969, Hall 1972).

A great deal of data is available on equid social organization, demography, seasonal distribution and feeding ecology, daily activity pattern, and reproduction. For the most part, however, the information is of a sporadic and short-term nature. As yet no long-term (5 to 10 years) study has been performed, nor has any study correlated data on population size and demography, behavior, and feeding selectivity with seasonal availability and quality of forage and water. Activity-budget data are critical to determining the energetic requirements of feral horses and burros. The resulting interpretation of nutritional status is particularly critical to understanding the lifetime productivity of females.

Equid Demography

The reproductive performance and longevity of an individual animal is partly a function of its genetic make-up, and partly its environment operating through its nutrition, physiology, and behavior. The collective performance of numerous individuals considered together as a population is expressed as a natality or fecundity rate, and as a survival rate. Such rates can be expected to vary annually to some degree within a population as yearly environmental conditions vary, and between populations as genetic make-up and environments differ.

These rates, in turn, interact to produce more synthetic population traits like age and sex composition, and rates of population change. The latter parameter alone discloses much about a species' ecological and evolutionary characteristics. It provides an indication of the demographic cushion with which it can absorb such environmental pressures as predation and competition, or human exploitation. Such related parameters as the net reproductive rate (average number of female young produced by the average female in her lifetime), mean generation length, and average reproductive value of an individual female at a given age all provide insights into the species' potential evolutionary plasticity.

From the practical standpoint of equid management, estimates of herd increase rates disclose the rates at which animals must be removed in order to hold them at some decided-upon level. Or alternatively, such rates make it possible to predict rates of herd growth in the absence of any artificial controls. They may also provide checks on the validity of census methods. Since this has been a controversial subject in North American equid management, we devote considerable attention to the subject in the sections below.

The Wild Horse

(1) Fecundity. Considerable work has, of course, been done on reproductive patterns in domestic horses. But very little information is available on natality rates in free-roaming wild horses. The rates that characterize well-managed, confined domestics may constitute the maxima of which the species is capable under optimum nutritional and breeding conditions, and under protection from the elements. The available data from wild herds indicate lower rates, doubtless the cost of field breeding, less-than-optimum nutrition, and the rigors of range life.

(a) Age at first female breeding. Although ovulation and conception begin at 1 year of age in domestic fillies, there appears to be a high fetal loss in mothers of this age. In one study (Ginther 1979) of mares confined to pens or small pastures and fed supplementary diets, 69 percent of the yearling females conceived but only 44 percent delivered at age 2.

In all the published material we examined, we found only one instance of conception at 1 year of age and foaling at 2 in wild horses. This was reported by Tyler (1972) who, in a study of New Forest ponies in Britain, observed one such case in 107 2-year-old mares over a 3-year period. Elsewhere, no 2-year foaling was observed in the following studies:

(i) Boyd (1980) in a 2-year study of a 400-horse herd in Wyoming.

(ii) Keiper (1979) in a 5-year study of Shetland ponies on Assateague Island (Maryland-Virginia), the population averaging about 300 animals.

(iii) Welsh (1975) in a 3-year study of 227 to 306 wild horses on Sable Island, Nova Scotia. Youngest mare seen copulating was 26 months of age.

(iv) Feist and McCullough (1975) in a 1-year study of 270 horses on the Pryor Mountain Wild Horse Range, Montana.

(v) Nelson (1979) in a 1-year study of 116 horses in the Jicarilla District of the Carson National Forest, New Mexico.

(b) Age-specific and herd fecundity. In one study of confined and well-fed domestics (Ginther 1979), the percentages of mares foaling rose from around 65 percent in the younger animals to values of 81 to 89 percent in ages approaching 12, then declined to 50 at age 20. In total, about 80 percent of a mixed-age herd became pregnant, while about 70 percent bore young. Since the gestation period is approximately a year, and mares experience post-partum ovulation and conception, these percentages approximate the percentage of mares in a mixed-age herd that could be expected to produce young each year. Removal of the younger animals, and keeping the herd stocked with the more fecund, 8 to 12-year-old animals could increase the expected annual foaling rate.

An important paper by Speelman and others (1944) summarizes reproductive rates of domestic mares raised under western range conditions near Miles City, Montana. These authors reported the foaling rates of 209 mares, each observed through several breeding seasons, so that a total of 953 individual breeding cycles was observed over a 15-year period. Range forage was the primary food source, and foals ran with mares until weaning, when they were given grain and hay until 1 year of age. From 1 year to maturity, and thereafter, pastures provided most of the food. No supplemental food was given except during periods of exceptionally severe weather or during work periods.

The 953 matings produced 567 pregnancies (59.6 percent) and 568 foals (one set of twins was born). Age-specific fecundity of these animals is shown in Table 2.3. Here, as in the study reported by Ginther (1979), fecundity rises as the mares age from 3 to 7 years, reaches a maximum in about the 8- to-11-year class, then declines somewhat in the older ages. But the foaling rates are generally lower in these range-reared animals.

These authors cited comparable statistics from other studies with percentages varying from 42.3 to 72.0 for herd means. In their own studies, annual mean percentages for the entire herd varied from 43.5 to 73.7.

Statistics of comparable volume and detail are not available for wild horse herds, but 3-year-old, 4-year-old, and herd foaling rates have variously been reported in the studies cited above. The manner of reporting has not been uniform among the studies, making comparison somewhat difficult in places. But it seems worthwhile detailing these results, recalculating where possible some of the authors' data in order to allow maximum comparison:

(i) Tyler (1972) detailed the age composition of the mares on her study area in each of the 3 years of her study (see her Table 1). The number of mares 3 years and older totaled 198, 211, and 219 in 1966, 1967, and 1968, respectively. She also reported the number of foals born in each of these years at 99, 109, and 84. These values produce annual foaling rates for 3-year-olds and older of 50, 52, and 38 percent. She states that "Most mares foaled for the first time when 3 or 4 years old, but some not until they were 5 years old." But since the foaling performance of these different age classes was not given, no other rates can be calculated. It should be pointed out that the colt foals were removed each year from this population, somewhat similar to the situation on Chincoteague National Wildlife Refuge, as discussed below.

(ii) Boyd (1980) reported that 11 percent (N = 9) of the 3-year-old mares under observation in 1978 foaled, 33 percent (N = 12) in 1979. In these years the percentage of 3-year-old and older mares foaling was 78 and 53; of the 4-year-olds and older, 86 and 55.

(iii) Keiper (1979) observed two populations on Assateague Island: (1) Those on the Assateague Island National Seashore (AINS, northern portion of island) which were unmanaged and allowed to pursue their own demographic structure and performance; (2) those of the Chincoteague National Wildlife Refuge (CNWR, southern portion of island) which were privately owned, mixed around each year presumably for husbandry purposes, and from which the foals were removed at the end of each summer for sale.

Table 2.3. Age-specific Percentages of Mares Bearing Foals Each Year in Range-Reared Domestic Horses (data from Speelman and others 1944).

Age[1]	No. Mares	% Bearing	Age[1]	No. Mares	% Bearing	Age[1]	No. Mares	% Bearing
3	4	25.0	9	78	65.4	15	24	50.0
4	99	56.6	10	67	67.2	16	18	61.1
5	125	57.6	11	56	69.6	17	12	41.7
6	105	58.1	12	47	57.4	18	7	0
7	96	60.4	13	40	50.0	19	2	0
8	94	70.2	14	29	58.6	20	2	50.0
						?	48	54.1

[1]This is the age at foaling. The foals were sired 1 year earlier.

Keiper reported foaling rates and numbers of mares for the two populations in his Table 4 as follows:

Year	AINS	CNWR
1975	58.8(17)	70.9(38)
1976	64.3(14)	81.0(37)
1977	70.5(17)	75.0(37)
1978	70.0(20)	---
1979	43.5(23)	70.8(24)
Mean	61.4	74.4

He attributed the differences between the two populations to the foal removal on CNWR, and resulting relaxation on the mares' physiological resources of not having foals suckling through the subsequent pregnancy. One might also speculate that the annual foal removal could have produced an older mare population with higher fecundity. The CNWR age composition was not given, and hence it is impossible to calculate age-specific fecundity rates for the population.

Such rates can be approximated for AINS, although we have encountered some difficulty in discerning the consistency between Keiper's Tables 1 and 4. He states in the footnote to Table 1 that all foals on AINS were from "mature" (4 and older) mares except for three born to 3-year-olds. The 5-year summary in this table lists 85 mature mares and 52 foals, for a foaling rate of 61 percent, the same mean as in Table 4 (see above). But Table 4 shows a 5-year total of 91 mares and 55 foals. Since the 5-year total of "immature" mares was 74 (his Table 1), and somewhere between a third and a half of these were probably 3-year-olds, the 91 in Table 4 cannot have been the combined 3-year-olds and older.

Since the 91 is close to the 85 "matures" in Table 1, we assume the fecundity rates in Table 4 and above are those for 4-year-olds and older, and are so recorded in our Table 2.4. If we assume conservatively that a third (25) of the 5-year total of 74 "immatures" in his Table 1 were 3-year-olds and add these to the 85 "matures," then the 52 foals constituted approximately a 47 percent 5-year-average foaling rate for the 3-year-olds and older (52/110 X 110). This would also imply a 3-year average 3-year-old foaling rate of somewhere around 12 percent (3/25 x 100).

(iv) Welsh (1975) provided the most detailed analysis of the fecundity of a wild horse herd, summarizing foaling rates over a 3-year period for 3-year-old mares, 4's, and the 5's and older which he called "adults." The results are as follows, the sample sizes given parenthetically after each rate:

	% Foaling By Year			
Age	1970	1971	1972	Mean
3	0(6)	19(16)	0(6)	11(28)
4	0(1)	50(6)	25(8)	33(15)
5+	63(76)	84(76)	52(45)	69(197)

In order to compare these with the results of other studies, which have combined results in slightly different ways, it is of interest to calculate the rates for 4-year-olds and older, and for 3-year-olds and older. We have done so as follows for the above columns:

3+	58(83)	71(98)	42(59)	60(240)
4+	62(77)	82(82)	47(53)	66(212)

(v) Feist and McCullough (1975) considered all mares 4 and older to be "adults," the 2- and 3-year-olds to be "immatures." In the year they observed the Pryor Mountain herd, 78 adult mares bore 33 foals, a foaling rate of 42 percent. In addition, two foals were produced by 3-year-olds. Although the 3-year-olds were not enumerated, the immature age class numbered 27 and we can hypothesize conservatively that about 10 of these were 3-year-olds. On this assumption, the 3-year-old foaling rate was somewhere near 20 percent, and the rate for all mares 3 years and older would be approximately 35/88 x = 40 percent.

(vi) Nelson (1979) observed 21 foals born to 38 "mature" (4 years and older) mares, a rate of 55 percent. Apparently no foals were born to younger mares. "Immature" animals numbered 14, and if as many as 5 of these were 3-year-olds, then the rate for all mares 3 years and older would be on the order of 21/43 x 100 = 49 percent.

(vii) Hall (n.d.) presented sex and age composition on the Pryor Mountain herd in 1971, and reported that 18 foals were seen in the area. Mares made up 40 percent of the herd of 80. Of the 80, 9 were 10 years or older, 42 were 4 to 9. Since 3-year-olds made up 9 percent of the herd, they numbered 80 x .09 = 7. If we apply the 40 percent female percentage, then the number of mares in each of these age classes approximated 4, 17, and 3, and totaled 24. The foaling rate for 3-year-olds and older therefore was on the order of 18/24 x 100 = 75 percent. There is no way to subdivide the rates any further.

All of these statistics are summarized in Table 2.4, and several generalizations seem justified. First, fecundity rates in wild horses appear to increase with age, at least in the first half to two-thirds of life, as we have seen is the case in confined and range-reared domestics. In the studies summarized in Table 2.4, the percentage of 3-year-olds foaling has varied between years and areas from 0 to 33 percent, and has averaged 13 percent. Most of the studies have not reported the rates for 4-year-olds, and the three values cited in Table 2.4 may or may not be typical. Judging by the abundant representation of rates for 4-year-olds and older, and for 5-year-olds and older, the rates in this latter class commonly rise above 60 percent, in individual years exceeding 80.

Because of these age-specific differences in fecundity, the rate one uses to express the performance of a given herd depends on the age classes included. The rate for the 5-year-olds and older animals can be expected to be higher than that for the 4-year-olds and older (the "adults" or "mature" animals of several authors), and in turn the rate for the 3-year-olds and older will be lower than that for the "matures." This is evident in Table 2.4. Furthermore, the rate for a herd will depend on its age composition: a herd with a large number of 3- and 4-year-olds is likely to have a lower rate than one with fewer of these ages and a greater number of older animals, other things being equal. Comparison between herds and years can only be precise when these variables are standardized.

Within these constraints, herd fecundity rates for the areas and years covered by the studies in Table 2.4 vary between 38 and 78 percent for the 3-year-olds and older animals, and average 54. The rates for the 4-year-old and older segments of the population vary between 42 and 86, and average 61.

Why fecundity in wild horses should be lower than that of confined domestics, and should vary markedly between years in some herds (cf. Welsh 1975, Boyd 1980), has been the subject of considerable speculation in the literature.

Several authors surmise that the main source of variation is not fertility, but the ability of the mare to carry a viable fetus to parturition. This ability, in the speculation of some, varies with weather conditions, food supplies, and perhaps the age of the mare. One gets the impression from reading the literature that reproduction is a heavy drain on the mare's physiological resources, and that added stress can result in abortion.

Thus Boyd (1980), citing published abortion rates of 10 percent in domestic horses, suspected the difference in foaling rates between her 2 years of study to have been due to variations in abortions and stillbirths resulting from the mild winter preceding the first study year, and a severe winter prior to the second. Keiper's (1979) suggestion that the higher foaling rate on CNWR was due to the removal of foals and release of mares from lactation, and consequent lower abortion rate was mentioned earlier. To Tyler (1972), abortions seemed "common" among New Forest ponies during late autumn, winter,

TABLE 2.4 Age-Specific and Herd Percentages of Mares Bearing Foals in Seven Wild Horse Studies. (See text for discussion of each and derivation of statistics.)

Source	Location and Year	% (and No.) of Mares Foaling by Age Class				
		3YO	3YO+	4YO	4YO+	5YO+
Feist & McCullough (1975)	Montana, 1970	20(10)[1]	38(88)[1]	-	42(79)	-
Hall (n.d.)	Montana, 1971	-	75(24)[1]	-	-	-
Boyd (1980)	Wyoming					
	1978	11(9)	78[2]	-	86[2]	-
	1979	33(12)	53[2]	-	55[2]	-
Welsh (1975)	Nova Scotia					
	1970	0(6)	58(83)	0(1)	62(77)	63(76)
	1971	19(16)	71(98)	50(6)	82(82)	84(76)
	1972	11(6)	42(59)	25(8)	47(53)	52(45)
Keiper (1979)	Maryland					
	1975	-	-	-	59(17)	-
	1976	-	-	-	64(14)	-
	1977	-	-	-	71(17)	-
	1978	-	-	-	70(20)	-
	1979	-	-	-	44(23)	-
	5-year mean	12(25)[1]	47(110)[1]	-	-	-
Nelson (1979)	New Mexico, 1977	0(5)[1]	49(43)[1]	-	55(38)	-
Tyler (1972)	Britain					
	1966	-	50(171)	-	-	-
	1967	-	52(167)	-	-	-
	1968	-	38(186)	-	-	-
Unweighted Means		13	54	25	61	66

[1]These values were calculated on the basis of certain assumptions. See text for derivation.

[2]No sample sizes given. The entire herd numbered 373 and 398 in the 2 years.

and early spring and could have been the major factor contributing to the low foaling rate. She actually saw nine aborted foals.

Welsh (1975) surmised that the differences in foaling rates between his 3 years of study (Table 2.4) were due to differences in abortion, these in turn resulting from poor nutrition and differences in severity of the three winters. The first was severe at the beginning but then eased, the second was mild throughout, and the third was long and severe throughout. Nelson (1979) observed differences in foaling between females that did and did not have access to revegetation areas. Females with access to these foaled a month earlier. They comprised 64 percent of the mature female population but contributed 73 percent of the foals.

Indications of a tenuous balance between the mare and her resources and the foal and its viability are suggested from several observations by these authors. In Welsh's study, the postnatal mortality of foals born to 3- and 4-year-old mares was higher than that for foals born to older females. In the first and third years of his study, abortion rates were higher and foal mortality lower, suggesting that the weak foals were lost before birth. In the second year, the abortion rate was lower, fecundity higher, but postnatal foal loss was the highest of the 3 years. In the middle year, half of the mares that foaled died, but only 18 percent of those that did not foal died.

While not endorsing the idea for her study, Boyd (1980) cites several authors (Klingel 1969c, Tyler 1972, Moehlman 1974, Nelson 1979) who have suggested that wild equid mares may commonly foal in alternate years. The phenomenon might reflect their inability to recover reserves sufficiently to bear a foal each year. She noted that older mares that foaled in May 1978 did not foal again until late 1979. One veterinarian has told us that if range-reared domestic mares are bred at 2 years of age and foal at 3, they are not likely to foal again at 4. It is not known whether these tendencies explain the fact that none of the herds summarized in Table 2.4 continued to foal during each year of observation at rates markedly above or below the means for the age classes.

Techniques are available for assessing pregnancy status of freshly captured wild mares and hence to allow estimates of probable natality rates. Appropriate data could be collected, in part, in connection with the adopt-a-horse program and with the projected burro removal operations. A single trained person with the capture teams could accomplish requisite sample collection and examination of the females. This could also be made a part of a capture program for marking purposes. It would be an essential part of field-testing contraceptives, since implanted pregnant animals would continue a normal pregnancy, delivery, and lactation but not return to heat. The effects of the contraceptive would not be evident until the following year in such animals.

(c) Foaling season. In captivity, some female domestic horses ovulate year-round with a cycle length of 21 to 22 days, but most tend to be seasonal depending on latitude. In the wild, this seasonality becomes strongly pronounced (Table 2.5), with May the major foaling month and over three-fourths of the foals commonly born in the 3-month period April to June. Even in the exceptional case of Sable Island, where young were born in all months of the year but January (Table 2.5), 77 percent were born during these 3 months.

In addition to the studies summarized in Table 2.5, Hall (n.d.) reported that the "majority" of mares had foaled in the Pryor Mountain herd (Montana) by mid-July. And Feist and McCullough (1975) found all of the foals born between 15 April and 30 June during their year of study on Pryor Mountain.

(2) Age Composition. In large areas where emigration and immigration are not important variables, the age composition of an animal population--numbers and percentages of animals in each age class--is produced by the interaction of its reproductive and mortality rates. Hence, in a general way it is indicative of the demographic characteristics of a population. More precisely, the age composition can be used to measure mortality or survival rates, provided that certain conditions hold within the population. These aspects will be explored shortly in the section on mortality.

At this point in our discussion, the subject of age composition is relevant to the question of herd fecundity. For as we have seen, fecundity appears to vary with the mare's age, and hence a herd's reproductive output and growth rate will depend on its age composition, or at least that of its mares.

For these reasons, we devote a substantial amount of space to an analysis of available information on age composition. This section covers the topic with respect to horses. Burros will be treated in a later section.

The BLM routinely determines the ages of horses brought in from herd roundups. Over the past few years, thousands of animals have been aged by the familiar tooth-aging method, and records are kept in BLM files on all of these animals. With BLM cooperation, we have obtained a large portion of this information and have summarized it in Table 2.6. These include animals gathered during 22 different periods and/or areas in four states. They total 4,825 females and 3,939 males, a sample equivalent to 15 percent of the 60,000 wild horses reported to occur in the western states.

In a normal age distribution, the numbers of animals in each age class should exceed the numbers in the next older class. The predominance of the 2-year-old class in these data (Table 2.7) indicates either that the foals and yearlings are not sampled in proportion to their abundance, or that the aging techniques are unreliable. Since there should be no problem with aging the foals, we are inclined toward the former explanation.

Wolfe (1980) used similar BLM roundup data to calculate survival rates from age structure. He, too, found the 0- and 1-year-old classes less numerous than the 2-year-olds.

A deficiency of foals and yearlings could occur in a localized population following 2 years of reproductive failure and/or low foal survival due to exceptional weather. But the fact that the data in

TABLE 2.5 Monthly Distribution of Foals Born in Five Studies of Wild Horse Herds

Month	Percent of Foals Born by Location and Source				
	Wyoming (Boyd 1980)[1]	Md.-Va. (Keiper 1979)[2]	NewMexico (Nelson 1979)	NovaScotia (Welsh 1975)[3]	Britain (Tyler 1972)[4]
January	0	0	0	0	0
February	0	0	0	1	0
March	0	0	0	1	2
April	9	17	33	20	
May	47	47	38	35	96
June	33	19	14	22	
July	7	11	10	10	2
August	4	4	5	6	1
September	1	3	0	1	0
October	0	0	0	2	0
November	0	0	0	1	0
December	0	0	0	1	0
No. in Sample	107	142	21	143	294

[1] 1979 only. 1978 not used because observation season delayed.

[2] 5-year average.

[3] 3-year average.

[4] Average for three studied breeding seasons. Winter births have been observed in New Forest ponies.

Tables 2.6 and 2.7 were taken over a 3-year period and a wide geographic range, the fact that 2-year-old predominance recurs in about two-thirds of the individual population samples, and Wolfe's similar result for other areas and years strongly indicates that it is a sampling artifact.

Beyond this, there is a strong predominance of animals in the younger age classes (Table 2.7) and a gradual decline in numbers in each successively older class. The sequence is not perfectly smooth, as there are slight divergences from the expected geometric rate of decline. But these could be due in part to sampling error and/or imperfections in the aging techniques. Overall, a gradual shrinkage occurs to the point where the number of animals in each age class 13 years of age and older constitute less than 1 percent of the total.

While the trends are more variable in the individual samples of Table 2.6, doubtless in part because the samples are smaller and more subject to sampling error, the general pattern shown in Table 2.7 tends to prevail in each of these smaller data sets. One can therefore infer that the pattern in Table 2.7 occurs widely over western horse herds.

Age composition from the available wild horse studies in the literature is based both on smaller samples and a failure to divide the data by each age class, as in Tables 2.6 and 2.7. But despite these deficiencies, they are of comparative interest and are summarized in Table 2.8.

Several generalizations may be drawn from this table, the first about the percentage of foals in the herds. Where the number of foals born is calculated as a percentage of a herd, it constitutes one measure of the reproductive output of that herd in that year. The values in Table 2.8 range from 13 to 23 percent, and average 17.1.

Secondly, this percentage can be used to calculate the percentage by which a given herd in a given year increases through reproduction from its numbers just before the foaling period to that immediately afterwards. The calculation is made by:

$$\frac{\%\ \text{Foals}}{100 - \%\ \text{Foals}} \times 100 = \%\ \text{Increase}$$

The calculated increase rate is a real property of a herd <u>only</u> if there is no mortality of adults during the foaling season, and <u>if</u> all foals survive. If there is mortality, then the percentage is only the potential by which the herd could have increased, and it overestimates the actual increase.

Furthermore, the percentages are <u>potential annual</u> rates of increase from herd size just before foaling to herd size at that point in the following year, <u>again on the condition that no mortality occurs during the year</u>. They therefore set upper limits on potential increase rates in the herds and years for which they are calculated. Bearing these conditions in mind, we can use the above equation to calculate <u>potential</u> increase rates for the herds in Table 2.8, recognizing that they overestimate the <u>actual</u> increase rates if there

TABLE 2.6 Age Composition of Horses Rounded Up During BLM Herd Reductions

State	District	Area	Date	Age Structure (Raw) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	MALES																							
WY	Rock Springs		1977	21	11	37	13	12	12	37	11	3	4	1	2	2	0	0	0	0	0	0	0	0
CA	Susanville		77-79	143	116	165	80	56	20	32	61	35	30	20	8	26	2	38	18	1	1	5	0	11
OR	Burns	S. Steens	1977	76	18	39	39	31	29	37	26	35	0	10	0	3	0	0	0	0	0	0	0	1
OR	Burns	S. Steens	1978	18	29	23	18	11	19	16	25	8	4	8	7	8	0	0	9	0	0	0	0	1
OR	Burns	S. Steens	1978	4	8	17	4	0	4	3	7	0	1	0	1	2	1	0	0	0	0	0	0	0
OR	Burns	Palamino Butte	1977	2	0	1	3	3	4	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0
OR	Burns	Stinking Water	1978	20	1	25	7	5	4	4	2	1	1	0	5	0	0	0	0	0	0	0	0	0
OR	Lakeview		1978	5	21	37	17	2	4	7	8	3	5	7	3	0	1	0	0	0	0	0	0	0
OR	Vale		1978	41	16	51	20	19	8	10	8	3	1	2	7	3	1	0	1	0	0	0	0	9
OR	Vale		1979	31	41	37	18	22	10	5	21	10	8	6	7	2	1	0	6	0	0	0	0	2
NV		Buffalo Hills	1979	5	2	11	3	1	0	1	10	12	4	3	0	4	0	0	0	0	0	0	0	0
NV	Ely	Monte Cristo	1979	1	5	14	1	2	1	1	1	5	0	2	2	0	0	0	0	0	0	0	0	0
NV		Gilbert Creek Manhatten	1979	24	3	31	23	6	12	6	15	11	8	7	0	2	0	0	0	0	0	0	0	0
NV		Palamino Valley	1977	174	79	162	129	88	30	47	52	50	42	24	21	9	1	1	0	0	0	0	0	0
NV		Pine Nut	78-79	3	12	19	9	4	0	3	5	6	2	4	0	0	0	0	0	1	0	0	0	0
NV		Battle Mt.	78-79	5	24	45	15	16	3	3	7	5	10	2	2	2	0	0	0	0	0	0	0	0
NV		Gosttute Ante. Valley	78-79	3	0	5	1	1	0	2	1	3	2	0	0	0	0	0	0	0	0	0	0	0
AZ	Phoenix	Burros	1979	50	34	53	28	23	16	11	13	4	2	4	2	9	1	1	4	0	0	1	0	1
CA	Susanville	Burros	1979	6	3	5	5	8	2	2	2	0	1	0	0	0	0	1	0	0	0	0	0	1
	FEMALES																							
WY	Rock Springs			25	8	35	9	18	2	10	18	1	9	2	0	3	2	0	0	0	1	1	0	0
CA	Susanville			74	125	174	141	106	47	93	94	45	34	20	11	18	2	19	7	1	0	4	0	0
OR	Burns	S. Steens	1977	70	15	47	57	40	41	44	19	37	1	34	0	12	0	1	1	0	0	0	0	0
OR	Burns	S. Steens	1978	28	24	26	30	18	27	22	24	11	1	14	3	8	1	0	2	0	0	0	0	0
OR	Burns	S. Steens	1978	0	3	18	7	6	4	5	1	2	0	1	2	0	0	0	0	0	0	0	0	0
OR	Burns	Palamino Butte		5	1	5	2	4	4	5	1	6	0	2	0	1	0	0	1	0	0	0	0	0
OR	Burns	Stinking Water		19	8	27	7	10	3	4	6	1	3	3	6	0	0	0	3	0	0	0	0	1
OR	Lakeview			14	10	16	12	9	8	6	6	2	3	0	4	1	0	0	6	1	0	1	0	1
OR	Vale		1978	47	13	44	39	27	7	17	19	2	1	2	6	0	0	0	6	0	0	0	0	3
OR	Vale		1979	39	30	47	32	28	9	15	24	4	8	7	22	9	4	0	7	0	0	0	0	1
NV		Buffalo Hills	1979	11	1	7	14	2	0	7	1	10	0	0	0	0	0	0	0	0	0	0	0	0
NV	Ely	Monte Cristo	1979	2	6	13	11	2	1	2	8	9	3	2	0	0	0	0	0	0	0	0	0	0
NV		Gilbert Creek Manhatten	1979	24	6	45	44	11	2	27	29	7	8	5	0	1	0	0	1	0	0	0	0	0
NV		Palamino Valley	1977	146	102	243	157	98	85	74	80	75	29	14	15	10	0	0	0	0	0	0	0	0
NV		Pine Nut	78-79	3	4	8	9	5	3	9	5	4	1	4	0	1	1	0	0	0	0	0	0	0
NV		Battle Mt.	78-79	5	25	78	26	10	6	17	19	20	5	5	2	2	0	0	0	0	0	0	0	0
NV		Gosttute Ante. Valley	78-79	2	0	6	3	1	1	1	3	3	4	0	0	0	0	0	0	0	0	0	0	0
AZ	Phoenix	Burros		51	38	81	44	34	38	33	27	15	7	14	4	10	3	1	4	1	0	0	0	4
CA	Susanville	Burros		9	3	5	5	3	4	2	3	1	0	0	1	0	0	1	0	0	0	0	0	2

TABLE 2.7 Summary of Wild Horse Age Composition Shown in Table 2.6

Age	Males No.	Males %	Females No.	Females %	Age	Males No.	Males %	Females No.	Females %
0[1]	632	16.0	575	11.9	11	67	1.7	76	1.6
1	423	10.7	422	8.8	12	72	1.8	76	1.6
2	777	19.7	925	19.2	13	8	0.2	13	0.3
3	433	11.0	649	13.5	14	41	1.0	22	0.5
4	310	7.9	434	9.0	15	38	1.0	38	0.8
5	178	4.5	292	6.1	16	2	0.1	3	0.1
6	229	5.8	393	8.2	17	1	0.0	1	0.0
7	276	7.0	387	8.0	18	6	0.2	6	0.1
8	195	5.0	255	5.3	19	0	0.0	0	0.0
9	125	3.2	117	2.4	20	26	0.7	12	0.3
10	100	2.5	129	2.7					

[1]Age 0 are foals.

TABLE 2.8 Age Composition of Wild Horse Herds

Source	Location and Year	F.A.B.[1]	F.S./F.[2]	Yrlg.	2s	3s	4+	Total Sample
		Percent in Each Age Class						
Feist & McCullough, 1975	Montana, 1970		13	11	⊢— 18 —⊣		58	270
Hall, n.d.	Montana, 1971		19	⊢——— 18 ———⊣			65	80
Boyd, 1979	Wyoming, 1978	23	16	-	-	-	-	373
	1979	18	15	-	-	-	-	398
Welsh, 1975	Nova Scotia, 1970-72[3]	16		12	9	8	-	12,678
Keiper, 1979	Maryland, 1975-79	17		16	⊢— 31 —⊣		37	315
Nelson, 1979	New Mexico, 1977	18		14	⊢— 20 —⊣		47	116
Tyler, 1972	Britain, 1966[4]	15		11	15	8	51	338
	1967[4]	17		9	10	13	51	329
	1968[4]	13		10	7	11	60	312
Wolfe, 1980	Western U.S.[5]	-	18	-	-	-	-	-
BLM	Western U.S.[6]	-	14	10	19	12	45	8,764
Means		17.1	15.8	11.6	12.0	10.4	51.8	
					⊢— 33.0 —⊣			

[1]Number of foals born as percentage of total herd.

[2]Number of foals in late summer or fall population as percentage of total herd.

[3]Three-year averages calculated from Welsh's Tables 54 and 55.

[4]The number of foals born each year was halved to estimate the number of females born. These were added to the female age compositions in Tyler's Table 1 to calculate the above percentages.

[5]Unweighted mean of percentages of 19, annual aerial counts in six states.

[6]From Table 2.7 in this report.

is any mortality. For the extremes (13 and 23), the potential increase rates are 15 and 30 percent. The average is 21.

A second point to be gleaned from Table 2.8 is that the percentages of late summer or fall herds which the foals constitute are lower, on the average (15.8 with a range of 13 to 19), than the percentages which the newly born foals comprise of the herds. This is doubtless due to mortality between birth and fall. Several authors (Tyler 1972, Welsh 1975, Keiper 1979) stress that most foal mortality occurs in the first month, indeed sometimes the first few days, of life. Thus, the fall foal percentage is only a rough indicator of herd natality. In some areas when foal mortality is especially high, the percentage may be more a reflection of foal mortality than of foal birth. In addition, any loss of older horses between the foaling season and fall is an additional variable affecting this statistic, tending to inflate it.

A third inference to draw from Table 2.8 is that the nonfoaling females of the herds (foals, yearlings, and 2-year-olds) average somewhere near 40 percent of the females, the exact figure depending on whether one uses the at-birth foal percentage or the late-summer/fall percentage. If the low-foaling 3-year-old females (Table 2.4) are added to this group, the new total makes up roughly half of the females and one-fourth of the herds. On average, therefore, the fully breeding 4-year-olds and older females (the "matures" of several authors) comprise only about one-fourth of most wild-horse herds.

(3) Survival. It is useful to consider two categories of survival data: those covering the first year and those covering all subsequent years.

(a) First-year survival. Appeal, once again, to data on domestic horses may suggest the maximum survival rates that could be expected of wild herds, with the actual values possibly lower. In the confined domestic herds cited above, where about 70 percent of bred mares bear young, foal mortality reduces the ratio to about 55 foals per 100 mares by the end of the foal's first year. This is a loss of about 21 percent, and a first-year survival rate of 79 percent. Speelman et al. (1944) report foal survival from birth to weaning in range-fed domestic herds at 87 percent.

Information on survival rates in wild herds comes from two sources, the first of which is direct observation of known individuals and/or herd segments in the intensively studied populations cited above:

(i) While not reporting total foal losses, Tyler (1972) concluded that most loss occurred in the first day of life.

(ii) Boyd (1979) reported the first-year survival rate of foals in 1978 to be 82.4 percent. Field work on the 1979 foal crop was not completed when she published, but survival to 2 months of age was 97.7 percent in that year.

(iii) Keiper (1979) also did not report total foal loss, but reported that 6 of 7 known foal deaths occurred in the first 3 weeks of life.

(iv) Welsh (1975) provides some of the most complete observations on foal loss, as follows:

Foals	1970	1971	1972	Means
No. born	48	70	25	--
% dying, 0-4 months	13	33	24	25
% dying, 4-16 months	10	51	11	24
% dying, 0-16 months	21	67	32	40

Except for what may be unusual 4 to 16-month losses in 1971, the loss rate in the early part of life is heavier than that after 4 months, although the latter is not insubstantial.

(v) Nelson (1979) observed no foal mortality between birth and September 1 among the 21 foals he observed in the Jicarilla herd in 1979.

(vi) Feist and McCullough (1975) recorded four foal deaths between birth and November 1 among the 35 foals he observed in the Pryor Mountain herd, a loss of 11 percent.

(vii) Hall (n.d.) had observed 18 foals on the Pryors in summer 1971. But at a November roundup of the entire herd, foals numbered 15, a number suggesting a loss of 3 (17 percent) during the period from July to November.

A second means of calculating survival rates is with age-composition measurements. In wild populations, the difference between number of foals at birth and the number of yearlings at the same date can be used to estimate first-year survival rate provided the population is a long unchanging one that has assumed a stationary age distribution from constant natality and mortality rates over a preceding period of several years. Few populations meet these criteria, and the ones from which we have cited age composition data do not. Thus Nelson's (1979) Jicarilla herd contained 21 foals and 16 yearlings, suggesting a 76 percent first-year survival rate (16/21 x 100 = 76). But his herd was increasing, a fact that would make this estimate conservative, and the numbers are small. The Pryor Mountain herd (Feist and McCullough 1975) contained 35 foals and 30 yearlings, implying an 86 percent first-year survival rate. The above reservations also apply here.

Keiper (1979) lists a 5-year total of 52 foals and 49 yearlings in the AINS population, implying a 94 percent first-year survival rate. Yet he observed 7 foal deaths, which would be 13 percent of the composite 5-year foal population, and he did not assume that he had seen all of the animals that died. (Note: annual survival rate s = 1 - a, the annual mortality rate. Both s and a are expressed as decimal fractions. Both can be multiplied by 100 to convert into percentages.)

Because of the apparent bias against foals and yearlings in the BLM roundup data (Tables 2.6 and 2.7), they cannot be used for calculating first-year survival. However, Wolfe (1980) used similar BLM roundup data to calculate survival rates from age structure. He, too, found the 0- and 1-year-old classes less numerous than the 2-year-olds, and for this reason we are reluctant to accept his low first-year survival estimates (see his Table 4 with a range of 28 to 70 percent, and a mean of 46).

But in his Table 2, Wolfe listed foal percentages based on herd-structure observations made in the field without rounding up the animals. The observations were made on 16 different populations in 6 states, some counted over a 3-year period and in many cases more than once a year. It would seem reasonable to assume that changes in those percentages between late summer after foaling, and the following late winter and spring, result at least in part from foal mortality. In 15 August counts, the mean foal percentage was 18.3 percent. In 17 January to March counts, the percentage declined to 13.3, and a reduction of 27 percent below the August mean. To what extent this could legitimately be taken as a 73 percent August-to-March survival rate is not known.

It is difficult to gain any balanced and precise overview of the magnitude of first-year survival from these disparate results. They are derived in many cases from small samples, span periods of time that vary from 2 months (Boyd in 1979) to 16 months (Welsh 1975), and in some cases involve assumptions that cannot be met or are of uncertain validity. Given these uncertainties, the 79 to 87 percent first-year survival rates in confined and range-reared domestics, Boyd's 82.4 percent first-year rate, Welsh's 79 to 33 percent 16-month rates, and the 73 percent rate calculated above from Wolfe's data suggest that 20 to 25 percent first-year mortality and 75 to 80 percent survival rates might not be uncommon.

It seems possible that this is a variable parameter, sensitive to a variety of variables including weather and range conditions, and responding to climatic and vegetative differences between areas.

Tyler (1972), emphasizing the importance of loss in the first day of life, observed congenital weaknesses and rejection by the mare as the main natural causes of early loss. Shooting and accidents were the more important human-related causes. She observed 6 foals older than one day that she believed were killed by stallions.

Boyd (1980) reported that 30 percent of known foal deaths occurred within the first week of life, 50 percent within the first month. Causes of 19 known foal deaths in 1978 were inexperienced mare (37 percent), congenital weakness (16 percent), miring in mud and accidents (26 percent), and winter debilitation (21 percent). Welsh (1975) reported lower survival of young in small and/or unstable herds, suggesting the role of social factors.

Boyd (1980) observed that some desertion occurs in summer when herds concentrate around water holes. Foals may get separated from their dams during the confusion and milling about, and the mares may leave the young behind when they disperse. She suggests that this tendency could increase as population size increases, thereby serving as one density dependent source of attrition.

The relationship described above between the mare's physical condition, her ability to carry a foal to birth, and herd natality may also be correlated with survival of foals brought to parturition. Thus, Welsh (1975) points out that Sable Island horses experienced different birth rates in the 3 years he observed them, attributing the differences to different abortion rates. In these same years, there was a rough inverse correlation between early foal survival and natality:

	1970	1971	1972
% 3 yr. + mares foaling	58	71	42
% foals surviving, 0-4 months	87	67	76

In Welsh's surmise, the weak foals were aborted in years with low natality, ultimately resulting in higher postnatal survival rates of the foals ultimately born. A somewhat similar pattern may be seen in Boyd's data:

	1978	1979
% 3 yr. + mares foaling	78	53
% foals surviving, 0-2 months	82	98

Hence there appears to be some evidence that natality rates and foal survival rates may be inverse to each other, at least in some cases.

Welsh further reported that the survival of foals born to 3- and 4-year-old mares is lower than that of foals from older mares. In this case, age-specific fecundity and subsequent foal survival are positively correlated, once again reflecting the dependency of the parameters on the mares' resources.

Establishing the magnitude of foal mortality more precisely, and its range of variation under different environmental pressures, would require lengthy and costly research. The most promising approach would probably be to capture large numbers of mares prior to foaling and determine which are pregnant. These would need to be marked or individually recognized by their color and structural characteristics, and then observed in the year after the foals are born in order to document birth and foal survival rates. It might be advantageous to telemeter the mares so that they could be readily located. A sample of 200 foals would not be large enough to provide very high statistical precision, since the confidence intervals around an estimated 80 percent survival rate at 0.025 probability level would be 74 and 85 (Mainland 1948). Yet, if only half of the mares foaled each year, 400 would need to be captured and tested in order to provide a sample of 200 foals.

An operation of this magnitude would provide an estimate of first-year foal survival for one population for 1 year. Gaining some view of the extent of year-to-year variation would require similar efforts for each of several years, and determining the extent of variation between areas would require such effort at numerous sites around the West.

(b) Survival of yearlings and older animals. Survival in older animals can be estimated with the two approaches used above for first-year survival estimates: direct observation of known individual or herd segments and analysis of age structure. Information from the first source is fragmentary, but is of some value:

(i) During her 3 years of observation, Tyler (1972) detected the death of 40 "older" ponies while she captured and saved 3 that were in dire straits. This is 43 out of a 3-year composite population of 979, a mortality rate of 4 percent (43/979 x 100), and an annual survival rate of 96 percent.

(ii) In Keiper's (1979) study, he observed 11 ponies 1 year and older that died over a 4-year observation period. This constituted a known mortality of 3 percent in the composite population of 315 for that time period, and a maximum survival estimate of 97 percent.

(iii) Welsh (1975) constructed time-specific life tables to calculate mortality rates in the Sable Island herd. We have calculated mean annual mortality rates from these by dividing the number of 0- to 4-month animals in his K l_x columns by the total numbers in those columns. The results suggest 16.2 percent mean annual mortality for mares (from his Table 54), 11.2 percent for males (from his Table 55), and 13.4 percent for the entire population. The corresponding survival rates are 83.8, 88.8, and 86.6 percent.

(iv) Feist and McCullough (1975) observed the death of one mare between May 1 and November 1, 1970, out of the Pryor Mountain herd of 270 animals.

(v) Nelson (1979) observed the death of 3 older animals in the Jicarilla herd of 116, while 3 more disappeared during his spring and summer observations. This could imply 5 percent loss through less than half of the year, and a maximum survival rate of 95 percent during this period.

In a stationary (constant) population with stable age distribution, the percentage of 1-year-olds in that portion of the population 1 year and older is equivalent to the mean annual mortality rate for that portion of the population. While neither of these conditions may be precisely true of the Pryor Mountain (Feist and McCullough 1975) and Jicarilla herds (Nelson 1979), the yearling percentages may give rough approximations of the mean annual mortality rates (Table 2.9). These are small samples, and if they were taken from increasing populations (and the Jicarilla was increasing) they overestimate the mortality rates. Hence the mean, annual adult survival rates for those animals 1 year of age and older appears to be around 80 to 90 percent or higher.

Table 2.9 Percentage of Yearlings Among Yearlings and Older Horses, Pryor Mountain and Jicarilla Herds.

Area	Sex	No. 1 Yr.+	No. Yrlgs.	Yrlg. %	0.25 Conf. Intl.
Pryor Mountain[1]	Females	125	19	15	9-22
	Males	110	11	10	5-17
Jicarilla[2]	Females	61	9	15	7-27
	Males	34	7	21	9-38

[1]From Feist and McCullough (1975).

[2]From Nelson (1979).

Similar calculations cannot be made with the data in Table 2.7 because of the inadequate representation of yearlings described above. But adult survival rates can be crudely calculated for those age classes from 2 through 12 years by transforming the numbers of animals in each class to logarithmic form, and regressing these values on age. The slope of the line estimates the mean, annual instantaneous mortality rate. Converting back to anti-logarithmic form provides the mean, annual finite survival rate for the 2 to 12 age classes. The regression for the mares produces an r^2 of 0.919 and a calculated, annual survival rate of 78 percent. The same values for the stallions are $r^2 = 0.926$ and an 80 percent annual survival rate. These values will be underestimates if the populations are increasing, and are not statistically different.

Wolfe (1980) used the Chapman-Robson method (Robson and Chapman 1961) to calculate similar rates in 2- to 9-year-old animals from 6 herds in 4 states. His results average 75 percent for 3 mare samples, 67 percent for 2 groups of stallions, and 74 percent for 3 herds of mixed sex.

These results collectively suggest adult survival rates of 67 to 80 percent per year. If the herds are increasing, these are underestimates. The degree of underestimation to be expected for survival rates calculated from age data when the population is increasing can be calculated as:

$$S^* = S e^{-r}$$

where S^* = apparent survival, S = true annual survival, and r = annual rate of increase. For example, if $S = 0.98$ and $r = 0.20$, then the apparent survival rate is 0.80. If $S = 0.90$ and $r = 0.15$, then the apparent rate is 0.77.

In sum, the evidence on mortality of yearlings and older animals is more equivocal than that on foals, and more elusive to generalize. At the least, one can say unequivocally that some loss has been detected in every herd that has been studied. With the exception of Feist and McCullough's single loss in a 7-month period, values of 3 to 5 percent known losses over periods of several months to a year recur in several studies and constitute the lowest in a range of available values. Estimates of 11 to 25 percent annual mortality and higher have been derived from several analyses, but depend on various assumptions of uncertain validity.

Mortality of these older animals, like the first-year rates, are doubtless subject to some between-year and between-area variation associated with weather, climate, and forage differences. However, we suspect that they are less sensitive to these environmental variables than the first-year rates, and are themselves less variable. Elucidating their magnitudes and ranges of variation more precisely would again require lengthy and costly research, probably most effectively carried out with radio telemetry. Once again, large sample sizes would be needed to provide estimates with narrow confidence intervals, and repeated annual studies in a number of areas would be needed to disclose the patterns of temporal and spatial variation.

(4) Sex Composition. The sex ratio of wild horses shows a slight preponderance of males in the first year of life (Table 2.10). As the animals age, the percentage of males gradually declines, reaching a low point somewhere around 4 to 6 years of age (see BLM data in Table 2.10). This shift suggests higher mortality and/or dispersal of males during this series of years. After the 4 to 6 ages, the percentage of males appears once again to increase progressively through life (BLM data in Table 2.10).

Welsh (1975) emphasized the reproductive hazards to which the mares are subject, suggesting that the costs of pregnancy and lactation may increase female mortality rates. It may be no coincidence that the shift toward males in the sex ratios begins after the 4 to 6 age classes. It is at age 5 that half or more of the mares begin to bear colts (Table 2.4).

Welsh (1975) observed that almost half the Sable Island mares that foaled in 1971 died, while 18 percent of those that did not foal died. Final cause of death was attributed to heat loss and starvation. Autopsies on 32 dead adults and 15 foals revealed that all but one had little body fat, and bone marrow fat levels ranged between 2.4 and 41.6 percent. Many had contracted spleens that lacked lymphoid follicles and had large amounts of hemosiderin. However, Welsh emphasized that food quality was similar between years and was rarely if ever limited in quantity. He attributes the susceptibility to starvation to the climatic differences between the mild winter of

TABLE 2.10 Age-Specific Sex Composition in Wild Horse Herds

<table>
<tr><th></th><th colspan="6">Percent Males ± 0.025 Confidence Limits by Age</th></tr>
<tr><th>Source</th><th>Foals</th><th>Yrlgs.</th><th>2-3</th><th>4-6</th><th>7-10</th><th>11 +</th></tr>
<tr><td>BLM Data[1]
(No. Animals)</td><td>52.4±4
(1207)</td><td>50.1±4
(845)</td><td>43.5±3
(2784)</td><td>39.1±2
(1836)</td><td>43.9±3
(1584)</td><td>49.4±5
(445)</td></tr>
<tr><td>Pryor Mtn.[2]
(No. Animals)</td><td>54.3±16
(35)</td><td>36.7±16
(30)</td><td>43.8±15
(48)</td><td colspan="3">49.7±8
(157)</td></tr>
<tr><td>Jicarilla[3]
(No. Animals)</td><td>57.1±21
(21)</td><td>43.8±25
(16)</td><td>41.7±16
(24)</td><td colspan="3">30.9±13
(55)</td></tr>
</table>

[1]From Table 2.7.

[2]From Feist and McCullough (1975).

[3]From Nelson (1979).

1971 and the severe winter of 1972, and the number and intensity of spring storms.

Whatever the mortality causes contributing to the sex-ratio changes in Table 2.10, the sex ratio for the entire sample in Tables 2.6, 2.7, and 2.10 is 55.0 percent female. A preponderance of females is common in a wide range of mammalian species and indicates higher male mortality rates.

The nearly balanced sex ratio in the older age classes in Table 2.10 suggests that unweighted mean, age-specific mortality rates for the two sexes and all age classes would be similar. This was already suggested by the similar slopes computed from regression analyses described above. But because such a large fraction (76 percent in Table 2.10) of the population is concentrated in the foal to 6-year-old age classes when the male-specific mortality appears higher and the sex ratio increasingly favors females, the weighted mean, annual mortality rate for the population would appear to be higher in the males than in the females. But Welsh's (1975) life-table analyses cited above in section (3)(b)(iii) contradict this conclusion.

(5) Population Trend. As mentioned above, the question of the rates at which horse herds increase has been one of the more disputed ones in the controversy surrounding the wild horse issue. Annual increase rates of 20 percent or more, apparently originating from the management agencies, have been cited fairly widely, but their origin and basis have been difficult to track down. Some are based on census results. Ryden (1978:294) describes one BLM estimate based on censuses of 20 percent increase between 1974 and 1975. Cook (1975) and Heady and Bartolome (1977) cite annual increase rates of 20 to 30 percent. Wolfe (1980) calculated finite, annual increase rates (λ) from BLM census data on 12 populations in 6 states which ranged from 1.08 (8 percent) to 1.30 (30 percent), and averaged 1.22 (22 percent) per year, but he was critical of the results.

In order to investigate further what preliminary inferences could be drawn from the agency censuses, we obtained data from 10 BLM districts and one national forest. These data include censuses of 67 horse herds, 3 burro herds, and 2 areas which contained both species (Table 2.11). The districts involved are Susanville and Riverside, California; Burns, Vale, and Lakeview, Oregon; Salmon, Idaho; Billings, Montana; Rock Springs, Wyoming; Salt Lake City, Utah; and Ely, Nevada. The national forest is the Humboldt in Nevada. These were selected on the recommendation of BLM officials as being representative and among the ones with the more complete data series.

The number of years through which each herd was censused varied between 1 and 11, and between 1 and 18 counts were taken of each herd. Most of the herds had been counted over 4 to 7 years.

Analyses disclosed several biases and uncontrolled variables that will be discussed in some detail in a later section on census. However, the two main problems need to be mentioned here:

(a) Inconsistent counting seasons. The first is a problem already detected by Ryden (1978:294). In a seasonally breeding animal

TABLE 2.11 Census Data on 72 Wild Horse and Burro Herds Obtained from BLM and Forest Service Files.

AREA	DISTRICT	STATE	AGENCY	YEAR	TOTAL COUNT	FOALS	YEARLING	ADULT	SEX RATIO (M:F)	STATS? MARKING?	CENSUS METHOD	SPEED	HOURS	FLIGHT PATTERN	# OBSERVERS	TOPO-VEGETATION	SEASON, CONDITIONS	INTERVIEWED?	ACCURACY	CAVEATS
Warner Lakes Res. Area	Lakeview	Ore.	BLM	1974	309	55		254									Feb., p. cloudy, snow			recent rain
				1975	334	86		248									Aug.			
Bluejoint Burro Herd				1978	48	10		38					3.0		2		Sept. clear - p. cloudy			
High Desert Res. Area	Lakeview	Ore.	BLM	1971	81	10		71			Air		3.8			junipers	Oct. hot still			estimates 11-20 more are
				1972	57	9		46			air						Apr.			for foal count, and to
Paisley Dale (Whiskey Hills)				1972	121	32		89			air		3.0				Oct. overcast, cool			[illegible] herd. good coverage
				1973	102	11	18	73			182 Cessna		3.4		3		Apr. cool cloudy			rain
				1973	70	11	5	54			182 Cessna		3.1		2		July hot dry			
				1973	102	14	7	81					3.75				Nov. patchy snow			poor conditions
				1974	219	49	7	163			182 Cessna		3.1		2		July calm			accurate
				1975	208	60					182 Cessna		3.5		3		July			accurate
				1977	53	5	5	43			Aeloft		3.0		3 + 1		Apr.			
				1978	67	8	8	57			Aeloft		3.1		2 + 1		July hot hazy			
Andrews Res. Area	Burns	Ore.	BLM	1972	35						fixed wing						Jan.			315,336 acres
Pueblo Mts.				1973	30						-									
				1974	60						helicopter									
				1975	66						-									
				1976	88						-									
				1977	67						-									
Andrews Res. Area	Burns	Ore.	BLM	1972	303						fixed wing; helicopter						Jan.			counts made by Vale District
Sheepshead Mts.				1973	191						-									
				1974	89						-									50,330 acres
				1975	108															
				1976	239															
				1977	(606 were combined with Alvord)															
Andrews Res. Area	Burns	Ore.	BLM	1974	177						fixed wing						Jan.			186,930 acres
Alvord				1975	202						-									
				1976	(242 proj.)															
				1977	(606 combined with Sheepshead)															
John Day Res. Area	Burns	Ore.	BLM	1973	176	15		159			helicopter					rough, brushy	Jan.			
				1973	75												Nov.		low	
Murderer's Creek				1974	171	(Forest Service also)											Mar.			low elevation winter range BLM land.
Riley Res. Area	Burns	Ore.	BLM								helicopter						Jan.			
Warm Springs			Horses	1975	153 (est. 200)	1	18	134												
			Burros	1975	12 (est. 30)	0	0	12												
Riley Res. Area	Burns	Ore.	BLM	1975	103 (est. 125)	0	23	80									Jan.			
[illegible] Buttes				1976	88 (est. 100)	0	15	73									Jan.			
Warner Lakes Res. Area	Lakeview	Ore.	BLM	1969	528						flown (?)		over 2 days				Oct.	Yes Art [illegible] Mark [illegible] 8/29/79	missed approx. 30.	area covered fairly well
				1970	463						-						Aug.			
		North Warner Mts:		1972	201	66		233			helicopter(?)						Mar.			
West [illegible] Burro Herd				1970	87						helicopter						Feb.			
				1970	60												Dec.			
				1971	64	9		55						similar flight patterns			Oct.			
				1972	44	6		38									Mar.			
				1972	77(94)	14(17)		63(77)									Oct.			
				1973	107	25		82									Apr.			
				1973	96	16		80			helicopter				2 + 1		Aug.			good coverage
				1973	93	9		84									Dec. good day			good coverage
				1974	133	23		110			182 Cessna		3.5		2 + 1		Aug.			
				1975	155	27		128			182 Cessna		2.0		2 + 1		Aug. good clear			
				1976	122	21		101			182 Cessna		3.1		2 + 1		Aug. good p. cloudy			rain previous days
				1977	75	15		60			helicopter						Aug.			
				1978	275	36							3.0		2		Sept. clear, p. cloudy			recent rain

TABLE 2.11 (cont.).

AREA	DISTRICT	STATE	AGENCY	YEAR	TOTAL COUNT	FOALS	YEARLING	ADULT	SEX RATIO (M:F)	STATS?	MARKING?	CENSUS METHOD	SPEED	HOURS	FLIGHT PATTERN	# OBSERVERS	TOPOG-VEGETATION	SEASON, CONDITIONS	INTERVIEWED?	ACCURACY	COMMENTS
[illegible]	Burns	Ore.	BLM	1972	28					yes		fixed wing			count area to determine location of bands, repeat on a more intensive level for count.	same observers		Jan.	yes R. Harding B. Phillips 8/30/79	not complete	considered good. [illegible] acres fenced pastures. [illegible] and [illegible] found in this area. Horses use 1/1 forage. [illegible] concept. Horse - Deer winter range.
				1973	44	7		37				"						Apr.		"	
Smyth Creek Herd.				1974	100							helicopter						Jan.		"	
				1975	104	17		87				"						Jan.		fairly accurate	
				1975	129	24	6	100				"						July		accurate	
				1976	129	24	7	98				"						Jan.		"	
				HERD REMOVED 91 HEAD JUNE 1976								"									
				1977	41	6	1	34										Feb.			
[illegible]	Burns	Ore.	BLM	1972	30	4		44		yes		fixed wing			same as above	same as above		Jan.	same as above	fair accurate	considered good data 1300 Acres, [illegible] and [illegible] herd [illegible] and [illegible]
				1973	25	2		23				"						Apr.	"	not accurate	
East Kiger Herd				1974	73	1	2	70				helicopter						Jan.		fair accurate	
				1974	94	16		78				horseback						May		accurate	
				1974	21	4		17	66:100			herd thinned during this period						Fall		"	[illegible] of [illegible] concept. with deer for winter forage prior to reduction
			100% count	1975	21	2		19				helicopter						Jan.		"	
				1975	26	5	1	20				"						July		"	
				1976	27	6		21				"						Jan.		"	
				1976	42	12		30				horseback						July		never may not be current	
				1976	31	8		23				on foot						Nov.			
				1976	34	8		26				fixed wing						Nov.		accurate	
												helicopter						Feb.		"	
[illegible]	Burns	Ore.	BLM	1972	72					yes		fixed wing			same as above	# and personnel varied		Jan.	same as above	Prob. not complete	
				1973	72	5		67				"						Apr.		"	
Riddle Mtn. Herd				1973	87							"						July			
				1974	191							helicopter						Jan.		accurate	
				1975	192	45		147				"						Jan.		"	
				1975	260	46	9	205				"						July		"	
				1976	235	30	24	193				"						Jan.		"	
				1976	46	2	3	41				"						July		one pasture only	
				1977	[illegible]	9	11	66				"						Oct.			
[illegible] Area	Burns	Ore.	BLM	1972	267							fixed wing						poor conditions in part of area			212,215 Acres
				1973	216							"									
S. Steens Area				1974	445							helicopter									Ideal climatic conditions for many offspring
				1975	376							"									
				1976	482							"									
				1977	900							"									
				1978	290							"									
[illegible] Area	Burns	Ore.	BLM	1972	214																292,160 acres
				1973	257							fixed wing									
Catlow				1974	434							"									
				1975	344							"									
				1976	440							"									
				1977	265							"									
												?									
[illegible]	Lakeview	Ore.	BLM	1971	223	61		162				182 Cessna						Oct. clear			covered well, 10-40 missed (est.)
				1972	329	80		288										Oct.			
Beaty Butte Herd				1973	366	25	64	279										Apr.			
				1974	413	85		328		yes				5		2 + 1		Jan. clear cold snow			
				1974	482	110		372		yes		182 Cessna		4		2 + 1		Aug. cool clear			
				1975	641	117		494		yes		182 Cessna		4.3		2 + 1		Aug. cool clear			good coverage
				1976	708	176		388		yes		182 Cessna		4.25		2 + 1		Aug. clear calm			recent rain
				1977	879	180		690				172 Cessna		4.2		2 + 1		Sept. overcast, p. cloudy			recent rain
				1978	273	64		229				182 Cessna		3.0		2 + 1					
[illegible]	Lakeview	Ore.	BLM	1972	148																not well covered
			Horse gathered	1973	182													Mar.			
				1973	329	91		288										Mar.			
[illegible] Horse Herd				1973	385													Aug.			
		40 head removed		1975	336	110		414										Oct. - Nov.			
		120 gathered		1976	430	100		330				182 Cessna		3.5		2 + 1		Aug. cool, p. cloudy			
		[illegible] more gathered		1978	371	92		279										Feb.			
												182 Cessna		3.0		2 + 1		Sept. cool clear			
		100 removed																			
[illegible]	Lakeview	Ore.	BLM	1971	186	36		150										Oct.			
				1972	267	65		202										Oct.			
				1973	281	27	40	214										Apr.			
[illegible] Horse Herd				1973	306	83		223										Aug.			
				1974	331	73		258				182 Cessna		5		2		Aug. good			
				1975	334	86		248				182 Cessna		3		3 + 1		Aug.			
				1976	353	81		272				182 Cessna		3.1		2 + 1		Aug. cool, p. cloudy			good coverage
																					good coverage

TABLE 2.11 (cont.).

AREA	DISTRICT	STATE	AGENCY	YEAR	TOTAL COUNT	FOALS	YEARLING	ADULT	SEX RATIO (M:F)	STATS?	MARKING?	CENSUS METHOD	SPEED	HOURS	FLIGHT PATTERN	# OBSERVERS	TOPOG.-VEGETATION	SEASON, CONDITIONS	STRATIFIED?	ACCURACY	COMMENTS
Jackies Butte	Vale	Ore.	BLM	1972	94	16		78				fixed wing			concentration areas. 2-3 observers used			Feb.			38,[illegible] acres
H.M.A.				1973	113	27		86				-						Feb.			
				1974	160	27		113				-						Apr.			
				1975	222	36		186				helicopter(?)						Apr.			
				1976	280	72		208				-						Aug.			
		127 removed		1977	201	56		145				-						Nov.			
				1978	235	37		198				-									
Barren Valley/ Sheepheads	Vale	Ore.	BLM	1972	539	104		435				Fixed wing						Jan.			619,770 acres
				1973	660	169		491				-						Jan.			
Alvord (inconjuction with Burns District)				1974	1217	249		968				-						Apr.			
				1975	1128	176		952				Helicopter(?)						Apr.			
		72 removed		1976	1453	323		1130				-						Aug.			
		201 removed		1977	795	177		618				-						Nov.			
				1978	955	176		779				-									
Morger Allotment	Vale	Ore.	BLM	1972	80	12		68				Fixed wing						Feb.			26,172 acres
H.M.A.				1973	85	13		72				-						Jan.			
				1974	151	27		124				helicopter						Oct.			
				1975	147	19		128				"?						Apr.			
		202 removed		1976	1	0		1				"?						Aug.			
Stockade	Vale	Ore.	BLM	1972	10	0		10				Fixed wing						Feb.			26,[illegible] acres
H.M.A.				1973	13	0		13				-						Jan.			
				1974	44	6		38				helicopter						Oct.			
				1975	54	5		49				"?						Apr.			
		1 removed		1976	60	9		51				"?						Aug.			
				1977	70	13		57				"?						Nov.			
				1978	74	11		63				"?						Sept.			
Hog Creek	Vale	Ore.	BLM	1972	18	3		15				Fixed wing						Feb.			18,120 acres
H.M.A.				1973	35	5		30				-						Jan.			
				1974	55	15		40				helicopter						Sept.			
				1975	70	6		64				"?						Apr.			
				1976	76	18		58				"?						Aug.			
		62 removed		1977	63	19		64				"?						Nov.			
				1978	80	14		66				"?						Aug.			
Cold Springs	Vale	Ore.	BLM	1972	71	19		52				Fixed wing						Sept.			21,160 acres
H.M.A.				1973	105	25		80				-						Jan.			
				1974	164	62		122				helicopter						Sept.			
				1975	230	29		201				"?						Apr.			
				1976	301	55		246				"?						Aug.			
		257 removed		1977	86	10		76				"?						Nov.			
				1978	69	5		64				"?						Aug.			
Pot Holes H.M.A.	Vale	Ore.	BLM	1972	17	2		15				fixed wing						Feb.			3,240 acres
				1973	21	2		19				fixed wing						Jan.			
				1974	19	6		13				helicopter						Sept.			
				1975	22	3		19				"?						Apr.			
				1976	23	4		19				"?						Aug.			
				1977	25	4		21				"?						Nov.			
				1978	41	7		34				"?						Aug.			
Basque H.M.A.	Vale	Ore.	BLM	1972	6	0		6				Fixed wing						Feb.			7,530 acres
				1973	6	1		5				Fixed wing						Jan.			
				1974	28	7		21				Helicopter						Sept.			
				1975	33	5		28				"?						Apr.			
				1976	37	9		28				"?						Aug.			
				1977	46	13		33				"?						Nov.			
				1978	43	6		37				"?						Aug.			
Lake Ridge H.M.A.	Vale	Ore.	BLM	1972	11	0		11				Fixed wing						Feb.			2,770 acres
				1973	4	0		6				-						Jan.			
				1974	5	2		3				Helicopter						Sept.			
				1975	12	1		11				"?						Apr.			
				1976	16	4		12				"?						Aug.			
				1977	15	3		12				"?						Nov.			
		26 removed		1978	0																

TABLE 2.11 (cont.).

AREA	DISTRICT	STATE	AGENCY	YEAR	TOTAL COUNT	FOALS	YEARLING	ADULT SEX RATIO (M:F)	STATS? MARKING?	CENSUS METHOD	SPEED	HOURS	FLIGHT PATTERN	# OBSERVERS	TOPO-VEGETATION	SEASON, CONDITIONS	INTERVIEWED?	ACCURACY	COMMENTS
Cottonwood Basin	Vale	Ore.	BLM	1972	2	0		2		Fixed wing						Feb.			2,100 acres
H.M.A.				1973	0	0		0		"						Jan.			
				1974	1	0		0		"						Apr.			
				1975	0	0		0		Helicopter?						Apr.			
				1976	0	0		0		"?						Aug.			
				1977	1	0		1		"?						Nov.			
				1978	1	0		1		"?						Aug.			
Cottonwood Creek	Vale	Ore.	BLM	1972	19	?	?	15		Fixed wing						Feb.			5,440 acres
H.M.A.				1973	34	7		27		Fixed wing						Feb.			
				1974	50	8		42		Helicopter						Sept.			
				1975	50	9		49		"?						Sept.			
				1976	64	16		47		"?						Aug.			
				1977	91	28		63		"?						Nov.			
				1978	71	16		57		"?						Aug.			
Shaffer Mtn. H.M.A.	Susanville	Calif.	BLM	1973	5	0		5		Helicopter			large flat areas	3	high level table	Feb.	yes		12,000 acres
possibly all claimed				1973	9	1		8		"			laid out in E-W	3	lands to rough	Aug.	Laura		
				1974	5	0		5		"			grid.	3	broken lava	Aug.	Lofthouse		
				1975	6	0		6		"			Mountainous	3	outcrops. Salt	Feb.	[illegible]		
				1975	8	0		6		"			flown up & down	3	desert shrub, Sagebrush	Aug.	[illegible] York Horse 5/25/79		
Fort Sage Mts.	Susanville	Calif.	BLM	1973	9	0		9		Helicopter				3	grassland,	Feb.			17,200 acres
H.M.A.				1973	8	0		8		"				3	juniper,	Aug.			
				1974	15	2		13		"				3	bunchgrass	Aug.			
				1975	11	1		10		"				3		Feb.			
possibly unauthorized use by domestics				1975	37	6		31		"				3		Aug.			
				1978	71	10		60											
Ravendale H.M.A.	Susanville	Calif.	BLM	1973	10	0		10		Helicopter				3		Feb.			28,600 acres
				1973	10	1		9		"				3		Aug.			
				1974	12	1		11		"				3		Aug.			
				1975	11	1		10		"				3		Feb.			
possibly unauthorized use by domestics				1975	24	2		22		"				3		Aug.			
				1978	26	2		24											
Round Mountain	Susanville	Calif.	BLM	1973	56	5		51		Helicopter				3		Feb.			7,600 acres
H.M.A.				1973	15	0		15		"				3		Aug.			
				1974	N/C	—		—		"				3		Aug.			
				1975	103	17		86		"				3		Feb.			
				1975	N/C	—		—		"				3		Aug.			
New Years Lake	Susanville	Calif.	BLM	1973	31	1		30		Helicopter				3		Feb.			343,000 acres
H.M.A.				1973	60	9		51		"				3		Aug.			
				1974	120	26		94		"				3		Aug.			
				1975	51	11		40		"				3		Feb.			
				1975	118	22		96		"				3		Aug.			
				1975	169	33		136											
				1977	98	18		80											
				1978	52	6		46											
Massacre Lake	Susanville	Calif.	BLM	1973	116	17		99		Helicopter				3		Feb.			130,000 acres
H.M.A.				1973	127	27		100		"				3		Aug.			
				1974	137	31		106		"				3		Aug.			
				1975	167	28		119		"				3		Feb.			
				1975	148	30		118		"				3		Aug.			
				1977	214	39		175											
				1978	172	21		151											
High Rock H.M.A.	Susanville	Calif. Nevada	BLM (1)	1973	136	19		117		Helicopter				3		Feb.			231,000 acres
			(1)	1973	177	35		142		"				3		Aug.			
			(1)	1974	207	27		180		"				3		Aug.			
			(1)	1975	215	38		177		"				3		Feb.			
			(1)	1975	236	44		192		"				3		Aug.			
			(2)	1977	265	47		216											
			(2)	1978	286	46		235											

TABLE 2.11 (cont.).

AREA	DISTRICT	STATE	AGENCY	YEAR	TOTAL COUNT	FOALS	YEARLING	ADULT	SEX RATIO (M:F)	STATS? MARKING?	CENSUS METHOD	SPEED	HOURS	FLIGHT PATTERN	# OBSERVERS	TOPO-VEGETATION	SEASON, CONDITIONS	INTERVIEWED?	ACCURACY	COMMENTS
Fox-Dog Mts. H.M.A.	Susanville	Calif.	BLM	1973	87	22		65			Helicopter				3		Feb.			94,000 acres
				1973	112	20		92			"				3		Aug.			
				1974	109	19		90			"				3		Aug.			
				1975	107	24		83			"				3		Feb.			
				1975	135	23		112			"				3		Aug.			
				1977	124	19		105												
				1978	72	11		61												
Soledad H.M.A.	Susanville	Calif.	BLM	1973	222	29		193			Helicopter				3		Feb.			130,000 acres
				1973	179	32		147			"				3		Aug.			
				1974	228	41		187			"				3		Aug.			
				1975	223	31		192			"				3		Feb.			
				1975	287	56		231			"				3		Aug.			
				1975	510	87		423												
				1977	347	73		274												
				1978	175	17		158												
Twin Peaks H.M.A.	Susanville	Calif.	BLM	1973	834	64		770			Helicopter				3		Feb.			Burros (160) 771,000 acres
				1973	1491	295		1196			"				3		Aug.			(106)
				1974	2023	409		1614			"				3		Aug.			(176)
				1975	1925	287		1638			"				3		Feb.			(170)
				1975	2687	648		2039			"				3		Aug.			(191)
				1977	2633	510		2123												(167) 4 miles
				1978	1654	168		1486												(123) 2 miles
[illegible] Planning Unit	Ely	Nev.	BLM						m/f		Helicopter						Feb.		est. missed 142	
Sand Spring H.U.				1973	302	53	27	302	173/127		"						"			
Pogonip Herd Unit				1973	14	2	1	11	6/5		"						"			
Bullcreek H.U.				1973	77	11	5	66	35/26		"						"			
White River H.U.				1973	7	1		6	4/2											
Whitepine Division	Humboldt	Nev.	Forest	1975	34	5		29	50/50	none	Helicopter						Jan.			
	National		Service	1975	55	13	4	38	50/50		"						Aug.			
Granite Mts.	Forest			1976	57	14	4	39	50/50		"						Jan.			
Wildcat Mts.	Humboldt	Nev.	Forest	1975	11	3		8	50/50		Helicopter						Jan.			
	National		Service	1975	0	0		0	50/50		"						Aug.			
	Forest			1976	11	3	1	7	50/50		"						Jan.			
[illegible]	Humboldt	Nev.	Forest	1975	14	4		10	50/50		Helicopter						Jan.			
	National		Service	1975	34	3	3	28	50/50		"						Aug.			
	Forest			1976	14	1		13	50/50		"						Jan.			
English Village	Humboldt	Nev.	Forest	1975	53	9		44	50/50		Helicopter						Jan.			
	National		Service	1975	52	10	5	37	50/50		"						Aug.			
	Forest			1976	32	4	4	24	50/50		"						Jan.			
Wig Mts.	Humboldt	Nev.	Forest	1975	83	13		70	50/50		Helicopter						Jan.			
	National		Service	1975	79	7	5	67	50/50		"						Aug.			
	Forest			1976	82	8	5	69	50/50		"						Jan.			
Wasatch Res. Area	Saltlake	Utah	BLM	1975	40	6	2	32			Aerial					rough/dense	Aug.		est. 30% missed	
				1977	46	10	4	32			aerial						July			
Squirrel Mts.				1978	14	2	0	12			aerial						July			
				1979	12	0	3	9			ground						Feb.			
Wasatch Res. Area	Saltlake	Utah	BLM	1974	77	17	3	57			Aerial						Aug.			
				1976	103	26	10	67			aerial						Aug.			
Onaqui Mts.				1977	115	20	10	85			aerial						July			
				1978	114	17	12	85			aerial						July			
Wasatch Res. Area	Saltlake	Utah	BLM	1975	173	31		142			Army helicopter						Jan.			
				1975	165	13	20	132			"						Aug.			
Cedar Mts.				1975		4	4	10	removed		"						Oct.			
				1976	134		24	110			"						Jan.			E. side of Cedars not flown
				1976	17	1	2	14			"						Apr.			
				1976	219	41	16	162			"						June			
				1976	54	burros died					"						July			
				1977	124		22	102			"						Feb.			
				1977	146	29	8	109			"						July			
				1978	169	—	32	137			"						Feb.			
				1978	164	31	17	116			"						July			
				1978	48	removed											Aug.			
				1979	132		27	105												

TABLE 2.11 (cont.).

AREA	DISTRICT	STATE	AGENCY	YEAR	TOTAL COUNT	FOALS	YEARLING	ADULT	SEX RATIO (M:F)	STATS? HABITAT?	CENSUS METHOD	SPEED	HOURS	FLIGHT PATTERN	# OBSERVERS	WHO-OBSERVATION	SEASON, CONDITIONS	INTERVIEWED?	ACCURACY	COMMENTS
Salt Wells Res. Area	Rock Springs	Wyo.	BLM																	
				1972	579						Cessna 205				2 + 1		Feb.			
				1974	1030															
Aspen Mtn.				1977	horses removed during this period						Super Cub						Feb.			
				1978	300						Cessna 206		10.5		2 + 1		Feb. snow			
				1979	624															
Salt Wells Res. Area	Rock Springs	Wyo.	BLM	1977	horses removed during this period															
				1978	122						Super Cub						Feb.			
				1979	160						Cessna 206		3.3				Feb. snow			
Black Butte																				
Salt Wells Res. Area	Rock Springs	Wyo.	BLM	1971	157						Aerial						July		752	10,000 acres
		counted by Rawlins Resource		1974	602						helicopter		7.3				Feb.			
				1975	603						helicopter		7.4				Feb.			
Adobe Town				1977	603						Cessna 206						Feb.			
[illegible]		788 removed		1978	500						Super Cub						Feb.			
				1979	879						Cessna 206		14.1		2 + 1		Feb. snow			
Kemmerer Res. Area	Rock Springs	Wyo.	BLM	1972	83												Feb.			
				1975	126										3		Mar.			
Cumberland				1978	87						Super Cub						Jan. snow - spotting difficult			
				1979	167						Cessna 206		5.6				Feb.			count low
Kemmerer Res. Area	Rock Springs	Wyo.	BLM	1972	52												Feb.			
				1975	41						aerial				3		Mar.			
Slate Creek				1978	64						super cub ?						Mar. snow - difficult			low
				1979	51						Cessna 206		7.5 with Carter		2 + 1		Feb. snow			
Kemmerer Res. Area	Rock Springs	Wyo.	BLM	1972	15												Feb.			
				1975	40						aerial				2 + 1		Mar.			
Carter				1978	60						aerial - Super cub?						Mar.			
											Cessna 206		7.5 with Slate Creek				Mar.			
Kemmerer Res. Area	Rock Springs	Wyo.	BLM	1972	34															
				1975	292						Aerial				2		Feb.			
Granger (split for aerial census after 1975 into S. and B.)				1978	96						super cub?						Mar.			
				1979	46						Cessna 206		3.6		2 + 1		Mar.			
				1979	19						Cessna 206		6.6		2 + 1		Mar.			
Rock Springs Totals				1977	6263															
				1978	5459															
				1979	6019															
Pryor Mountain	Billings	Mont.	BLM	1969	218	2		216			Helicopter			start after	2 + 1		Jan.	yes		
				1969	215	0		215			"			10:00 a.m.	2 + 1		Mar.	Bud Brown		
Wild Horse Range				1969	232	24		202			"			Start low			June	area manager		
				1970	131	4		127			"			work up mtn.			May	9/6/79		
				1970	142	15		127			"						Sept.			
				1971	137	2		135			"						Mar.			
				1971	170	18		152	m f		"			Start daylight			July			
				1974	135	26		109	30/79		"			up - down	2					
				1976	143			143	48/95											
				1977	171			171	99/103		Super Cub?						Mar.			
				1977	100	22	9	78			"						May			est. 150 total
				1977	90	3		87			"						June			
				1977	108	17		91			"					•	Dec.			Alts rough
				1977	68	15		53									Jan.			
				1978	130-143	25														
		winter 1977-78		1978	89				34/60											
		severe		1979	86				26/49											
				1979	80-85	9														
				1979	no count															
Three Fingers	Vale	Ore.	BLM	1972	66	2		64			Fixed wing			don't fly in snow			Feb.	yes 8/31/79		70,000 acres
				1973	120	25		95			Fixed wing			Flat country N-W			Feb.			
H.M.A.				1974	234	55		179			"			Grid pattern.			Apr.			
				1975	444	65		379			helicopter(?)			where horses known			Apr.			
		removed 260		1976	223	37		188			"			fly indiscriminately			Aug.			estimate 444
				1977	299	74		225			"			to find			Nov.			
				1978	344	39		305			"						Aug.			est. total = 350

TABLE 2.11 (cont.).

AREA	DISTRICT	STATE	AGENCY	YEAR	TOTAL COUNT	FOALS	YEARLING	ADULT SEX RATIO (M:F)	STATS' MARKING?	CENSUS METHOD	SPEED	HOURS	FLIGHT PATTERN	# OBSERVERS	TERRAIN-VEGETATION	SEASON, CONDITIONS	INTERVIEWED?	ACCURACY	COMMENTS
Pinedale Res. Area LaBarge Herd	Rock Springs	Wyo.	BLM	1970 1976 1977 1978 1979	50-60 33 37 91 76					air Cessna 206 Cessna 206		1.9	(1978 description) district broken up into smaller areas to be covered in 4-5 hours. Use natural boundaries	2 + 1 2 + 1		Feb. Feb. snow cover excellent	yes Kim Bros 9/5/79	incomplete	accurate counts because small size of area; nature of country, numerous roads
Pinedale Res. Area Desert Herd	Rock Springs	Wyo.	BLM	1971 1975 1975 1976 1977 1978 1979	110 160 336 208 208 209 273					fixed wing Cessna 206 Super Cub 106* Cessna 206		5(?)	1-2 should do entire county; able to read map; should fly 200ft. up. Should be done in Feb.	2 + 1		Mar. Feb. Aug. Feb. Feb. Feb. snow			10-12 claimed
Big Sandy Res. Area (Green River Res. Area) Little Colorado Desert	Rock Springs	Wyo.	BLM	1972 1974 1975 1975 1977 1978 1979	248 339 254 446 663 446 623					Super Cub Cessna 205 Cessna 206 Super Cub Cessna		6.5 10.1	North-South Grids	2 + 1 2 + 1		Feb. snow Feb. Feb. Aug. Feb. Feb. Feb. snow		possibly incomplete	576,000 acres
Big Sandy Res. Area (Green River Res. Area) (Farson Res. Area) Oregon Buttes	Rock Springs	Wyo.	BLM	1971 1972 1974	300 635 901					Cessna 205			5 - 5 Grid	2 + 1		Feb. Feb.			
Big Sandy Res. Area Triangle	Rock Springs	Wyo.	BLM	1977 1978 1979	53 36 43					Super Cub 150 Cessna 206		3.5	this & Gold Creek	2 + 1		Feb. Feb. snow			
Big Sandy Res. Area Gold Creek	Rock Springs	Wyo.	BLM	1977 1978 1979	14 15 13					Super Cub Cessna 206		3.5	this plus Triangle	2 + 1		Feb. Feb. snow			
Big Sandy Res. Area Continental Peak	Rock Springs	Wyo.	BLM	1977 1978 1979	1311 1200 1302					Cessna 206 Super Cub Cessna 206		9.5		2 + 1		Feb. Feb. Feb. snow			
Big Sandy Res. Area 12 Mile (+, old Superior unit)	Rock Springs	Wyo.	BLM	1977 1978 1979	(262) horses removed during this period 728 588					Super Cub Cessna 206		4.3		2 + 1		Feb. Feb. snow			
Big Sandy Res. Area Superior (broken up after 1976) (into Superior and 12 mile)	Rock Springs	Wyo.	BLM	1972 1976 1977 1978 1979	357 758 horses removed during this period 334 266					Cessna 205 Super Cub Cessna 206		3.7	N-S Grids	2 + 1 2 + 1		Jan. snow deep Feb. Feb. Feb. snow			
Big Sandy Res. Area Wells Unit	Rock Springs	Wyo.	BLM	1977 1978 1979	horses removed during this period 326 352					Super cub Cessna 206		2.5		2 + 1		Feb. Feb. snow			
Big Sandy Res. Area Pilot Butte	Rock Springs	Wyo.	BLM	1972 1976 1977 1978 1979	579 1038 horses removed during this period 497 533					Cessna 205 Super Cub 150 Cessna 206		5.4		2 + 1 2 + 1		Feb. Feb. Feb. Feb. snow			
Salt Wells Res. Area Firehole	Rock Springs	Wyo.	BLM	1978 1979	32 11					Super Cub Cessna 206		2.6		2 + 1		Feb. Feb. snow			

TABLE 2.11 (cont.).

AREA	DISTRICT	STATE	AGENCY	YEAR	TOTAL COUNT	FOALS	YEARLINGS	ADULT SEX RATIO (M:F)	STATS? MARKING?	CENSUS METHOD	SPEED	HOURS	FLIGHT PATTERN	# OBSERVERS	TOPO-VEGETATION	SEASON, CONDITIONS	EXPERIMENT?	ACCURACY	COMMENTS
[illegible] Crisis [illegible] Area - White Pine District	Ely - Humboldt National Forest	Nev.	BLM/ Forest Service	1973 1975	30 141	11 7	5 7	61 127	(11 unclassified)	Fixed wing helicopter						Jan. Mar.			
Challis Fair	Salmon	Idaho	BLM	1971 1972 1973 1974 1975	150 214 274 353 407	 60 79 62	 18	 196 (274) (345)		Fixed wing " " " Helicopter						Spring			
Providence, Woods & Hackberry Mtns.	Riverside Barstow	Calif.	BLM	1974	47					Bell helicopter		9	orderly lines, roughly following topography 30 - 100' up.		gently sloping to rugged	June clear, hot light wind			160,000 acres concentrated at Major Springs
Granite Mts.	Riverside Barstow	Calif.	BLM	1974	83					Bell helicopter	25-40 kn	2 days	60 - 100' up		gently sloping to rugged	June excellent			concentrated at Major Springs.

population, numbers increase during the breeding season and decline during the remainder of the year due to mortality. Comparisons between years must be made at the same stage of the life cycle in order to avoid bias from this seasonal cycle in numbers. The counting season has not been standardized in much of the agency census work, counts being made early in some years prior to foaling, in other years being made after foaling.

(b) Variation in aircraft used. Some herds were censused in the early years with fixed-wing aircraft, and in later years with helicopters. In some of the censuses in Table 2.11, the method was not specified. Analysis in the later section on census shows an abrupt increase in the years in which helicopter counts replaced fixed-wing counts, indicating that this method is considerably more efficient at detecting horses.

Viewed uncritically, about half of the census series in Table 2.11 tended to increase during the census years, about a fourth were roughly stationary, and about a fourth tended downwards. In the last two cases, a number of the declines were caused by sudden, 1-year reductions, and one wonders whether a number of these were due to actual removals that were not recorded in the files we saw. The general impression is that the census values tend to increase, and Ryden (1978:295) concedes that the prevailing evidence points to increases in horse herds since 1971 despite her suspicions about the precise validity of the agency censuses.

In the 72 herds shown in Table 2.11, there are 25 sets of consecutive census years that (a) span 3 or more years, (b) were taken with either fixed-wing aircraft or helicopters throughout, and (c) in which the census season was held reasonably constant (i.e., prefoaling or postfoaling). These 25 sets are as follows, labeled by the BLM district and herd name:

SUSANVILLE
- Tuledad: 73-75
- Shafter Mtn.: 73-75
- New Years Lake: 73-75
- Massacre Lake: 73-75

BURNS
- Smyth Creek: 74-76
- Riddle Mtn.:: 74-76
- S. Steens: 74-77
- Catlow: 72-76

LAKEVIEW
- Beaty Butte: 74-77
- Bluejoint: 74-76
- West Hogback: 73-75

SALMON
- Challis: 71-74

VALE
- Three Fingers: 72-74
- Three Fingers: 76-78
- Cottonwood Creek 74-78
- Jackies Butte, 72-74
- Stockade: 74-78
- Hog Creek: 74-78
- Cold Springs: 74-76
- Pot Holes: 74-78
- Basque: 74-78
- Lake Ridge: 74-77

BILLINGS
- Pryor Mtn.: 69-71

ROCK SPRINGS
- Desert: 76-78
- Continental Peak: 77-79

We converted the individual census values for each of the 25 sets (15 3-year, 4 4-year, and 6 5-year sets) to logarithmic form and regressed them over time to calculate 25 slopes (and therefore 25 instantaneous rates of change). Both a slope coefficient (b) and its variance were calculated for each set. A weighted average slope ($\bar{b}$) was calculated by

$$\bar{b} = \sum_{i=i}^{25} b_i w_i \Big/ \sum_{i=i}^{25} w_i \quad \text{where}$$

$$w_i = \frac{1}{\text{var}\ (\bar{b})}$$

The variance of the weighted mean $\bar{b}$ was then calculated by

$$\text{var}\ (\bar{b}) = \sum_{i=1}^{25} w_i \ (b_i - \bar{b})^2 \Big/ \left((n-1) \sum_{i=1}^{25} w_i \right)$$

This enables calculation of 95 percent confidence intervals about the mean rate of change. Finally, the mean rate of change, its confidence intervals, and the individual rates were taken to calculate finite rates of change and confidence intervals.

Of the 25 calculated rates of change, 22 were positive while 3 were negative. The weighted, mean annual finite rate of change (λ) for the 25 sets and 0.05 confidence interval is 1.162±.001, suggesting a 16 percent mean, annual rate of increase.

The 25 sets were subdivided into the fixed-wing and helicopter censuses, and the unweighted means for these two groups were +22 percent (9 sets) and +15 percent (16 sets), respectively. The group was also subdivided into a group censused in the earlier years (1971-75), the intermediate years (1974-76), and recent years (1975-79). These showed increase rates of +25 percent (4 sets), +18 percent (6 sets), and +15 percent (15 sets).

These two subtests are confounded because of the prevalence of fixed-wing censuses in the earlier years, and helicopters in the later. Hence it is difficult to say whether this apparent chronological trend is a function of changing techniques or actually declining increase rates.

While helicopter counts appear to be more efficient at finding animals, and a change from fixed-wing to helicopter censuses obviously increases the number of animals seen, no such change is involved in the 25 tests. They were restricted to sets of fixed-wing-only or helicopter-only counts. Hence the declining increase rates would appear to be attributable to other causes. At least three factors are conceivable:

(a) Increased counting skill. It seems possible that censusing proficiency increased in the early years when agency personnel were first conducting the counts. Hence, the higher apparent increase rates of the early years could result from increasing census efficiency, herd growth, or both. Frei and others (1979) have previously presented evidence to show that observers experienced in horse census see a larger fraction of the animals than inexperienced observers.

(b) Increased visibility of large herds. The herd-size bias discussed later in the section on census could be increasing the proportion of horses seen. If the populations have increased, the herd sizes may have grown and their visibility increased.

(c) Increased herd density. There may be an actual density-dependent reduction in herd growth. As they increase and begin to press the limits of their food resources, their reproductive and survival rates may be ebbing somewhat.

All of this is fraught with uncertainties. There are many unknowns about the accuracy, precision, and validity of the census results. But one might think that more weight could be given to the trends implied by the counts, which thereby would serve the function of indices, than the absolute accuracy of census values themselves. This would acknowledge that there may be biases in the counts, but would assume that those biases are relatively constant.

However, these results and the earlier views on rates of increase contrast sharply with the findings of Nelson (1979), Conley (1979), and Wolfe (1980), who used a more deductive, less empirical approach. They calculated rates of horse population increase using Lotka method and Leslie matrix techniques, respectively. These authors used fecundity rates like those cited above, giving most credence to limited, first production of young at 3 years of age, and about 50 percent of all older mares bearing young each year. They then calculated the increase rates that would occur from the interaction of these fecundity rates with a range of survival rates.

Both authors found the increase rates resulting from "probable" fecundity and survival rates to fall in a range well below 10 percent per year. Only with unrealistically high fecundity rates in Wolfe's calculations, and survival rates approaching 100 percent in Conley's case, could annual increase rates well above 10 percent be attained. They concluded that rates of herd growth as high as 20 percent per year, like those suggested by both agency personnel and a number of authors, were beyond the biological capability of large, established herds which had assumed remote approximations of geometric age structures.

In a further effort to determine what increase rates may be for large segments of the western horse populations, we performed life-table calculations from the age-specific fecundity and survival schedules discussed above. The goal was to calculate r, the instantaneous rate of change, and from it λ, the finite rate of change. Calculations were performed as follows:

$r = (\log_e R_o)/T$ where

R_o, the net reproductive rate = $\sum_{x=o}^{20} l_x m_x$ where

x = age

l_x = probability of survival to age x

m_x = number of female young produced by a female of age x

T, the mean generation length, $\sum_{x=o}^{20} l_x m_x x \Big/ \sum l_x m_x$

$\lambda = \text{antilog}_e r$

Three sets of fecundity schedules were used in these exploratory analyses, in descending order of fecundity rates: (a) a "maximum" schedule involving rates that seemed, on the basis of reports reviewed above, as high as could be expected from any horse herd, namely 25 percent of 3-year-olds foaling, 60 percent of 4-year-olds, and 80 percent of 5-year and older animals; (b) the fecundity schedule of range-reared domestics summarized in Table 2.3; and the average of the seven wild-horse studies reported in Table 2.4. In the latter case, the 13 percent of 3-year-olds and the 66 percent of 5-year and older mares were used. But the mean (25 percent) in Table 2.4 for 4-year-olds was based only on three measurements of small numbers of animals, and thought perhaps to be too low by chance. Hence a 50-percent rate was used for this age class. These schedules would seem to be in the high range for reported wild-horse fecundity, and higher than that used by Conley (1979) in his analyses.

A range of survival rates was used that appeared to fall in the higher range of values reviewed above. Nine combinations of rates were used with each of the three fecundity schedules: (a) annual "adult" survival rate of 1.0 and first-year rates for foals of 1.0, 0.95, 0.90, 0.80; (b) annual "adult" survival rate of 0.95 and first-year rates of 0.95, 0.90, 0.80; and (c) annual "adult" survival rate of 0.90 and first-year rates of 0.90 and 0.80.

In total, finite increase rates (λ) were calculated for 27 combinations of fecundity and survival rates (see Table 2.12).

The results are similar to those of Conley (1979) and Wolfe (1980) who used similar rates, and like theirs must be considered somewhat abstract. The second and third columns of rates are based on observed fecundity schedules but, because survival rates are imperfectly known, are based on somewhat hypothetical or "for instance" survival rates. The values also apply to hypothetical populations that have age distributions resulting from the fecundity and survival rates used in each test. And finally, population students will recognize that our equation for r produces only an approximation of this parameter. With the somewhat problematic precision of the fecundity and survival rates we have used, we did not engage in the more time-consuming iteration of the r values in the discrete-time form of the Leonhard Euler equation.

To what extent do these rates simulate increase rates of real-world herds? They do so to the extent that the fecundity and survival rates in real herds are similar to those in Table 2.12, and age structures in the herds approximate the exponential series

TABLE 2.12 Annual Finite Rates of Population Increase (λ) Possible Under Differing Rates of Fecundity and Survival

Annual Survival Rates		Annual λ Values by Fecundity Rates[1]		
1 Yr.+	Foal	Max. Fecund.[2]	Range Dom.[3]	This Study[4]
1.0	1.0	1.17	1.16	1.16
	.95	1.17	1.15	1.15
	.90	1.16	1.14	1.14
	.80	1.15	1.13	1.13
.95	.95	1.13	1.11	1.11
	.90	1.09	1.07	1.07
	.80	1.03	.96	.97
.90	.90	1.09	1.06	1.06
	.80	.99	.96	.96

[1]These are the multiples by which the population would increase each year. To change them to annual percentage increase, subtract 1.0 and multiply the remainder by 100.

[2]25 percent of 3-year-old mares foaling, 60 percent of 4-year-olds, and 80 percent of 5-year-olds and older.

[3]Fecundity rates of range-reared domestics shown in Table 2.3.

[4]The 3-year and 5+ averages shown in Table 2.4. A 50 percent rate was used for 4-year-olds.

produced by those rates. As we have said, the fecundity schedules are approximately those of the herd reported by Speelman and others (1944), the averages of seven wild-horse studies, and a hypothetically high set. We have reviewed the available data on herd survival rates above, and the range of values shown in Table 2.12 would appear to represent the higher, more conservative rates. The age distributions in Tables 2.6 and 2.7, and those reported in Table 2.8, while not exactly smooth, geometric series and subject to the foal and yearling biases, still constitute shrinking frequency distributions that crudely resemble exponential or geometric series.

If one were to select the fecundity and survival rates that seem to be indicated by the field data on wild horses discussed above and general experience with wild animal populations, one would probably select the right-hand fecundity schedule in Table 2.12. All studied herds have been found to experience some mortality, and a 0.95 survival rate for the older animals and 0.9 or 0.8 for foals would seem justified, if not conservative, from the available studies.

Yet these combinations produce increase rates well below 10 percent ($\lambda = 1.10$) per year, and considerably below the rates implied by the censuses. Rates similar to those indicated by the censuses are produced only in Table 2.12 combinations of virtually no mortality. A 20 percent per year increase rate requires that no mortality occur, and that half of the 3-year-olds and 100 percent of mares 4 years and older produce young each year. Since even domestic herds sustain some mortality and less than 100 percent fecundity, it is difficult to reconcile the differences between the Table 2.12 results and the census rates.

In general, wild horses have rather conservative demography by the standards of most mammalian species. This conservatism is imposed by the following characteristics: only one foal is normally borne; not all "mature" females produce one foal each year; and the age of sexual maturity is delayed, with only a small fraction of 3-year-olds bearing young and the 4-year-olds being the first effective breeding age. Since some young are produced each year, any herd that has been in existence for 4 years or more will have foal, yearling, and 2-year-old components, which are included in the total from which herd increase rates are calculated, but which contribute nothing to the immediate increase. As Tables 2.6 and 2.7 have shown, these become sizeable components of wild herds. In particular, the late maturity date is a strong determinant of the increase rate, as Cole (1954) has shown. And Conley's (1979) calculations that the reproductive output of females older than 11 years of age is an insignificant contribution to the increase rate also match with Cole's findings.

We are not able at this stage to explain the difference between the herd increase rates predicted in Table 2.12, and in Conley's (1979) and Wolfe's (1980) projections on the one hand, and those implied by the censuses on the other. The problem will only be resolved by more intensive research both on horse demography and the census methods. But it needs resolution because it bears on several important management issues.

One such issue is the size of the 1971 horse population. Some observers have been advocating that horse herds be reduced to the levels that prevailed in the year when the Wild and Free-roaming Horse and Burro Act was passed. That population size could be approximated by projecting backward from a known 1979 population, using the appropriate rate of population increase. The BLM has been reporting that wild horses in the western United States increased from a total of about 17,000 animals in 1971 to a total of 58,000 in 1978 or 1979. Projecting backwards from a 1979 population of 58,000 horses with an annual increase rate of 16 percent produces a 1971 population of 17,116. If the more conservative increase rate of 15 percent derived from recent, helicopter counts is used, the 1971 population would have been 18,960. If the 1979 census is conservative, as it is likely to be to an unknown degree, the 1971 projections are similarly conservative.

But if an annual increase rate of 7 percent is more realistic, then the 1971 population was something approaching twice that projected by a 16 percent increase rate. Ryden (1978:295) has already suggested that the 1971 population estimates may be conservative.

A second way in which increase rates are relevant to management is the rates at which herds must be reduced in order to maintain them at decided-upon levels. If a policy decision determines that a given herd must be maintained at some specified level by removing the annual increment, the number of animals to be removed annually and the associated cost will obviously be very different depending on whether the herd increases by 7 percent or 16 percent each year.

We conclude that research on both demography and census are needed to resolve this question. In the case of demographic studies, data on reproductive rates can be obtained quite readily as indicated below. Determining survival rates will be more expensive and will require more time.

Feral Asses

As with horses, there is abundant information on the demographic characteristics of domestic donkeys. But the evidence on wild herds is more fragmentary than that on wild horses and considerably less exists than is needed to develop firm generalizations on their demography. Most of the information on wild populations is based on studies in six areas. While thorough and intensive, these have necessarily dealt with small numbers (in most of the cases, less than 200 animals), and for short periods of 1 to 3 years. This data shortage is all the more tantalizing in light of intriguing hints of fundamental differences between burro and horse demography which, if real, may reflect the different ecogeographic origins of these two species.

(1) Fecundity:

(a) Age at first female breeding. Burro mares commonly begin sexual activity at about 1 year of age. Moehlman (1974) observed sexual activities in jennies at 11 months of age in Death Valley, as did Woodward (1976) at 10 to 12 months in the Chemehuevi Mountains of California, and Morgart (1978) at 1.5 years in Bandelier National Monument, New Mexico. Since gestation is approximately a year, as in the horse, the potential age of first foaling is between 2 and 2.5 years, 1 year younger than that in wild horses; and this potential has been realized to some degree in most cases so far studied.

Although Moehlman (1974) found typical age of first foaling to be 3.5 to 4 years during her study in Death Valley--a situation once again similar to the horse--other authors have observed jennies foaling at 2 years of age. Woodward (1976) considered 2 years (N = 4) to be the first age of foaling in a young population where 75 percent of a sample of 20 "adult-sized" animals were 3 years old or younger. Douglas and Norment (1977) found one jenny foaling at less than 3 years of age in Death Valley. In Seegmiller's study (in litt.), a female that had been captured and aged 5 months earlier was seen with a newborn foal when she was about 25 months old. Ruffner and Carothers (1977) found "reproductively active" (pregnant or lactating) jennies between 1 and 2 years of age. And among 666 burros rounded up on the BLM Phoenix District, which we will detail later (Table 2.16), 8 of 81 jennies judged to be 2 years old were followed by foals. Since a third of the foals in the herd had become separated from their dams, and foals were underrepresented in the sample, it is possible that more of the 81 2-year-olds had borne young.

(b) Age-specific and herd fecundity. Shorter periods of study, smaller samples, and failure of most studies to subdivide the mares into as many age classes as have the horse investigators make the discernment of age-specific fecundity schedules in burros more difficult. But further analysis of the different authors' data permits a fragmentary and tentative picture:

(i) Moehlman (1974:56-58) found no foaling by 2-year-olds, as mentioned above. Only in the third year of her study (1972), and that a partial year, did she observe foaling by 3-year-olds (two jennies). In 1970, 63 percent of "adult" (i.e., 4-year-olds and older) jennies bore young. In 1971, this percentage dropped to 47, and when 2- and 3-year-olds were included, the percentage was 41. While fragmentary, these results suggest the same pattern we observed in horses: an increase in fecundity as mares advance through the early age classes. Thus, Moehlman found no foaling in 2-year-olds, limited reproduction in 3-year-olds, and somewhere around half of 4-year-olds and older mares bearing foals.

(ii) Woodward (1976:42) observed 14 jennies of "coltbearing age" (2 years old and older), of which 79 percent were accompanied by foals in the Chemehuevi Mountains (California) population she studied. Elsewhere, she generalized that jennies produced foals on the average of every 16.2 months, and this produced an annual natality rate of 75 percent foaling (Woodward 1979b).

(iii) Douglass and Norment (1977:30) concluded that 56.8 percent of females foaled in the 12-month period 1 November 1975 to 31 October 1976 in the Wildrose-Emigrant population of Death Valley. Since he observed one mare foaling before 3 years of age, we assume the rate applies to all 2-year-olds and older females. In a radio-collared sample of 10 females in 1976, 9 (90 percent) foaled.

(iv) Morgart (1978:33) reported 77 percent of the "adult" females on his study area bearing foals. Since 23 young were dropped (p. 29) this implies a sample of 30 jennies. Since three 2-year-olds foaled, we assume the term "adult" applies to 2-year-old and older females. Of a sample of 11 "potentially reproductive" marked females, 8 (73 percent) foaled in 1975.

(v) Seegmiller (1977:24) reported an "adult" (2 years+) population of 58 burros on his study area in the Bill Williams Mountains of western Arizona. Since 57 percent of these were females, the "adult" jenny population was 33. While he studied the population for 14 months and 20 foals were born in the period, 16 were born in the 12-month period June 1974 through May 1975. Hence the 1-year natality rate was 16/33 x 100 = 48 percent for 2-year-olds and older jennies.

Seegmiller did not age all of, or determine the number of, 2-year-olds in the population. But he did ascertain the yearling population at about 15. If we make some allowance for mortality and herd growth, there could have been abut 10 or 12 2-year-olds. Hence, the three 2-year-olds producing foals probably constituted a material fraction of that age class.

(vi) McCort (1980:24) reported a 1975 population of 27 2-year-old and older female burros on Ossabaw Island (Georgia). Between May 1975 and May 1976, these animals bore 16 foals. Hence the natality rate was 16/27 X 100 = 59 percent for the year.

(vii) The 81 2-year-old jennies accompained by 8 foals in the BLM roundup data cited above suggest a minimum of 10 percent foaling in that age class of that Arizona population. Since some mortality between birth and the roundup may have occurred, and since some of the unaccompanied foals may have been borne by the 2-year-olds, the percentage is conservative in all probability.

(viii) Ruffner and Carothers (1977) reported 89 percent and 78 percent of the jennies collected from two Grand Canyon herds to be "reproductively active," a term that implies pregnant and/or lactating. This manner of reporting the data does not provide a clear estimate of annual fecundity rates because it lumps the present year's live foals with the fetuses in utero. Using their data, we have been able to calculate the range of possible pregnancy rates in these herds as follows, first for Bedrock Canyon.

(1) Nine females were collected at Bedrock Canyon, although the ages are not given.
(2) Eight of these (89 percent) were pregnant or lactating, indicating that they were at least 1 year old.
(3) Six embryos were recovered from them.
(4) If all nine females were yearlings and older, the pregnancy rate was 6/9 X 100 = 67 percent.
(5) If only the eight were yearlings and older, the pregnancy rate was 6/8 X 100 = 75 percent.

For the Lower Canyon Herd:

(1) Twenty-two females were collected, age not given.
(2) Of these, 16 (73 percent) were pregnant or lactating, and hence were the minimum number of yearlings and older.
(3) Fourteen embryos were recovered from them.
(4) If all 22 females were yearlings and older, the pregnancy rate was 14/22 X 100 = 64 percent.
(5) If only the 16 were yearlings and older, the pregnancy rate was 14/16 X 100 = 88 percent.

Since some prenatal loss in the form of resorption and/or abortion is possible, these percentages cannot necessarily be taken as natality rates. Furthermore, whatever natality rates they do imply cannot be ascribed to any given age group in the population except that, at the birth of the foals, they would be the 2-year-olds and older animals of the population.

The above fecundity estimates, except for those of Ruffner and Carothers, are summarized in Table 2.13. While they are disjunct and based on small samples, some tentative generalizations can be explored.

The first is the clear indication that some fraction of 2-year-olds foal in most populations so far studied. Thus, wild asses begin bearing foals a year younger than do wild horses. The BLM data and speculative analyses on Morgart's results suggest that the fraction of 2-year-old jennies foaling may be of a magnitude similar to that in 3-year-old wild mares (Table 2.4).

There is some evidence that the percentage of jennies foaling increases in each age class between the 2- and 4-year olds. It seems reasonable to suspect that this is part of an age-specific increase in fecundity up to some optimum age class or range, as discussed above for horses.

Although the data are too few to compare fecundity rates of the older age classes in burros and horses, the net effect of the earlier burro reproduction appears to result in higher rates in two or more of the younger age classes. This can be seen by comparing the means from Table 2.4 and 2.13 in Table 2.14.

TABLE 2.13 Age-Specific and Herd Percentages of Jennies Bearing Foals in Seven Wild Ass Herds (See text for discussion of each and derivation of statistics.)

Source	Location and Year	% (and No.) of Mares Foaling by Age Class			
		2YO	2YO+	3YO+	4YO+
Moehlman (1974)	Death Valley, Calif.				
	1970	0	-	-	63
	1971	0	41	-	47
Woodward (1976)	So. Calif. 1974	-	79(14)	-	-
Douglas & Norment (1977)	Death Valley, Calif. 1976	-	57(42)	-	-
Morgart (1978)	No. New Mexico, 1975	-	77(30)	-	-
Seegmiller (1977)	W. Arizona, 1974-75	-	48(33)	-	-
McCort (1980)	Georgia, 1975	-	59(27)	-	-
BLM	Arizona, 1979	10(81)	-	-	-
Unweighted Means		10	60	-	55

Table 2.14. Comparison of Annual Age-Specific Fecundity Rates in Wild Asses and Wild Horses.

Species	Annual Percentage Foaling By Age Class [1]						
	2YO	2YO+	3YO	3YO+	4YO	4YO+	5YO+
Horses	0	-	13	54	(50)[2]	61	66
Burros	10	60	(>60)[3]	(>60)[3]	(>60)[3]	(>60)[4]	(>60)[3]

[1]Nonparenthetical percentages are from Tables 2.4 and 2.13.

[2]The 25 percent obtained for this age class (Table 2.4) was based on 3 years' data from a single study and seems low as an average for wild horses. The 50 percent is a speculative value which seems more likely.

[3]If 60 percent of 2-year-olds and older jennies bear young on the average, and 2-year-olds bear at a markedly lower rate, then the proportion of 3-year-olds bearing should be greater than 60. The value may increase progressively through each age class if there is a progressive rise in fecundity with each advancing year.

[4]Since Moehlman's herd was demonstrably less fecund than the other herds studied, we have used this value as more nearly approaching a norm for the species than the 55 percent shown in Table 2.4.

This comparison suggests that fecundity rates, at least in age classes 2 through 4, may be higher in burros than in horses. The age structure of those portions of the herds that are 2-year-olds and older appear similar in horses and burros, as we will see shortly. Unless the foaling rates of 5-year-old and older jennies are lower than that of mares, the comparison in Table 2.14 implies that total herd fecundity in burros tends to be higher than that of wild horses, on the average.

(c) Foaling season. In one study of captive donkey mares, Kohli and Suri (1957) kept records on the outcome of 1,192 services by jacks occurring throughout the year. They found no statistically significant variation in fertility rates, the monthly values varying between 42.5 and 51.3 percent pregnancy from the services.

Feral asses in some populations similarly reproduce year-round, as reported by Moehlman (1974), Woodward (1976) for the Chemehuevi Mountains in southeastern California, Seegmiller (1977) for the Bill Williams Mountains in western Arizona, and McCort (1980) for Ossabaw Island, Georgia (Table 2.15). However, a degree of seasonality has evolved in some populations. Thus Moehlman found most foals born in May, June, and July. Ruffner and Carothers (1977) reported nearly all foaling in the 5-month period March to July, with one fetus projected to a November birth.

TABLE 2.15 Monthly Distribution of Foals Born in Two Studies of Burro Herds

Month	Percent Foals Born by Location and Source		
	Georgia (McCort 1980)	Death Valley (Moehlman 1974)[1]	Grand Canyon (Ruffner & Carothers 1977)
January	21	4	0
February	0	1	0
March	7	1	40
April	7	7	25
May	14	15	0
June	7	19	20
July	7	26	10
August	0	6	0
September	21	6	0
October	7	7	0
November	7	3	5
December	0	3	0
No. in Samples	14	68	20

[1]Combined totals for 1970 and 1971.

Morgart (1978) reported that all births occurred between June and November during his period of observation on Bandieler National Monument, New Mexico. But he did not begin those observations until May 20, 1978. Ohmart and Bicknell (1975) had collected 15 jennies in Bandelier in February of that same year, and among the pregnant ones they found fetuses ranging in age from 90 days to near term. They concluded that colts were dropped "at any time of year" in the area.

(2) Age Composition. We have obtained information from BLM files on burro roundups in the Phoenix, Arizona District. This has provided age-composition data on burro populations similar to that on wild horses reviewed in Table 2.7, and is shown in Table 2.16. These data show fewer foals and yearlings than 2-year-olds, a pattern also evident in the horse data. We attributed the latter to sampling bias, and are inclined to assume the same for the burros.

Beyond the irregularity, the burro age distribution is similar to that of horses in having a predominance of animals in the younger age classes and a progressive decline in each older group. The trend is not perfectly smooth, due no doubt in large measure to sampling error. But the general trend is clear. And once again, a large fraction of the population is concentrated in the young age groups that bear few or no foals: over 40 percent of jennies are in the foal, yearling, and 2-year-old classes.

Table 2.16. Age Composition of Feral Asses Rounded Up in the Phoenix BLM District in 1979

	Males		Females			Males		Females	
Age	No.	%	No.	%	Age	No.	%	No.	%
0	50	19.3	51	12.5	11	2	0.8	4	1.0
1	34	13.1	38	9.3	12	9	3.5	10	2.4
2	53	20.5	81	19.8	13	1	0.4	3	0.7
3	28	10.8	44	10.8	14	1	0.4	1	0.2
4	23	8.9	34	8.3	15	4	1.5	4	1.0
5	16	6.2	38	9.3	16	0	0	1	0.2
6	11	4.3	33	8.1	17	0	0	0	0
7	13	5.0	27	6.6	18	1	0.4	0	0
8	4	1.5	15	3.7	19	0	0	0	0
9	2	0.8	7	1.7	20	1	0.4	4	1.0
10	4	1.5	14	3.4					

Some additional information on age composition can be obtained by summarizing published data from the various studies (Table 2.17). While these are generally subdivided into only three age classes, they give some insight not only into age composition, but also into herd dynamics as we discussed above for horses. We have listed separately the foals-at-birth percentages and the percentages of the late-summer or fall populations accounted for by foals, as we did with horses

TABLE 2.17 Age Composition of Wild Burro Herds

Source	Location and Year	Percent in Each Age Class						Total Sample
		FAB[1]	FS/F[2]	Yrlg.	2YO	3YO	4YO+	
Moehlman (1974)	Death Valley							
	1970	22		13		64		174
	1971	14		14		67		202
Woodward (1976)	S.E. Calif.							
	1974	23				-		83
Seegmiller (1977)	W. Arizona							
	1974		19	19		62		88-92
Morgart (1978)	N. New Mexico							
	1975		22	21		57		90-100
Douglas & Norment (1977)	Death Valley							
	1975[3]		15	6		79		66
	1976[3]		15	5		80		102
Ruffner & Carothers (1977)	Grand Canyon							
	1976[4]		11	17		72		18
	1976[5]		9	11		70		45
Walker & Ohmart (1978)	Lake Havasu Ariz.-Calif.							
	1976[6]		23	7		70		268
McCort (1980)	Georgia							
	1975		14	12		74		73
White (1980)	Death Valley							
	1978[7]		15	10		75		774
	1979[7]		18	4		78		176
BLM	Arizona							
	1979[8]		15	11		76		666
Unweighted Means		19.7	16.0	11.5		71.1		-

[1] Number of foals born as percentage of total herd.
[2] Number of foals in late summer or fall populations as percentage of total herd.
[3] October percentages from Douglas and Norment (1977), Table 1.
[4] Bedrock Canyon Herd.
[5] Lower Canyon Herd.
[6] September-November counts.
[7] August-November counts.
[8] From Table 2.16 of this report.

(Table 2.8). The rationale for this separation, and the meaning of differences between the two sets of values, were discussed above.

The means for both sets of burro values are higher than the analogous means for horses, as would be expected of a species with a higher reproductive rate, although the differences are not statistically significant. But 4 of 14 individual burro values exceed 20 percent, while only 1 of 14 horse values does so.

The burro means are not statistically greater than the horse means, at least in part because of the greater variability in the burro values. Thus, the late-summer/fall values for the latter range between 9 and 23, those for horses between 13 and 19. The respective coefficients of variation are 26.8 and 15.6 percent. This variation is probably the result of between-year and between-area variation in natality or foal survival, or both.

(3) Survival. As with the horse data, survival information on burros is considered in terms of first-year survival and survival of older animals.

(a) First-year survival. There is evidence from field observations that survival rates are quite variable in burro foals. Thus, Carothers (1976) observed the high rate of "reproductively active" (pregnant or lactating) females in two areas of Grand Canyon described above, but found very few foals in the same areas during the months of July, August, and September. He suspected that this might be due to high pre- or postpartum mortality.

More specifically, the data or Ruffner and Carothers (1977) showed 89 percent of "all females" (N = 9) pregnant or lactating in the Bedrock Canyon herd. With six embryos found on autopsy, this is a 67 percent pregnancy rate for all females irrespective of age. Yet this herd only had two foals (11 percent of 18 animals). In the Lower Canyon herd, 73 percent of 22 females were pregnant or lactating and carried 14 embryos (64 percent pregnancy). This sample contained 4 foals (9 percent of the 45 animals sampled).

Moehlman (1974) observed three pregnant jennies during her study of the Wildrose-Emigrant Canyon population in Death Valley. These animals were not accompained by foals at a later date, suggesting that they had aborted or lost their young. She counted the number of foals and yearlings each year in her population between 1970 and 1972. This allows first-year survival estimates based on the shrinkage of two cohorts. These results are as follows:

Year:	1970		1971		1972
Foals:	39		29		--
Yearlings:	--		28		23
Implied survival (yrlg./foal):		.72		.79	

Three years after Moehlman's study, Douglas and Norment (1977) observed high foaling rates in the same population. The large discrepancy that they observed (Table 2.17) between the percentages of foals in the population and the percentages of yearlings could reflect the foal mortality that they suggested was occurring. White (1980) calculated a first-year survival rate of 0.66 between 1977 and 1978 for the Butte Valley population in Death Valley.

Dead foals are occasionally found. National Park Service (NPS) officials found a live foal being fed upon by coyotes in Death Valley and gave it to Moehlman (1974). Norment and Douglas found two at Death Valley in a little over a year's observations, and Norment (Norment and Douglas 1977) found a still-born fetus along the Colorado River in Grand Canyon.

In contrast to the above findings, Ohmart and others (1975) and Seegmiller (1977) found no evidence of foal mortality in Arizona, nor did Morgart (1978) in the Bandelier Monument herd.

In sum, these varied sources of evidence suggested that foal mortality in burros may vary between areas from very low rates (Ohmart and others 1975, Seegmiller 1977), Morgart 1978), through the moderate ones calculated from Moehlman's (1974) data, to the high ones implied by Douglas and Norment's (1977) Death Valley yearling percentages and Carother's (1978) observations in Grand Canyon. The great range of yearling percentages in Table 2.17 further suggests this variability, with a 44 percent coefficient of variation about the mean yearling percentage being more than half again as large as the coefficient for the foal percentage. Year-to-year variation within areas probably adds further to the variability.

(b) Yearling and older survival. We attempted preliminary estimates of survival rates in the 2-year-old and older animals in Table 2.16 by regressing logarithms of the number of animals in each age class on age, as we did above with horses. (We did not extend the regression through the yearlings because of the apparent sampling bias against their numbers.) The calculated finite, annual survival rates are 0.78 for jennies, 0.70 for jacks. If the population was increasing at the time of the roundup, these rates underestimate the true population values, as discussed above. The slopes for the two sexes are not statistically different, and are roughly comparable with those calculated above for horses.

Very little adult mortality has been observed by any investigators. Both Moehlman (1974) and Douglas and Norment (1977) saw only occasional dead animals. The latter authors observed four natural deaths out of a population of 86 2-year-olds and older animals in a little more than a year's observations, an observed loss of about 5 percent. One of the deaths was a jenny that died foaling. Seegmiller (1977) saw only one natural death of older animals in the Bill Williams herd, although he saw 11 carcasses of animals which apparently had been shot. Most authors agree that predatory loss is almost nonexistent.

These varied sources suggest that adult mortality has beeen light in all of the areas in which it has been studied.

(4) Sex Composition. The studies reporting sex composition do not present a consistent picture. Woodward (1976), Douglas and Norment (1977), G. A. Ruffner (as cited in Douglas and Norment 1977),

and Walker and Ohmart (1978) all report appreciable excesses of males ranging from 53 percent (Ruffner) to 68 percent (Douglas and Norment). Woodward also concluded that jacks survive longer than jennies.

To the contrary, Seegmiller (1977) reported 46 percent males in the Bill Williams herd while Morgart (1978) reported 43 percent in Bandelier Monument. And the percentage of males in the Phoenix District roundup is 39 (Table 2.16). This preponderance of females also parallels the sex composition in horses discussed above. Furthermore there is a suggestion (Table 2.18) of the same age-specific changes in sex ratios that were observed in the horse (Table 2.10): a balanced ratio at birth, increasing distortion toward females in early and mid-life, and a partial restoration of balance in the older ages.

Table 2.18. Age-Specific Sex Ratios in Burros Rounded Up in the BLM Phoenix District, 1979.[1]

	Age				
	Foals	1-3	4-6	7-10	11-20
% Males ± 0.025 C.L.	50±10	41±6	33±7	27±9	41±15
Sample Size	101	278	157	86	46

[1]Data from Table 2.16.

Whether these sex-ratio discrepancies reflect real differences between populations or sampling bias is not known. Douglas and Norment (1977) suggest that there may be a tendency to see males more readily when they display partially turgid penises or announce their presence by braying.

(5) Population Trend. Because the demographic parameters we have been reviewing are both more variable and less precisely known than those for horses analyzed above, life-table calculation of increase rates becomes more problematical. In review, we have seen that:

(a) Fecundity rates vary over a wide range. The low end, as reported by Moehlman (1974), is comparable with that of horses, with the 4-year-old jennies the youngest effective breeders and foaling rates of adult females 41 to 63 percent. At the high end, some fraction of 2-year-olds foal; and annual foaling rates as high as 79 percent (Table 2.13), and in one small sample as high as 90 percent, have been reported.

(b) First-year survival rates appear similarly variable, with some values conceivably below 0.5, and others approaching 1.0.

(c) Adult survival rates appear high and comparable with those of horses, probably falling somewhere in the range between 0.7 and 1.0.

One of the first questions we can address is the advantage burros gain over horses by the fact that they breed 1 year earlier. Cole (1954) has shown that population increase rates are extremely sensitive to the age of first breeding, more so than to moderate variations in total number of young produced. We have performed life-table calculations on annual increase rates of both horses and burros, using a hypothetical rate of first foaling in 3-year-old horses and in 2-year-old burros of 25 percent. All older age classes were assigned 50 percent foaling rates. All age classes were assigned a 0.9 mean annual survivorship. The results produced a potential, annual increase rate of 4 percent in horses and 13 percent in burros. Clearly, the difference in this variable alone provides the burros with a materially higher potential rate of increase, provided that survival rates are similar.

As in horses, some high rates of increase have been reported for burro populations:

(a) Douglas and Norment (1977) calculated an 18 percent ($\lambda = 1.18$) annual increase rate for Death Valley burros in the mid 1970s following herd reduction.

(b) Ohmart and others (1975) estimated 20 to 25 percent for the Havasu Resource Area in California-Arizona over an 18-month period, doubtless utilizing the work of Woodward (1976) and Seegmiller (1977) who arrived at similar conclusions for the same locale.

(c) Morgart (1978) inferred a 29 percent ($\lambda = 1.29$) annual increase rate for Bandelier Monument.

We can now calculate what demographic patterns would be required (and we do not suggest that they necessarily occur in nature) to attain rates of these magnitudes. We performed calculations based on the following three hypothetical conditions:

(i) Half of 2-year-olds and 60 percent of all older ages foaling each year.

(ii) Half of 2-year-olds and 80 percent of all older ages foaling each year.

(iii) Half of 2-year-olds and 100 percent of all older ages foaling each year.

Given these schedules and 1.0 survival rates, burro herds could increase at the following three, respective rates:

(i) $\lambda = 1.16$ (16 percent per year)
(ii) $\lambda = 1.20$ (20 percent per year)
(iii) $\lambda = 1.22$ (22 percent per year)

One additional implicit assumption is an age distribution approximating a geometric series.

Obviously, the three published rates of increase reported above reach or exceed the biological limits of the species. In populations with age distributions like that in Table 2.16, they could only obtain with no mortality and maximum possible reproductive rates. But since several of the values are based on intensive observations of small herds over periods of time, one hesitates to question their validity.

Not all burro herds have been reported to increase at these high rates. The Bedrock Canyon Herd in Grand Canyon had experienced periodic reduction, and Ruffner and Carothers (1977) found high reproductive rates, a high proportion of young animals (78 percent between 1 month and 4 years of age), excellent physical condition, and presumed population increase prior to their removal effort. But the Lower Canyon Herd had not been subject to human interference, had only 49 percent of its individuals in the first 4 age classes, was not in as good physical condition, and was presumed to be roughly stationary or growing only slightly. Similarly, Moehlman's (1974) Death Valley herd had not been exploited for some years, exhibited a low reproductive rate, and appeared to increase at 4.8 and 9.7 percent from 1970 to 1971 and from 1971 to 1972.

While observing substantial fractions of foals in the Butte Valley population of Death Valley (Table 2.17), White (1980) measured almost no population change from 1976 to 1979. He concluded that the population was stabilized by emigration and perhaps the low first-year survival described above. He further concluded that densities were roughly 5 to 6 times Moehlman's (1974), 7 to 9 times those of Douglas and Norment (1977), and some of the highest ever reported.

What ecological patterns can now be inferred from the disparate results that we have reviewed in the past several pages? No definitive answers are possible, but we suggest some hypotheses that might serve as leads for future research. It seems instructive to consider asses in comparison with horses.

The domestic, and now feral or "wild," horse is derived from the wild Przewalski's horse (*Equus caballus prezewalskii*). Its original distribution was the high-latitude Asian and European steppes with their strong summer-winter contrasts, and a semi-arid to mesic precipitation pattern. Such a climatic regime placed survival value on a warm-season foaling period and marked reproductive seasonality. With a moisture regime of intermediate dependability, probably made less risky by strong nomadic habits, relatively fixed and unvarying reproductive rates could evolve and endure. We cannot speculate on why those rates are so conservative.

The North American wild horse is now settled in the New World ecogeographic analog of its ancestral range: the western Great Plains and the Intermountain sagebrush and salt-desert-shrub steppes. Its reproductive pattern is highly seasonal (Table 2.5) and of limited variation (Tables 2.4 and 2.8).

The domestic donkey, and now feral burro, is descended from the African wild ass (*Equus asinus*). Its native range is the low-latitude (10°N), arid regions of northeast Africa. A combination of minor, seasonal changes in temperatures and photoperiod permitted the evolution of a year-round reproductive capability as it has in so many low-latitude species.

Similarly, the North American feral burro is largely a denizen of the continent's "hot" deserts, particularly the Mojave and Sonoran. At the southerly extremes of its U.S. distribution in southern California and Arizona (latitude ca 34 to 34.5°N), and on Ossabaw Island, Georgia (ca 31°N), there is no statistically demonstrable seasonality to its breeding. But at the slightly higher latitudes and/or altitudes of Bandelier Monument (ca 36°N), Grand Canyon (ca 36°N), and Death Valley (ca 36.5°N), a degree of seasonality has developed (Table 2.15), although it is not as marked as that in horses (Table 2.5).

One trait that has definite survival value in arid regions is demographic flexibility. Deserts are the most variable of all terrestrial systems in terms of precipitation and primary production. Many desert animal species the world over, ranging from snails and insects to birds and mammals, possess great flexibiity in a variety of demographic parameters. They reproduce and increase rapidly during periods of above-average rainfall, and take advantage of temporarily favorable conditions. But they curtail reproductive activities during drought periods. Some species have abandoned all reproductive seasonality and developed the ability to breed at any time of year when capricious rain occurs.

It seems possible that the variability in the burro data we have reviewed may reflect the demographic flexibility of a desert species. Its population processes may adjust to such vicissitudes as subnormal rainfall, inadequate forage, and population density. Several observers whom we contacted during the course of this study expressed the view that burro foaling rates are higher during years of above-average precipitation and abundant forage than in years when rainfall is below.

Several authors have suggested that observed variations in reproductive and/or survival rates are due to variations in density. Douglas and Norment (1977) postulated that the differences between the foaling rates they observed and those of Moehlman (1974) were a function of the differing population densities (Figure 2.1). The herds studied by Douglas and Norment (1977) and Woodward (1976) had been lowered by herd reduction prior to the studies, and their high increase rates and high proportions of young animals were thought to be responses to reduced density.

Ruffner and Carothers (1977) proposed a similar hypothesis for the two Grand Canyon populations, the Bedrock Canyon herd having a lower density, a higher reproductive rate, a larger proportion of young animals in the population, and a presumed higher increase rate than the Lower Canyon herd. White's (1980) report of high emigration and low foal survival rates associated with exceptionally high density may fit this same pattern.

If these hypotheses are correct, they may have important management implications. Burros appear to have materially higher potential increase rates than horses, and to be capable of populating an area rapidly. Indeed, Woodward (1976) called it "[t]he epitome of a successful colonizing species...." If the management goal for a given area is to maintain burros at low to moderate numbers, or as in the national parks to eliminate them and prevent their repopulation, it may require diligence and continuous effort.

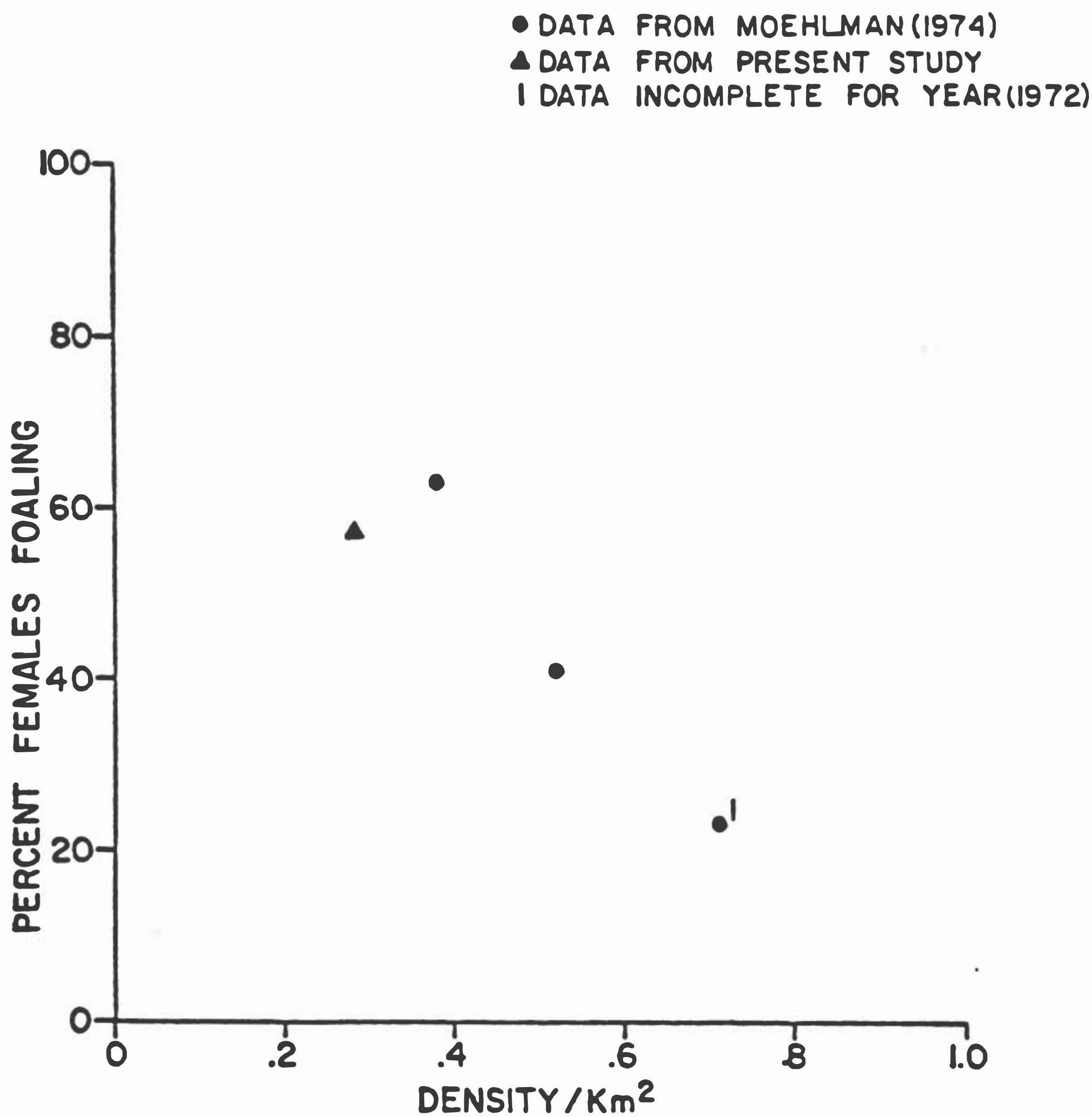


Figure 2.1 Relationship of the percentage of jennies foaling to population density in Wildrose-Emigrant population of Death Valley (after Douglas and Norment 1977).

However, burros may also have considerable ability to limit their own density, once their numbers begin to weigh on their own populations and their environments. Conceivably this phenomenon could reduce the need for herd control. The important question is whether that limitation is effected at densities below which vegetation impacts and conflicts with other values are excessive in terms of specified management goals. Our later discussions on the effects of burros on other ecosystem components bear on this question.

All of this is speculative and supported by a thin data base. The subject of demography needs considerable research aimed at measuring more fully the reproductive, foal-survival, and adult-survival rates, and their variation due to different environmental pressures. They will need to be measured in a number of areas to disclose the basis for differences cited above, and for several years in each area to record the range of variation and its causation.

Foaling rates should be fairly accessible at nominal expense by examining animals at roundups. But as with horses, research on survival rates will be considerably more demanding of time, logistics, and funds. In all probability, telemetry will be an indispensible tool.

One other problem that concerns some observers is uncertainty about accurately determining burro ages. Many of the hypotheses about burro demography developed above--first breeding age, age-specific fecundity, and survival rates--presume that the authors cited were able to age the animals accurately. In fact, age criteria have not been specifically worked out for burros. Burro investigators use the tooth-eruption and wear pattern worked out for horses (see Welsh 1975 for review). This has been justified by Woodward (1976), Ruffner and Carothers (1977), and McCort (1980) on the grounds that the pattern has been found similar in three different species of *Equus*: the plains zebra (*E. burchelli*), the mountain zebra (*E. zebra*), and *E. caballus* itself. The assumption is that the same pattern holds for *E. asinus*. Woodward (1976) was able to make limited tests on the assumption by checking dentition of animals she had earlier captured and marked while they were foals. She found no discrepancies. But additional research would give more confidence in the validity of the assumption.

Demography-Related Characteristics of the Mare Reproductive Cycle

The domestic mare begins ovulating at about 1 year of age--that is, the first season after the year of birth. The adult mare is seasonally polyestrous, with a cycle length of 21 to 22 days between ovulations. Spontaneous prolongation of luteal activity is common in the mare and can extend the cycle length to 2 months. Horse mares can cycle year-round; however, they tend to be seasonal depending upon latitude, with perhaps 2 to 6 months of anestrus during the winter. The pony mare is more strictly seasonal (as are the Pryor Mountain wild horses), with all animals cycling by May and none after September.

Multiple ovulations are common in the mare and may occur in 10 to 25 percent of cycles. Multiple ovulations and the multiple conceptions that can occur from them may represent a significant part of the apparent early pregnancy failure rate. Multiple ovulations will not make a significant demographic contribution (less than 0.1 percent of thoroughbred foals are survivors of twin pregnancies), since twins are rarely carried to term in domestic mares and have significantly lower birth weights and reduced rates of survival. Multiple ovulations and twinning very rarely occur in ponies. It is unknown whether multiple ovulations and multiple implantations occur in the wild horse.

Another curious feature of the horse is that unfertilized ova do not leave the fallopian tubes and persist over a period of months while degenerating. Thus, the recent ovulatory history of the mare can be ascertained by flushing and examining tubal washings for ova.

The onset of estrus, as well as the occurrence and frequency of ovulation, have been shown to be modulated by nutrition. Furthermore, embryonic survival is reduced by poor nutrition. Thus nutritional status in late winter and early spring may affect age of first breeding and time of onset of estrus and successful establishment of pregnancy, even if ovulation and breeding occur. The seasonal cessation of estrus in the fall may be a function of genetics and nutrition and also of light, since time of reproduction in the mare and pony has been shown to be modulated by artificial changes in photoperiod.

Sexual receptivity in the horse mare is said to average 5.7 days, whereas the pony mare responds for about 8 days--5.7 days before ovulation and 2.3 days after. Mares can exhibit estrous behavior without ovulating and animals can ovulate while exhibiting very low levels of estrous behavior (Asa 1979). Occasional animals can exhibit more or less continuous estrous behavior and willingness to copulate regardless of ovulatory status.

The sequence of endocrine and gonadal events after conception have been concisely represented in Figure 10 of Stabenfeldt and Hughes (1977). Gestation length is about 340 days in horses. These events provide the rationale for a series of tests for pregnancy, the usefulness of which is related to the stage of pregnancy and viability of the fetus. Some of these tests are summarized in Ginther (1979). They include rectal palpation of the reproductive tract (days 24 to 45), pregnant mare serum gonadotropin (PMSG) (days 45 to 120), progesterone (days 45 to 130), and estrogens (days 120 to 340). An elevated PMSG test combined with a low progesterone result indicate a dead or resorbing embryo. The level of progesterone in milk can be used to detect pregnancy in a lactating mare. Urinary estrogens are useful beginning about 100 to 110 days past conception. Ultrasound detection of fetal heartbeat can be used from 45 to 90 days (approximately 100 percent effective after 90 days) to term.

Delivery usually occurs at night and lasts about 10 to 15 minutes in uncomplicated births. Premature delivery can be induced by administration of exogenous corticosteroids (100 mg of dexamethasone around days 321-324 with delivery on day 328). These foals survive.

Since capture and handling of late pregnant mares often results in early parturition, delivery could be induced in a controlled manner by means of these drugs. The whole issue of premature delivery might be avoided with drug-capture techniques that use tranquilizers rather than succinylcholine, which does not alter the animal's awareness of environmental events and produces symptoms of "stress" in white-tailed deer (Wesson and others 1979).

A "foal heat" (estrus and ovulation), occurs over about 7 to 9 days and within 13 days after foaling in domestic mares. Successful breeding is possible at this time and is commonly done in domestic animals. Foal heat is likely to occur in wild horses, but its modulation by nutrition has not been studied. Thus, it is important to test captured mares that have accompanying foals or are lactating for pregnancy (milk progesterone, PMSG, serum progesterone) to establish the frequency of this annual rebreeding in wild populations and its relationship to age. This testing could be initiated in the adopt-a-horse program, especially with animals captured in the fall, using the combined techniques of PMSG and progesterone from blood samples and ultrasound detection of fetal heartbeat.

Live foals are produced by about 70 out of 100 well-managed domestic mares bred. About 80 mares in 100 are estimated to become pregnant; thus failure to conceive is about 20 percent. This failure rate may be due to frequent use of hand-breeding or to inbreeding depression, since 90 to 100 percent of pasture-bred quarter horse mares are reported to become pregnant. The death rate of live foals varies widely depending upon season of birth and source of data: about 55 percent of mares bred may have foals that survive to 1 year of age. This figure is close to that reported for wild horses, but that fact may only be coincidental given the multiple uncertainties of the domestic animal data. We cannot safely conclude that mares breed each year on the average in the wild (i.e., breed at foal heat if previously pregnant) rather than in alternate years. Direct study will be necessary.

Although 1-year-old domestic fillies do ovulate and can become pregnant, many of them lose their fetuses: 69 percent conceived and 44 percent delivered in one study (Mitchell and Allen 1975). It is unlikely that animals of this age conceive in the wild. However, the actual year of first breeding will require direct study. It has been suggested that first breeding is delayed until the age of 3 or 4 years in the wild and that it is modulated by nutrition.

Age-specific fertility in domestic mares has been reported to vary between 65 and 79 percent up to age 7, between 81 and 89 percent to age 12, and then to decline gradually to 50 percent at age 20 (Ginther 1979). Age-specific mortality rates useful to wild horse demographic studies cannot be inferred from domestic data, except that juvenile mortality can be high and strongly dependent upon management conditions.

In conclusion, if age-specific fertility and mortality data of wild mares are necessary for management purposes, then they will have to be collected from studies of wild populations. The techniques are available for assessing pregnancy states of freshly captured wild mares and hence to allow estimates of fertility and probable natality rates. Methods for applying these techniques to captured wild horses are discussed under "Feral Horses: Fecundity" in the section on "Equid Demography."

Genetic Polymorphism

A knowledge of equid genetics can contribute to management in at least two significant ways. First, an animal population must embody a certain amount of genetic diversity in order to be able to adapt to marked environmental changes and survive. The genetic composition of a population is presumably adjusted to render it most fit for its contemporary environment. However, a large population will contain considerable diversity, the extremes of which may not necessarily be the most fit individuals for that environment. But given a profound environmental change, such as climatic oscillation, some of the previously marginal genotypes may now be the best adapted and serve as a breeding source for a new, better-adjusted population.

In order for a population to have a sufficient probability of survival, it must be large enough to contain enough genetic variability to meet likely environmental contingencies. A management program could well determine what this size is, and set as an objective the maintenance of individual populations at or above this level. If forage allocation or other considerations prohibited populations of minimum size in certain areas, this situation might be the basis for deciding to remove entire, small herds from such areas.

A second management implication relates to the contentious issue of the lineage of wild horse herds. Many of the individuals and groups who strongly support wild horse management (e.g., Ryden 1978) contend that many of these extant herds are derived from previously abundant Spanish mustangs. Opposition groups, such as livestock and wildlife interests, argue that most wild horses today stem from escaped or released draft horses, cavalry mounts, and saddle animals.

This dispute could be settled by genetic studies. The biophysical characteristics of blood enzymes and proteins have been found to be so closely associated with genetic make-up that these serum constituents can be used as delicate and precise genetic markers. It is quite likely that the serum proteins of the Spanish barbs and the Arabian breed (the apparent progenitors of the Spanish mustangs), as well as those of the different domestic breeds, could be precisely identified and described in contemporary, captive animals and then sought in wild herds. In all probability, the complex lineage of wild animals could be worked out with considerable precision.

At present, information on equid population genetics is scarce. There are apparently no systematic studies of the levels of genetic variation in wild equids. Data, however, do exist with respect to some domestic breeds. The genetics of coat color of the horse has been under intensive study for more than half a century. Because the genetics of color variants is fairly well-known in many cases, it seems that the coat color information available from the BLM census studies could be used to obtain some information on gene frequencies. Nevertheless, for the reasons advanced in the section on "Needed Research" (below), it seems that such information by itself is not sufficient to obtain estimates of genetic variation in wild equid populations comparable to the estimates that exist for many other kinds of organisms. The study of blood enzymes and other proteins is, at present, the best method for obtaining such estimates.

An important study of the genetics of blood systems was published by Stormont and Suzuki in 1964. These authors studied 16 blood factors in equine blood and established that a minimum of eight gene loci are responsible for the control of blood groups in horses. Extensive polymorphisms exist in at least four of the eight loci: the minimum number of alleles is six at one locus, five at another, and three at each of two other loci (Stormont and Suzuki 1964). Allelic frequencies at the various loci were found to be different in different breeds; two breeds in particular (Shetland ponies and thoroughbreds) are markedly different with respect to those frequencies, as shown in Table 2.19.

A practical extension of the genetic analysis of blood groups was presented by the same authors in 1965. In cases when a mare had mated with two different stallions, it became possible to exclude one of the two stallions from paternity in about 65 percent of the cases (Stormont and Suzuki 1965). The genetics of blood groups has also been used to confirm the inheritance of coat color in equids (Trommershausen-Smith and others 1976). The chestnut rule in coat-color genetics asserts that matings between chestnut horses never produce bay, black, brown, or grey offspring; the grey rule asserts that grey offspring must have at least one grey parent. The authors studied nine alleged exceptions to the chestnut rule, and eight alleged exceptions to the grey rule. Study of the blood groups of the animals involved demonstrated that the "exceptions" were due to incorrect parentage assignation. These two applications of blood-group genetics illustrate the resolving power of genetic studies.

An early investigation of genetic variation in horse proteins other than those involved in blood-group determination was also published by Stormont and Suzuki (1963); it involved variation in albumin phenotypes. Gahne (1966) studied variation in four blood proteins, each encoded at a different gene locus, by means of gel electrophoresis. The number of alleles found at each of the four loci was: albumin, 2; prealbumin, 4; esterase, 4; and transferrin, 6.

Stormont (1979) has recently reviewed the genetic studies of blood proteins in horses. Table 2.20, adapted from his publications, gives the number of alleles known at each of the eight loci responsible for the polymorphisms observed in each of the corresponding proteins. (For an additional review, see Kaminski 1979).

Other genetically determined proteins studied in horses are: α-galactosidase (Beutler and Kuhl 1972), butylcholinesterase (Chiu and others 1972), liver alcohol dehydrogenase (Ryzewski and Pietruszco 1977), and hemoglobin (Sandberg and Bengtsson 1972).

Several of the protein polymorphisms studied in horses have also been investigated in burros: transferrin (Niece and Kracht 1967),

TABLE 2.19 Estimates of the Frequencies of Alleles of Eight Blood-group Loci in Shetland Ponies and Thoroughbreds

Loci	Alleles	Frequencies in Shetlands	Frequencies in Thoroughbreds
	a^{A1}	0.3107	0.7050
	$a^{A'}$	0.2852	0.0290
A	a^{H}	0.0358	0.0036
	$a^{A'H}$	0.0601	0.0000
	a	0.3082	0.2624
	d^{D}	0.1392	0.0000
D	d^{J}	0.1215	0.1503
	d	0.7394	0.8497
	p^{P1}	0.3415	0.2058
P	$p^{P'}$	0.0483	0.0910
	p	0.6102	0.7031
	q^{Q}	0.1519	0.5082
	q^{R}	0.3869	0.0000
	q^{S}	0.0103	0.1038
Q	q^{QR}	0.1306	0.0756
	q^{RS}	0.1893	0.3125
	q	0.1310	0.0000
C*	c^{C}	0.6521	0.7317
K*	k^{K}	0.1796	0.0635
T*	t^{T}	0.4505	0.6594
U*	u^{U}	0.3174	0.1485

*The frequency of the alternative allele at each of these loci is simply 1 minus the figure shown.

SOURCE: Data from Stormont and Suzuki (1964).

TABLE 2.20 Number of Alleles Associated with Various Blood Proteins in Horses

Protein	Number of Alleles	References
Serum proteins		
Albumin	2	Stormont and Suzuki (1963); Gahne (1966)
Prealbumin	8	Gahne (1966); Braend (1970); Trommershausen-Smith and Suzuki (1978a)
Postalbumin	2	Braend (1970); Stormont (1972); Trommershausen-Smith and Suzuki (1978a)
Esterase	4	Gahne (1966); Scott (1970)
Transferrin	6	Gahne (1966); Braend and Stormont (1974)
Red-blood-cell proteins		
Carbonic anhydrase	3	Sandberg (1968); Deutsch and others (1972a,b)[a]; Deutsch and Bray (1975)[a]
Catalase	2	Kelly and others (1971)
6-Phosphogluconate dehydrogenase	2	Sandberg and Bengtasson (1972)

[a]References not included in Stormont's review.

hemoglobin (Trujillo and others 1967, Isaacs 1970), esterase (Kaminski 1970), 6-phosphogluconate dehydrogenase (Bergman and Gustavsson 1971, Hof and Osterhoff 1973), and albumin (Blake and Douglas 1978). Esterase (Kaminski 1970, Kaminski and others 1978) and 6-phosphogluconate dehydrogenase (Hof and Osterhoff 1973) have been studied in other equids as well.

The present state of knowledge concerning the genetics of natural populations of wild and free-roaming horses and burros may be summarized as follows:

1. No information exists about these populations concerning any of the relevant genetic questions, such as the amount of genetic variation within populations, the amount of genetic differentiation between populations, and the pattern of genetic relatedness ("phylogeny") of the wild populations and the domestic breeds.
2. No studies exist of domestic horses or donkeys that would give valid estimates of the amount of genetic variation within a breed, the amount of genetic differentiation between breeds, or the pattern of genetic relatedness among breeds. To obtain these estimates would require the systematic study of a random sample of genes (i.e., random with respect to the degree of variation). The existing studies concentrate on one or another gene (responsible for a given coat color, blood group, or protein) and, in general, pay particular attention to genes known to be polymorphic.
3. Genetic information exists, particularly for domestic horses, with respect to coat colors, blood groups, and various proteins; polymorphism appears to be pervasive (and, it would seem, as extensive at least as in other vertebrates). The successful application of the techniques of gel electrophoresis to the study of a number of protein polymorphisms indicates that such techniques could be used to obtain the kind of population genetic information needed (see the two previous paragraphs).

Food Habits of Horses and Burros

Since North American wild burros and horses occupy rather different biomes--burros in the hot or southern deserts, and horses largely in the plains, steppes, and cold or northern deserts--marked differences in food habits are to be expected, and possibly in nutritional characteristics as well. At least part of the burro's ability to adapt to the harsh environmental conditions of the desert Southwest probably relates to the broad spectrum of plant species it will accept as food. Most studies show that burros are highly opportunistic feeders, and can greatly alter their diets in response to forage availability and phenology (Browning 1960, Hansen and Martin 1973, Koehler 1974, Woodward and Ohmart 1976, Jordan and others 1979a, Seegmiller and Ohmart 1980). They apparently prefer green grasses and forbs when these are available (Hansen and Martin 1973, Woodward and Ohmart 1976). However, virtually all researchers have remarked that, during dry seasons or periods when forage is scarce, burros utilize plants and plant parts not usually considered forage for domestic ruminants. For example, Ohmart (1975) observed burros consuming large palo verde (Cercidium microphyllum) branches, and Koehler (1974) reported them eating yucca (Yucca spp.) plants and bark from cholla cactus (Opuntia imbricata). In their comprehensive review of literature on equine nutrition, Robinson and Slade (1974) observed that domestic donkeys may have a higher capacity for digesting crude fiber than either horses or cattle, and that feral equids of both species can survive on diets deficient in total nitrogen as well as specific amino acids. These physiological capacities might well contribute to the burro's adaptability to such low-quality forages.

Table 2.21 displays a representative, though not exhaustive, summary of food-habit studies conducted on burro populations in several environments. Variations in the grass component, compared with that of horses (see Table 2.22 and later sections of this report) further emphasize the plastic nature of burro feeding habits.

In contrast to the dearth of information on grazing impacts, considerable research effort has been devoted to studying the diets of horses over a wide range of conditions in the West. Much of this research has been supported either directly or indirectly by the BLM. In some cases, diets of sympatric ungulates have also been studied to ascertain the degree of dietary overlap. Results of several of these studies are summarized in Table 2.22.

While some studies have reported that forbs (Smith 1949, Archer 1973, Hansen 1976, Wagner 1978, BLM 1979c) and browse (Frischknecht 1975, Hansen 1976) are periodically important in horse diets, most studies (Hubbard and Hansen 1976, Hansen and others 1977, Olsen and Hansen 1977, Salter 1978, Vavra and Sneva 1978, Salter and Hudson 1979) have emphasized that gramineous species constitute the major proportion of the annual diet. This state of affairs is emphasized by the low variability associated with the grass component in Table 2.22, which is based on studies conducted over all seasons and under many different environmental conditions. In a parallel situation, Casebeer and Koss (1970) found that zebra diets more closely matched the grass composition of the vegetation type where they grazed than did those of three species of ruminants: cattle, wildbeest, and hartebeest.

Archer (1977) and P. V. Fonnesbeck (Utah State University, personal communication, 1979) both found that horses can be highly selective feeders, even showing preferences for short, new growth in a sward while rejecting the older growth of grasses present there. Stoddart and others (1975) noted that horses are the most selective grazers of domestic livestock and, under conditions of forage scarcity where heavy utilization has been forced, no other animal matches the horse's ability to crop the vegetation closely. Arnold and Dudzinski (1978) have made similar observations.

Several authors reported that horses and cattle often consume very similar diets in sympatric situations (Olsen and Hansen 1977, Salter 1978, Vavra and Sneva 1978). Vavra and Sneva (1978) found that similarity of diets was greatest in dry years and during seasons of dormancy when forage is least available. Some potential

TABLE 2.21 Diets of Free-Roaming Burros Over a Range of Vegetation Types and Seasons, as Determined by Fecal and Stomach-Content Analysis

Study	Vegetation Type	Month/ Season(s)	Dietary Composition (%) Grasses	Forbs	Browse
Woodward and Ohmart (1976)	Mojave Desert (lower Colorado River-Chemehuevi Mts.	Jan.	0.0	22.7	73.8
		Feb.	1.2	46.9	36.0
		Mar.	2.2	77.4	19.5
		Apr.	7.7	58.2	34.1
		May	0.2	51.9	38.1
		June	0.0	37.2	58.0
		July	2.0	12.1	82.3
		Aug.	2.4	13.9	78.8
		Sept.	2.3	8.4	83.8
		Oct.	12.6	8.0	74.0
		Nov.	2.9	10.9	82.9
		Dec.	14.3	11.2	73.1
		Annual mean	3.9	30.1	61.1
Hansen and Martin (1973)	Mohave Desert (in lower Grand Canyon)	Mar.	79.6	15.8	5.7
		Annual mean	68.6	13.1	13.7
Jordon and others (1979)	Mohave Desert (Grand Canyon Nat'l. Park)	July	47.8	17.4	31.8
		Aug.	34.4	15.2	48.7
		Sept.	23.3	10.1	64.2
		Annual mean	35.2	14.2	48.2
Seegmiller and Ohmart (1976)	Colorado Desert (lower Colorado River-Bill Williams Mts.)	Jan.-Mar.	1.8	56.5	39.6
		Apr.-June	30.1	34.5	30.4
		July-Oct.	33.1	11.2	48.6
		Annual mean	22.0	33.0	40.0
Browning (1960) (stomach contents)	Mohave Desert (Death Valley)	Spring and fall	10.0	39.0	50.0
Mean and coefficient of variation (%) over all five studies			27.3 (84.2)	22.6 (46.0)	40.8 (49.0)

TABLE 2.22 Diets of Wild, Free-Roaming Horses Over a Range of Vegetation Types and Seasons, as Determined by Fecal Analysis

Study	Vegetation Type(s)	Season(s)	Dietary Composition (%)		
			Grasses	Forbs	Browse
Hansen (1976)	Desert grassland	Spring	58	28	9
		Summer	58	13	28
		Fall	36	31	28
		Winter	36	42	21
		Annual	47	28.5	21.5
Hubbard and Hansen (1976)	Mountain shrub	Annual	85	1	12
	Pinyon-juniper	Annual	89	0	7
	Ecotone	Annual	97	0	2
Hansen and others (1977)	Sagebrush-grass and pinyon-juniper	Annual	94	0	5
Olsen and Hansen (1977)	Sagebrush-grass and saltbrush	Annual	91	8	1
Salter and Hudson (1979)	Upper foothills of boreal forest	Jan-Mar	87.5	0.6	5.9
		Apr-May	92.5	0.8	3.0
		June-Aug	98.5	0.8	2.3
		Sept-Oct	95.2	1.9	1.5
		Nov-Dec	89.3	0.4	5.1
		Annual	92.6	0.8	3.6
Vavra and Sneva (1978)	Desert-forest fringe of the cold desert	Normal Year			
		Spring	99	--	--
		Fall	98	--	--
		Winter	100	--	--
		Annual	99	--	--
		Dry Year			
		Spring	95	--	--
		Summer	100	--	--
		Fall	100	--	--
		Winter	97	--	--
		Annual	98	--	--
Vavra and Sneva (1978)	Sagebrush-grass (4 locations varying in sage-brush dominance)	Annual	92.8	7.0	0.2
		Annual	95.9	3.6	0.5
		Annual	85.8	12.9	1.2
		Annual	95.2	2.5	2.4
Mean and coefficient of variation (%) over all seven studies			89.4 (15.1)	5.8 (146.7)	5.1 (125.7)

food-competition relationships are also reported to exist between horses and elk during winter and spring (Salter and Hudson 1979), and particularly between horses and such climax species as bison, bighorn sheep, and pronghorn antelope (Wagner 1978), which apparently have more restrictive dietary niches.

Some caution is necessary, however, in interpreting dietary overlap as a strong indication of competition. Mere dietary overlap does not directly translate into exploitative competition unless shared forage resources are in short supply. In this connection, Salter and Hudson (1979) noted that horses were ubiquitous in their distribution over several major plant-community types. There was little contemporaneous spatial overlap between horses and cattle, even though fecal analysis showed 67 percent overlap in their summer diets.

Noticeably absent from most studies on horse diets is any type of quantitative description of food availability. Likewise, few studies have adequately described the spatial relationships of horses and sympatric ungulates. Hence, very little, if anything, can legitimately be said about competition for food between horses and domestic or wild ruminants. Certainly, no populations of horses and sympatric species have been monitored for purposes of identifying competitive exclusion resulting from exploitation of the food supply.

Equid Forage Requirements and Nutrition

Knowledge of forage requirements and nutrition is important to effective management of horse and burro populations and the ranges they occupy. From the standpoint of animal welfare, the horse or burro biologist must understand the animals' nutritional needs for maintenance and reproduction in relation to the nutritional plane that the range is capable of providing seasonally. From the standpoint of range welfare, the manager must have reasonably good estimates of the quantities of forage consumed daily by a given animal population in order to establish stocking rates and, if necessary, allocate forage to other herbivores occupying the range. The two needs are not distinct and call for close collaboration between the range manager and the horse or burro biologist. The following discussion will first address factors affecting forage requirements and then discuss equid nutrition in the rangeland setting.

Theoretically, the configuration of the equid digestive tract makes these animals less limited than ruminants by the quantity of forage dry matter they can turn over per unit of time (Bell 1969, Janis 1976). The implication to the range manager is that horses may be able to consume more forage per unit of body weight than cows can. Hence the animal unit (AU) requirement for forage might be more for horses than for equivalent-sized cows, especially on ranges where forage is of poor nutritional quality. (An animal unit is considered to be a 454-kg (1,000-lb) cow or her equivalent by Stoddart and others [1975].) Apparently, some grazing-capacity assessments conducted by the BLM for cows and horses have gone forward on the assumption that a mature horse is roughly equivalent to 1.25 AU.

Heady (1975), in speaking of exchange ratios for various animal species on rangelands, states that "... if the food eaten is reasonably the same for both species being compared, the ratio of metabolic weights gives the exchange." He used the widely accepted interspecies mean of body weight raised to the fractional power of 0.75 to define metabolic body weight. Thus, using this procedure, a 454-kg horse and a 454-kg cow both have metabolic body weights of 98 kg and both are equivalent to 1.0 AU. In practice, however, such exchange ratios are profoundly affected by the kind of range, the age and physiological status of the animals, and the kinds of forage consumed. Hence they appear to offer little basis for comparing animals as dissimilar as cattle and horses.

Another possible approach in comparing ruminant species is the use of recommended nutrient standards, such as those assembled by the National Research Council for sheep (NAS 1968) and cattle (NAS 1976). Such a comparison could be based on either digestible or metabolizable energy requirements. However, direct comparisons of such energy standards between horses (NAS 1976) and ruminants are not advisable because of differences in digestible-energy utilization by equines and ruminants. Considerable energy from easily digestible foods is absorbed as glucose in the foregut of the equid. Undigested material, consisting largely of plant cell walls, is subsequently fermented in the cecum, yielding volatile fatty acids (VFA) that are absorbed and utilized as energy substrates by the animal. In ruminant digestion, however, fermentation occurs in the foregut, and consequently there is a major dependence on VFAs as energy substrates, with little or no direct utilization of glucose.

As forage matures and becomes less digestible, fermentation in the cecum becomes relatively more important to the equid (Hintz and others 1979). Under such conditions, decreasing amounts of energy are absorbed as glucose in the foregut and increasing amounts are derived as VFAs in the hindgut. More metabolizable energy is available from foregut utilization of glucose than from hindgut utilization of VFAs, because the fermention process is attended by losses of methane and heat that do not occur in foregut gastric digestion. Hence, the equid obtains less metabolizable energy from each unit of digestible energy as the digestibility of its food declines. This shift is not as much of a problem in ruminants, since the proportion of food that is fermented remains relatively constant over the entire range of forage digestibility. Moe and Tyrrell (1976) found that for ruminants, metabolizable energy expressed as a percentage of digestible energy ranged from 80 percent for forage diets to about 88 percent for high-concentrate diets. The relationship of digestibility, dietary fiber, and energy nutrition of the equid are discussed in detail (with numerous appropriate reference sources) in Appendix A.

Estimates of daily forage requirements for horses, based on required total digestible nutrients (TDN), have occasionally been suggested. Data on TDN requirements are readily available for both horses (NAS 1973) and cattle (NAS 1976) and would, as first approximations, appear to offer a simple method for equating forage requirements of the two species. However, such comparisons must be interpreted with caution. An example follows.

For a 400-kg mare and a 400-kg cow, both in the last 90 days of gestation, recommended TDN levels are 3.72 kg daily for the mare (NAS 1973) and 4.00 kg daily for the cow (NAS 1976). Forage diets are assumed to supply 4,000 kcal of digestible energy per kg of TDN for horses (Fonnesbeck 1968). Thus, according to this approach, cows would require some 7.5 percent more TDN than mares of equivalent size and physiological status. The difference of 0.28 kg TDN per day (4.00 - 3.72 = 0.28) can presumably be attributed to the less efficient utilization of digestible energy by the ruminant, which is the result of fermentive losses discussed earlier.

The main deficiency in this approach is that there is no direct way of translating TDN to quantities of forage dry matter actually consumed. The latter quantity is of most interest to the range manager who must allocate a fixed forage resource to one or more grazing animal populations. Presumably, if equids digest highly fibrous forage diets less thoroughly than do ruminants, and the rate at which digested material is passed through the equid is not limited by the configuration of the digestive tract as it is in ruminants, a horse might consume more forage in order to extract its required quantity of TDN (or energy) than would an equivalent-sized ruminant.

Demment (Appendix A) approached this question on a theoretical basis and, using published data and some assumptions, constructed a family of curves comparing intake of similar-sized horses and cattle as a function of dietary crude-fiber content. At dietary crude-fiber levels lower than 40 percent, horses would consume less dry matter per day than would cows; however, above about 45 percent dietary crude fiber, horses would consume more dry matter per unit of body weight than cows, and the difference would increase at an increasing rate. In this connection, Stoddart and Greaves (1942) reported that native grass species (including *Agropyron*, *Bromus*, *Stipa*, and *Poa* spp.) from northern Utah mountains contained about 28 percent crude fiber in spring and 36 percent in fall. Crude-fiber values higher than 40 percent of dry matter are uncommon in native range forages (NAS 1971).

Although the accounts are few and some of the data are questionable, the published literature seems to support the contention that equids may, in fact, have relatively higher rates of forage intake than do ruminants of equivalent size. After extensive review of the literature, Cordova and others (1977) concluded that realistic estimates of intake for grazing ruminants fall in the range of 40 to 90 g/kg $BW^{0.75}$, where $BW^{0.75}$ is the metabolic body weight of an animal. Intake rates at the lower end of the range were associated with mature and cured forages and those at the upper end with immature, easily digestible forages. Thus, forage intake by horses and burros should approach or exceed 90 g/kg $BW^{0.75}$ before being accepted as evidence that their intake requirements are higher than those of ruminants.

Koehler (1974), citing an obscure "U.S. Forest Service personal communications" reference, stated that daily intake by burros on Bandelier National Monument was approximately 11 lbs (5 kg), but he did not give the average weight of the animals. The NPS (1979) assumed that the daily intake by Grand Canyon burros was 5.1 kg of forage per 167-kg animal, versus 1.6 kg of forage per 64-kg sympatric bighorn sheep. These values convert to 110 and 71 g/kg $BW^{0.75}$ for burros and bighorns, respectively, but the difference is complicated by differences in body size of the two species. Apparently, the NPS used the same estimates of intake requirement for burros in both Bandelier National Monument and Grand Canyon National Park. This value was taken from work done by Maloiy (1970) with the Somali wild ass. Darlington and Hershberger (1968) found that ponies voluntarily consumed timothy hay at 82 g DM/kg $BW^{0.75}$ per day (DM = dry matter). Intake levels of orchard grass and alfalfa were 65 to 90 and 80 to 83 g DM/kg $BW^{0.75}$, respectively. The fact that the intake rates of confined ponies approached or equaled 90 g/kg $BW^{0.75}$ indicates that under free-ranging conditions their intake requirement may, in fact, be higher than that of ruminants. Recalculation of intake data presented by Ngethe (1976) suggests that zebras are capable of daily forage-intake rates of at least 157 to 165 g/kg $BW^{0.75}$. Ngethe's zebras were fed a cafeteria-style diet of cut grasses, but apparently the pens he used allowed the animals to exercise. Both of the foregoing studies measured intake in the highly controlled pen situation, and thus there is no reason to question the accuracy of the data. However, they probably underestimate intake by free-ranging animals, since the latter presumably have somewhat higher maintenance energy costs. Obviously this question requires research, particularly in terms of the mid- and low-quality native forages that characterize rangeland during much of the year.

Janis (1976) suggested that, due to their presumed greater intake rates, equids are superior to ruminants in dealing with high-fiber forages, providing that intake is not limited by the actual quantity of forage available. In other words, equids might have a competitive advantage over ruminants in situations where a critical nutrient such as nitrogen is present in low concentrations in the available forage. This is not to say that equids digest protein any more efficiently than ruminants (Vander Noot and Gilbreath 1970), but they possibly have "access" to a greater amount of the nutrient by the fact that they can process a larger quantity of food (Robinson and Slade 1974, Hintz and others 1978). The ruminant's throughput rate is limited by the capacity of the rumen and the fermentation rate there.

The question of equid digestive physiology is of considerable theoretical, as well as practical, interest. Several recent reviews of equine nutrition (Slade and Robinson 1970, Mehren and Phillips 1972, Robinson and Slade 1974, Hintz and Schryver 1978) have covered various aspects of the topic. Janis (1976) discussed the evolutionary aspects of equid digestion and possible ramifications regarding interactions with other sympatric ungulates. The reader is referred to these papers, as well as to Appendix A, for more detailed discussions of digestive physiology and possible ecological relationships.

Nutritional Value of Diets Consumed on Rangelands

Cook (1975) expressed the widely held belief that most western ranges lack suitable year-round forage resources to sustain resident populations of horses and burros, and that eventually this lack will limit their populations by fostering poor reproduction, disease, and starvation. Although we are not aware of any documented evidence (i.e., demographic studies) that such limitations presently exist, animals in poor body condition have periodically been observed on some horse ranges. Young and others (1976) suggested that Great Basin plant communities have not evolved in association with equids since their Pleistocene extinction, and that feral horses were only able to expand their ranges into the Basin <u>after</u> the advent of Europeans. At any rate, now that wild horses and burros are established on many ranges, it must be determined whether the seasonal quality and quantity of their food are currently creating limitations.

Generally, forage availability and nutritional quality are greatest during the season(s) of active plant growth. As plants mature, crude fiber, lignin, and cellulose increase. Part of the change in nutritional composition is the result of decreases in leaf-to-stem ratios, changes in chemical constituents within plant structures, and some leaching. These lead to lower digestibility in most cases. After maturation, leaching of soluble carbohydrates, proteins, and certain minerals and vitamins greatly accelerates and continues throughout the period of dormancy. Some species are more susceptible to leaching than others, and it is more severe among herbaceous plants than among shrubs. Shrubs maintain protein and vitamin levels better than do herbs, but they do not provide enough metabolizable energy to sustain weights in domestic livestock (Cook 1975). Leaf drop and shatter also contribute to qualitative, as well as quantitative, losses during dormancy.

The areas in which the major horse and burro herds roam differ in climate, and thus support somewhat different regimes of plant growth. In southwestern regions, rainfall patterns range from a single winter mode in southern California, through a bimodal precipitation pattern in Arizona, to a single summer mode in New Mexico. In areas where the bimodal pattern holds, two annual peaks in forage quality are often observed: one in late winter and early spring (provided winter rains occur), and one in late summer (Cable and Shumway 1966). Grasses mature during the latter period. In the Great Basin region and adjacent high plains areas of Wyoming and Colorado, precipitation occurs mainly from September to April, much of it as snow. Most plant growth occurs during spring and early summer, with the vegetation becoming dormant by mid- to late summer and remaining so throughout the ensuing fall and winter. Moderate temperatures and adequate precipitation in fall may sometimes result in some "greenup" of vegetation (primarily gramineous species) at that time. Thus, forage quality is generally highest during late winter and early spring--and again in late summer--in the southwestern region, and during spring and early summer in the Great Basin-Intermountain region. Drought conditions in either region can reduce the availability of forage during growing seasons and during periods of dormancy. Snows often greatly reduce forage availability during the winter in the Great Basin-Intermountain region.

Raleigh (1970), working in the sagebrush-bunchgrass region of Southeastern Oregon, reported that nitrogen in the diets of grazing cattle declined from 3.01 percent (18.8 percent crude protein) in early May to 0.46 percent (2.9 percent crude protein) in mid-September. Further declines into the fall and winter may have been observed if the study had continued past September. In the same study, digestible nitrogen available from forage had fallen below recommended levels for cows nursing calves (NAS 1976) as early as late June. Digestible energy reached levels deficient to cows with calves in mid-July.

If one substitutes recommended levels of crude protein and digestible energy for lactating mares (NAS 1973) into Raleigh's (1970) curves for forage quality, digestible protein (or digestible nitrogen x 6.25) would appear to become deficient in early June, but a deficiency of digestible energy would appear unlikely, even into September. This exercise assumes that horses would consume diets similar to those of cattle, and--on the basis of horse-diet data published by Vavra and Sneva (1978) for the same general area--this may not be an unreasonable assumption. But it does not consider the possibility that horses may compensate for low-quality forage by eating more of it (Janis 1976).

Cook and Harris (1968) and Rittenhouse and Vavra (1979) provide a comprehensive summary of nutritional data for domestic animals in salt-desert shrub and sagebrush vegetation areas of the Great Basin. In addition, Murray and others (1978) have recently published a detailed account of nutritional values for some 20 important forage species common to the Great Basin area. Their data were presented in such a way that the effects of plant phenology or stage of maturity can be clearly ascertained.

The studies mentioned above, as well as numerous others (Vallentine 1978 lists some 715 bibliographic entries on range-animal nutrition specific to the western United States), have focused entirely on the nutritional value of range forage for domestic cattle and sheep. Fewer studies (e.g., Smith 1952, 1954, 1957; Dietz and others 1962; Short and others 1966; Urness and others 1975) have considered wildlife species. But virtually all studies, whether concerned with wild or domestic creatures, have been carried out on ruminants. Essentially no data exist on the nutrition of the free-ranging equid in the western United States. Moreover, the studies on domestic animals have generally been done from the perspective of economically effective levels of animal production. It is conceivable that, in the case of wild horses and burros, the question of mere survival may occasionally be the important one.

Studies with ruminants have shown that nutritional deficiencies in animals cannot necessarily be determined by comparing the nutritional value of hand-harvested forage plants with animal requirements. By selectively feeding on specific plant parts, the grazing animal usually ingests food that is of considerably higher quality than that of the plant as a whole. The detailed data presented by McCulloch and Urness (1973) on white-tailed and mule deer in Arizona chaparral show that by selectively feeding, deer maintained a relatively uniform level of protein intake all year long, even though the gross amount of protein available in the vegetation fluctuated markedly from season to season. Similar findings are reported for cattle (Hardison and others 1954) and sheep (Arnold 1964).

Langlands and Sanson (1976), however, using cattle and sheep as experimental subjects, demonstrated that there are limits to what can be gained by selective feeding. As forage availability declined during the course of their study, a point was reached at which the most nutritious forage became too difficult to obtain in sufficient quantities to make seeking it worthwhile. If utilization becomes heavy enough and animals can no longer afford to select just the most nutritious food, the nutritive value and digestibility of their intake will eventually decrease. The utilization level at which animal selectivity no longer meets nutritional requirements becomes a primary concern. This type of information is scarce for domestic ruminants (Pieper and others 1959, Cook and others 1962) and is totally lacking for wild horses and burros.

When considering possible nutritional deficiencies in equids, it is important to recognize that the recycling and storage of some nutrients may buffer some apparent deficiencies in the diet. Nitrogen recycling in horses (Robinson and Slade 1974) may lower the maintenance requirement during seasons of plant dormancy when crude-protein availability is low. Church and Pond (1976) reported that ruminants can store reserves of vitamin A in the liver for 90 to 120 days. Recycling and storage are perhaps more important to horses than burros, however, because the latter typically have year-round access to evergreen plants in the types of habitats they occupy. Furthermore, parts of the Great Basin-Intermountain region support palatable shrubs that contain good sources of vitamin A all year (Cook and Harris 1968).

If, as Janis (1976) and Hintz and others (1978) suggest, equids do compensate for a low availability of critical nutrients by processing larger volumes of forage, then the most important nutritional consideration to wild horses and burros may be the quantity rather than the quality of forage. On horse and burro ranges, forage availability is most often limited by the degree of current annual production, utilization, and sometimes snow cover. This last limitation may not be as important for horses, since they are often reported to be capable of pawing through snow for forage. Salter and Hudson (1979) reported that horses were "adept" at obtaining forage beneath snow as deep as 0.6 m, and that they foraged in snow-covered areas even when south slopes were bare. In the same study, winter diets reached a low of 6 percent crude protein and a high of 52 percent acid detergent fiber, probably acceptable levels for maintenance.

Probably the most critical criterion for evaluating horse and burro forage supplies is the extent to which energy is available and the degree to which availability coincides with requirements. As is true for most mammals, the nutritional demands of horses and burros are highest during the last trimester of gestation (when 90 percent of fetal growth occurs), and during lactation and growth (see NAS 1973 for specific values). Energy required for thermoregulation may also be substantial at times during winter months, but data inadequacies prevent evaluation of this topic. Some of these periods of high requirement coincide with the period(s) of peak forage nutritional values. Energy for maintenance of body temperature in winter is a notable exception, but such a demand is generally not as enduring or as great as those for reproduction and lactation.

Wild and free-roaming-horses generally foal in the spring when forage is generally nutritious. Thus, nutrient requirements of lactating mares and foals are probably met except when droughts are extreme or ranges severely depleted. Although it is not documented, fetal development may sometimes be inhibited, especially on ranges where forage is scarce in winter. Yearlings may also suffer insufficient intake for growth on depleted ranges and during harsh winters.

Burros, by contrast, foal year-round, with a peak in spring and summer, as discussed above under "Equid Demography." Consequently, performance of jennies, survival of foals, and growth of colts are likely to be less dependent on seasonal greenup than on annual productivity of the range. Greenup will certainly favor reproductive success, but this event coincides with the peak requirements of only a portion of some herds. In other herds foaling is virtually as seasonal as it is in horses.

Basically, we assume that wild horses and burros are limited by the same constraints in food supply as are grazing ruminants, the main difference being that horses and burros may be more resistant to depleted forage supplies than are ruminants. This presumption, however, must be verified.

Habitat Preference and Use, and Interspecific Competition

Forage preferences and consumption rates alone do not provide enough information to support decisions for a given land unit on the amount of forage to be allocated to horses and/or burros, livestock, and wildlife, and on the numbers of each type of animal to be carried on the unit. Several different patterns of interaction could be envisaged between these categories of species--patterns that would influence decision making.

1. The different groups might select mutually exclusive habitat types, and whether forage preferences were similar or not, would not affect each other's populations. No interspecific competition would occur in this situation.

2. The different groups might have overlapping habitat preferences but through behavioral interaction, segregate into discrete portions of the habitat. If competition here is gauged by what a species is capable of in the absence of the other, this example

could be classed as competition if forage in one (or more) of the habitats became limiting to the species occupying it (them).

3. The different groups might have overlapping habitat preferences and remain sympatric. If they had different forage requirements, they would not compete. If they had overlapping forage requirements, but were not present in sufficient numbers to deplete the forage to limiting amounts, they would not compete. But if the forage were reduced to the point of affecting the welfare of one or more of the groups, then competition would occur.

Clearly, when developing criteria for site suitability it is important to understand habitat preferences and uses, and whether competition is a possibility or a reality. Possible competition between wild horses and cattle was reviewed before the following comments were made.

Broadly viewed, habitat analysis and evaluation--the techniques of which are reviewed in deVos and Mosby (1971)--address two complementary sets of questions. One set involves the structural characteristics of the habitat in terms of vegetation, topography, soils, and water. Extensive literature exists on the measurement of habitat in such diverse organisms as small mammals (Rosenzweig and Winakur 1969; M'Closkey 1972, 1975, 1976, 1978; Rosenzweig 1973; M'Closkey and Lajoie 1975; M'Closkey and Fieldwick 1975; Conley 1976; Lemen and Rosenzweig 1978), medium-sized mammals (Conley and Southward unpublished), molluscs (Green 1971), a variety of birds and other taxa (Shugart and Patton 1972), and elk (<u>Cervus elaphus</u>) and mule deer (<u>Odocoileus hemionus</u>) (Sivinski 1979).

A second set of questions involves the behavioral responses of animals to the habitat. These questions are concerned with the habitat aspects that are required for such activities as feeding, breeding, parturition, escape, and protection from weather, and collectively are subsumed under the term "habitat selection."

In establishing suitability criteria for horses and burros, it is important to recognize that while there is some optimum for them that might appropriately be termed the "preferred habitat," the animals may be forced to occupy suboptimum conditions due to habitat degradation, competitive displacement by other species, or simply the absence of the optimum. This type of habitat may be called the "subsistence habitat." The parallel terms of animal response are "habitat preference" and "habitat use." The distinction is made here because it cannot be automatically assumed that an animal's presence in a given type necessarily implies that that type is optimum.

Since interspecific competition can profoundly affect a species' habitat-use patterns, and must be taken into account in allocating forage among the several species groups dealt with here, it should be considered in some detail. By most definitions, interspecific competition is judged on the basis of two criteria (Milne 1961, Conley 1976): (1) two species compete when they both use some resource that is present in short supply; and (2) in using the resource, each species reduces the other's population performance, and ultimately fitness, to levels below what these measures would be in the absence of the other species. The important implication is that two species can use the same resource, but if their joint use does not reduce it to the point where each limits the other's demographic performance, they are not competing.

This point seems to have escaped the writers of much of the literature on competition. The extensive writing on dietary similarities among wild equids, livestock, and wildlife often infers competition without evidence of resource limitation or population effect. These reports (Cole 1954, Tueller and Lesperance 1970, Hansen and others 1973, Hansen and Reid 1975, Hubbard and Hansen 1976, Hansen and others 1977, Hansen and Clark 1977, Olsen and Hansen 1977, unpublished data obtained from BLM files) provide important data for describing the biology of each species, assuming the efficiency of the techniques used (Hansen and others 1973, Todd and Hansen 1974, Deardon and others 1975; but see Keiss 1977, Smith and Shandruk 1979, Vavra and others 1978). But such information is not sufficient to demonstrate competition among the species involved even when the vegetation is surveyed (e.g., Jordon and others 1979), much less when it is not (e.g., Hansen 1976).

Two species may use more than one common resource, and they may conceivably compete for one without competing for the other(s). It was mentioned earlier that two species may segregate into separate areas of the habitat as the result of behavioral interactions, and thus may eliminate competition for food. There are reports in the literature of this situation occurring between domestic animals and wildlife. Jeffery (1963) and Mackie (1970) reported that when cattle were present elk vacated areas that they otherwise occupied.

These flexible patterns of resource use are explained in Hutchinson's (1958) construct of the niche occupied by a species. In the absence of competition, a species occupies some broad portion of the resource spectrum for which it has tolerance; Hutchinson terms this portion the "fundamental" niche. In the presence of competitors, the species may constrict its distribution into some subset of the fundamental niche for which it is best adapted, and this subset is called the "realized" niche.

If a species expands its use or occupancy of resources upon the removal of another species, circumstantial evidence of competition has been established. This expansion has been termed "ecological release" (Ricklefs 1973, Pianka 1974). The concept has been used by various workers to infer competitive pressures (Ayala 1970; Koplin and Hoffmann 1968; Peterson 1973; Neill 1974, 1975; Rosenzweig 1973; Schroder and Rosenzweig 1975; Davis 1973; Simon 1975; Grant 1969, 1971; Morris and Grant 1972; Grant 1975; Crowell 1973; Crowell and Pimm 1976). Avoidance is more generally the response between competing species than outright aggression (Andrzejewski and Olszewaki 1963, Kikkawa 1964, Colvin 1973, Grant 1978), but exceptions exist, particularly under experimental conditions (Conley 1976). It has long been recognized that "niche space" is a highly complex phenomenon, and that in any given circumstance only a portion of such a theoretical construct can actually be measured. This process, called "a partial analysis of niche" by Maguire (1967), has been followed by a number of recent workers.

All of this discussion comes down to the point of discerning and measuring competition between wild equids, livestock, and other wildlife so that it can be provided for in management plans. Since an essential criterion of competition is the creation of a population effect, its existence cannot absolutely be established without experimentally manipulating one species and ascertaining whether the other responds.

If equids are competing with other species for food, the effect is presumably on nutrition and ultimately demographic performance. Since equid demography is so conservative, a demographic change following experimental reduction in a suspected competitor would be difficult to measure in the time available for this project. It is hoped that a nutritional change could be detected through blood analysis (described below under "Needed Research"), and that the demographic results could then be assumed. Research on possible nutritional response is outlined in Chapter 5.

If equids partition the habitat with other species through behavioral interaction, this state of affairs can be identified readily through experiment. Habitat use can be measured in the presence and absence of suspected competitors. Such experiments are outlined in Chapter 5 of this report.

NEEDED RESEARCH

Overview

Rationale for Projects 1 Through 7

It is clear from the "State of Knowledge" sections in this and later chapters that there is not enough of the information needed to formulate effective horse/burro management plans. Broad gaps in understanding exist in nearly all aspects of management. In order to fill these gaps, the Committee is advocating the 18 research projects listed in Chapter 1 of this report. We believe that the data base provided by these projects will help develop the more effective equid management programs toward which the BLM and USFS are moving, and which PL 95-514 prescribes. The projects are divided into four groups, which correspond to the four main chapters of this report. The first three groups also correspond roughly to the areas of concern of the three subcommittees and to the three connotations, discussed above, of the term "excess" used in PL 95-514.

In considering what is implied by the term "excess," we have approached the matter from the following perspective. Any given tract of land has a certain ecological potential to support herbivores in an equilibrium state. That potential is determined by the site's climate, topography, soils, water, and vegetative characteristics, as well as by the nature of the collective herbivores themselves. Policy decisions based on biological, sociopolitical, and economic considerations can allocate some portion of that potential to equids. As brought forth in our discussion at the beginning of Chapter 2, equids reach excess numbers when they increase to population levels that (a) threaten their own health and welfare, (b) threaten other components of the ecosystem they occupy, and/or (c) interfere with other management goals for that area.

In order to allocate a portion of the area's potential to equids, the manner in which they use it in terms of habitat selection, food consumption, and interaction with other animals must be understood. Once the allocation is made, their biological performance--in terms of nutrition, demography, behavior, and genetics--must be monitored to detect when the animals are approaching excess numbers in the first sense, and are threatening to exceed the portion of the area's potential allocated to them.

Accordingly, the seven research projects that are discussed in this chapter are designed to assist in making the allocation decisions, and to monitor the welfare and biological performance of the animals. These are:

- Project 1. Habitat Preference and Use by Co-occurring and Separately Occurring Feral Equids and Cattle
- Project 2. Food Consumption Rates and Nutrition of Wild and Free-Roaming Horses and Burros and Their Associated Species
- Project 3. Nutritional Plane, Condition Measures, and Reproductive Performance in Domestic Mares
- Project 4. Blood Assay of Experimental Equids and Livestock in Projects 1, 2, 3, 5, and 8
- Project 5. Demography of Wild Horses and Burros
- Project 6. Social Structure, Feeding Ecology, and Population Dynamics of Wild and Free-Roaming Horses and Burros
- Project 7. Genetic Polymorphism.

The projects set forth in Chapter 3 address the welfare of other ecosystem components and the second connotation of what constitutes "excess" numbers, while those in Chapter 4 address the third connotation.

Time Constraints

There is one aspect of the research on which the Committee strongly and unanimously concurs, and we believe that we must declare our view on the matter forcefully. PL 95-514 and the BLM/NAS contract decree that the research shall be carried out essentially in the 2-year period covering 1980 and 1981, and that the Committee is to marshall the evidence and complete a final report in 1982. It is the Committee's opinion that much of the information needed to provide a sound base for management programs cannot be generated in a 2-year period. The area in question encompasses semi-arid and arid regions. Such climatic types are the most variable on earth. Rainfall, varying from year to year in a largely random and unpredictable fashion, may differ by a factor of 10 between 2 successive years. Vegetative production is equally variable.

Consequently, the composition and quantity of forage available to horses and burros, as well as to other herbivores, varies markedly between years. Any hope of ascertaining the overall patterns of food preference, nutritional condition (and therefore behavioral and demographic performance), competition with other herbivores, and impacts on vegetation and watersheds depends on long-term research that covers the full range of climatic variability. At the very least this work would take 6 to 10 years.

The research program that we propose in the following pages will increase our current knowledge of horses and burros substantially. But we wish to make it clear that a 2-year effort would fall considerably short of supplying the informational needs that have been discussed in the foregoing pages. In a number of cases, a 2-year effort would add so little to what we now know that one could question the wisdom of making the commitment to it.

Integration, Scale, and Geographic Distribution

Project 1 should be conducted with study plots no smaller than 5 to 6 square miles per experimental treatment (to be outlined shortly), and possibly much larger. The types of scientific observations to be made will include equid behavior and habitat measurement. Project 2 (and Projects 8 and 9, to be outlined later) should be conducted in study plots ranging in size from about 100 to 300 acres per experimental treatment. The scientific observations to be made include range ecology, feeding behavior and nutrition, and measurement of various watershed parameters. Thus several disciplines will be needed, and the location and design of experiments will need to consider the availability of these capabilities. In addition, Project 4 should be carried out in conjunction with Projects 1, 2, and 8, and therefore should be planned and designed in coordination with them. Project 10 (discussed later) is likely to need a study area of about the same size as that needed for Project 1, but will require the presence of a riparian zone. Therefore, where possible (i.e., where scientists of both disciplines are available) both Projects 1 and 10 should be carried out in the same sample plots.

The ideal integration of these projects can be seen below in the scheme for a single replication.

	Grazing Intensity	
Class of Animals	Moderate	Heavy
Horses	Projects 1, 4, 10 Proj. 2, 4, 8, 9	Projects 1, 4, 10 Proj. 2, 4, 8, 9
Cattle	Projects 1, 4, 7 Proj. 2, 4, 8, 9	Projects 1, 4, 10 Proj 2, 4, 8, 9
Horses and Cattle	Projects 1, 4, 10 Proj. 2, 4, 8, 9	Projects 1, 4, 10 Proj. 2, 4, 8, 9
Neither	Proj. 2, 9	Proj. 2, 9

Each of these experiments should be replicated three or four times, perhaps once in each of three or four states. It is not essential that the large-scale (1, 10) and small-scale (2, 4, 8) studies be combined at a single site as shown here. If expertise for Project 1--but not for Projects 2, 8, and 9--exists in a single area, then a replication of Project 1 could be carried out in one area, and a replication of 2, 8, and 9 elsewhere. But if the combined expertise can be brought together in a single area, then integration is desirable and efficiency is gained.

First priority is given here to horses and cattle because the possibility of competition, both behavioral and nutritional, seems to be greatest. However, if funds permit, sheep could be included, although their addition to the above scheme would double the number of experimental treatments in each replication. A similar rate of increase could be anticipated with the addition of each additional wild ruminant species. The scheme could also be repeated using burros instead of horses.

Details of the individual projects follow.

Project 1. Habitat Preference and Use by Co-occurring and Separately Occurring Feral Equids and Cattle

Rationale

As discussed above, before proper resource allocation and development of site-suitability criteria can be carried out, it is necessary to understand the habitat preferences of equids and other large herbivores on the range, and how their use of preferred habitat might be modified by interspecific competition. Since preferences--as well as the presence and distribution of the different species--may vary seasonally, it is desirable to initiate studies on this phase as early as possible. They should be conducted year-round throughout the period of this program.

Objectives

1. Determine utilization patterns in relation to habitat structure (vegetation, topography, soil, and water) demonstrated by feral equids and domestic bovids in the presence of, and the absence of, potential competitors (i.e., equids alone, equids and cattle, cattle alone).
2. Develop an appropriate multivariate statistical model that allows testing of the null hypothesis: "there is no difference in utilization patterns between equids and bovids."
3. Use the statistical model in (2), above, to describe probabilities of habitat utilization patterns that can be used to develop site-suitability criteria for both equids and cattle.

4. Synthesize the results from (1) through (3) above with the nutrition program, and evaluate the existence of, and potential for, competition between the two species.

Methodology

1. A single experimental block should be a large area containing wild horses or burros.

2. Such a block should be subdivided into six treatment cells about 5 to 6 square miles each, and containing adequate habitat and topographic diversity.

   a. Cattle stocked at proper, long-term carrying capacity levels.
   b. Cattle stocked at levels considered to be excessive with regard to long-term health of the vegetation.
   c. Equids stocked at levels described in a.
   d. Equids stocked at levels described in b.
   e. Equids and cattle stocked as in a.
   f. Equids and cattle stocked as in b.

These cells must be large and diverse enough to allow natural segregation of habitat use patterns if differences exist, and to allow for sufficient numbers of individuals to ensure statistical reliability.

3. To eliminate bias, the sampling program should be a suitable random or stratified-random design, and should concentrate on activities related to (a) feeding and watering, (b) escape (from pests or disturbance), and (c) parturition and care of newborn. For each of these categories, multivariable vectors representing characteristics of habitat structure are to be obtained. Variables chosen for measurement should reflect local conditions and incorporate consideration of vegetative structure, aspect (topography), edaphic structure (in the broad sense), and availability of water and/or other special requirements. It is desirable to use telemetered individuals to facilitate location for observation. In keeping with the nutrition experiments, the use of breeding-age females should be emphasized in order to maximize the potential for detecting demographic effects if they exist.

4. Preliminary measurements should be evaluated for variation, and sample sizes computed (e.g., Cochran 1977) for stated levels of precision. Statistical procedures should follow the example of workers cited above (e.g., M'Closkey 1975, Shugart and Patton 1972, Sivinski 1979). Multivariate analyses that allow testing of null and alternate hypotheses and projections to group membership should be emphasized. Suitable divisions of data sets should be included to maximize predictability.

5. This entire experiment should be replicated three or four times in as many states so that generalized statements can eventually be made about equid and bovid habitat preferences and use patterns, and possible effects of competition.

6. Blood assays should be taken (see Project 5), and the reproductive condition of mares should be checked in the appropriate season.

Project 2. Food Consumption Rates and Nutrition of Wild and Free-Roaming Horses and Burros and Their Associated Species

Rationale

Knowledge of animal impacts on plant communities addresses only half of the complex question of grazing animal management. The range manager must also understand the autecological limitations on animal production. Studies of this nature provide the critical link between the plant community and the demographic response of the animal population in question. Considerable research has been conducted on the nutrition and feeding ecology of sheep and cattle (e.g., Cook and Harris 1968; Cook and others 1953, 1962, 1967), mule deer (e.g., Dietz and Nagy 1976, Smith 1952, Smith 1959, Hansen and Reid 1975), and pronghorn antelope (e.g., Beale and Smith 1970, Mitchell and Smoliak 1971, Severson and May 1967, Severson and others 1968). However, little comparable work has been done on either the horse or burro under range conditions.

Virtually no information exists on daily forage intake by horses. This information is critical in that it enters into calculation of grazing capacities under the BLM's forage allocation system, and it supplies the quantitative perspective for any nutritional evaluation of habitat.

From an experimental and technical point of view, studies on nutritional value (i.e., chemical composition) of range forage ingested by grazing horses and studies on forage intake can logically be integrated and can proceed simultaneously. However, the dietary chemical composition has secondary priority and could be delayed or deleted if necessary. Studies on food habits can also be integrated into such an inquiry, and the data can be easily obtained in conjunction with work on nutrition and intake. All of these components are presented as objectives on the assumption that they will proceed simultaneously under a single experimental design.

Objectives

1. Determine seasonal botanical composition of diets in relation to kinds and amounts of available forage.
2. Determine daily forage intake as related to animal size and physiological status (i.e., maintenance, gestation, lactation) and to kind and amounts of available forage.
3. Determine nutritional value of the diet as related to animals' nutritional demands and as affected by season and kinds and amounts of available forage. Major attention should be given to

dietary nitrogen, phosphorus, digestible energy content, and fiber components according to the system of Van Soest (1967).

Methodology

1. Objectives in this study can be met by using domestic horses and tractable livestock (cows or sheep) as experimental subjects.

2. Diets should be determined by a technique other than fecal analysis. Use of animals fitted with esophageal fistulae and cannulae, with subsequent microscopic analysis of fistular extrusa (reviewed by Theurer and others 1976) is a valid technique that is probably feasible under the constraints of the present design. Alternatively, a bite-count technique (Wallmo and Neff 1970) or a suitable modification thereof would be appropriate if carefully controlled and validated with a proven procedure, such as the fistulated animal technique. These specifications do not preclude the use of the fecal-analysis technique. Indeed, this study would provide an opportunity to validate it under field conditions. However, it should not be relied upon as the sole procedure, since its accuracy and precision are presently subject to question (Smith and Shandruck 1979, Vavra and others 1978).

3. Diets should be sampled on at least a monthly basis during times when animals inhabit the particular range being studied. Detailed information on forage available (such as that derived from Project 8, the "grazing impacts" study) should be obtained in conjunction with dietary sampling.

4. Nutritional value of diets should also be studied on a monthly basis, and such studies could be linked with diet-analysis studies, as outlined under objective 1 above. Laboratory analysis of samples obtained either from animals (via fistulae) or by hand plucking should include as a minimum: dry matter, nitrogen (crude protein), phosphorus, gross energy, cell walls, cellular constituents, and lignin.

5. In addition, estimates of forage digestibility should be obtained for ruminant species grazing with horses. In-vitro techniques are recommended, preferably those of Tilley and Terry (1963). However, since in-vitro procedures have apparently not been perfected for equid species, a limited number of in-vivo digestion trials with horses will be required. Such trials should employ classical techniques in which penned animals are fed controlled quantities and total feces are collected. The major forage species constituting the seasonal diets of horses should be fed in mixtures approximating the proportions normally ingested by the animals (as determined under objective 1, above). This approach is limited by the logistics of harvesting suitable quantities of native forages for feeding trials. However, alternative methods such as the lignin-ratio method appear undependable. These trials will offer the opportunity for development of in-vitro procedures directly applicable to equid species. This technique development should be pursued, as the

potential payoff is large in relation to the small marginal investment of research time and funds.

6. Forage intake by the grazing animal should be measured by the procedure of Garrigus and Rusk (1939), described by the equation:

$$\text{Dry matter intake} = \left(\frac{\text{Fecal output}}{100} - \%\ \text{dry matter digestibility}\right) \times 100$$

7. Fecal output should be measured using total collection procedures with animals wearing fecal collection bags. Alternatively, indicators of indigestibility (e.g., Cr_2O_3 or appropriate rare-earth compounds) can be used to estimate fecal output if adequately validated and quantitated.

8. Intake studies on horses should focus on the reproductive female and the field experiments should be phased so that they cover the three major physiological phases: maintenance, gestation (especially the last trimester of pregnancy), and lactation.

Project 3. Nutritional Plane, Condition Measures, and Reproductive Performance in Domestic Mares

Rationale

The nutritional condition of the female is considered to be of primary importance to estrus, ovulation, and early survival of the offspring from conception to weaning. The rate at which offspring are produced is a critical demographic parameter when estimating rates of population increase. If levels of energy and nitrogen intake can be successfully linked with reproductive success, and these levels of response can be predicted by measures of condition of the animal, then the ability to estimate reproductive rate from range condition or nutritional condition of the animals is greatly enhanced.

Objectives

1. Determine the relationship between the nutritional plane of a mare and the probability that she will produce a foal.

2. Assess condition measures for their ability to predict the relationship between nutrition level and reproductive success. Should some condition measures prove to be successful predictors of reproductive rate, they could be used to estimate these rates in wild populations.

Methodology

1. Confine groups of 10 domestic mares for 2 years (or 15 to 20 if conducted in 1 year) in each of the nine blocks to be described

below. Do not use ponies. Ideally, the study should run for 2 years, since the given nutritional plane may have a cumulative effect. Reproduction in one year often reflects nutrition from a previous year, although acute nutritional deprivation can delay onset of estrus or perhaps inhibit it completely if there is no improvement in food supply. The mares should range in age from 4 to 10 years. The age of onset of estrus is a separate question.

2. The nine feeding blocks are all the possible combinations of three levels of energy and three levels of nitrogen intake. This nine-block design can be achieved in several ways:

a. Levels are set in absolute intake values for energy and nitrogen and not varied throughout the experiment. This method is the simplest to conduct. The constant feeding system has the advantage that a particular level of energy and nitrogen intake can be related directly to success in a particular stage of reproduction.

b. Three levels of energy are fed, simulating various winter conditions. After "winter," each of these three groups is divided into three groups and fed at high, medium, and low spring conditions. This design examines the nine possible conditions of a poor-, medium-, or high-quality winter being followed by a poor-, medium-, or high-quality spring. The advantage of this design is that it simulates the real sequence of events in wild populations more accurately than would a constant ration. However, the experiment will contain 81 cells if the design includes nitrogen as well as energy, and hence is too large to accomplish with a reasonable effort.

c. Nutritional levels are fed as some percentage of the NRC requirements for maintenance, gestation, and lactation. In this case nutritional intake at a particular level would increase during gestation and lactation according to some percentage of the increment suggested by the NRC. The difficult aspect is to establish the levels for feeding the nutrients. Investigators might choose to employ conditions existing on very good and very poor ranges and to include an intermediate level.

d. Nutritional levels are set as a percentage of dry weight and horses are fed ad libitum. This technique allows the horse to respond naturally to poor food by increasing its intake. The percentage of dry matter as a measure of nutritional level is more easily translated into range conditions than other measures used in the three previous designs. The horses will not be on a constant plane of nutrition and the establishment of high, medium, and low nutritional levels will be difficult. However, some preliminary feeding trials might establish the capability.

3. The following reproductive parameters should be measured to establish quantitative relationships between nutritional plane and reproductive success, which may then be used for demographic models of specific ranges:

a. Estrus (onset and behavior)
b. Ovulation rate (rectal palpation)
c. Number of estrus cycles before pregnancy (behavior and progesterone), extended cycles (prolonged corpora-lutea life).
d. Conception
e. Implantation rate (rectal palpation, PMSG, progesterone)
f. Embryonic loss (PMSG, progesterone, urinary estrogens)
g. Foaling rate (count live abortions and stillbirths)
h. Length of gestation (dates of breeding)
i. Parturition (independent or requiring assistance, duration of birth)
j. Weight of foal at birth
k. Lactation behavior (ability to nurse, acceptance by mare)
l. Nutritional composition of milk (colostrum at 2 and 6 weeks, protein, fat, carbohydrate)
m. Milk production (probably difficult to quantify)
n. Foal growth and behavior (weekly weight, withers height, etc., and simple estimate of activity level).

4. Condition measures should be made every 2 weeks in order to establish measures that correlate with empirical intake data, general condition measurements, reproductive parameters, and seasonal variation. These standards would allow evaluation of particular wild herds and assist demographic projections of population changes. Recommended tests are:

a. Hematology (CBC)
b. Chemistry (serum urea nitrogen, glucose, triglycerides, serum protein and albumin, uric acid, bilirubin, free fatty acids (NEFA), CPK, ketones, haptoglobin, transferrin)
c. Hair bulb diameter.

5. Behavioral sampling should be performed for the following purposes: determining activity levels so that nutritional levels can be accurately generalized to free-roaming populations, whose activity levels are likely to be different; correlating differences in reproductive performance and condition to activity measures; and comparing nutritional treatment effects on activity.

a. Specific behavioral sampling: When females in the experiment are mated, behavioral samples identical to those used in the contraceptive experiment (Project 18) will be recorded. These data will show how the nutritional plane affects the sequence of sexual behaviors between the stallion and the mare.

b. Focal animals: The groups for this experiment will be composed of mares from each nutritional group and an experienced stallion.

c. Sampling schedule: The sampling schedule should take place primarily during the breeding season so that good activity profiles are available for different phases of the breeding cycle.

d. Specific behavioral samples: Behavior of the animals is important to the determination and function of their social groups and to successful breeding. Since nutrition affects the reproductive success of the animal, it will be essential to measure the differences in behavior between nutritional groups to determine the sensitive points in the reproductive cycles. The effect of behavioral changes in individuals on the group's social dynamics might be monitored and the ecological and management implications of these effects can be suggested.

e. Sampling scheme: Besides the activity and frequency of social behavior sampled by FSP (see Project 6) method, the reproductive behavior needs to be sampled in detail. Reproductive behavior can be divided into functional categories. These divisions are established because breakdown in the reproductive act can be attributed either to the mare or the stallion and the point at which failure occurs can be assigned to a particular phase of the reproductive interaction. The objective of this sample will be to monitor behavior of mares of different nutritional planes and that of their stallions to determine differences in each of these functional categories. Differences can then be related to failure of behaviors at these stages of reproductive sequence. Continuous focal samples should be taken. The timing of the samples and their intensity can be determined by the researcher. The continuous samples will record the occurrence of sexual behaviors upon a time record. From these samples the rates of behavior can be calculated and tested against estimates for wild populations.

Spacing data will provide information on the distance maintained between individuals in the groups. Such data can be taken at a point in time where the distances and identity of the individuals are recorded. These samples would be taken at the beginning and end of all half-hour FSP samples. These data will allow a comparison not only of sexual states but also of dominance rank. Spatial displacements, usually a reliable indicator of relative dominance between individuals, will be recorded as part of the continuous focal samples.

Project 4. Blood Assay of Experimental Equids and Livestock in Projects 1, 2, 3, 5, and 8.

Rationale

It has been suggested above that various blood characteristics might be used to provide sensitive and easily obtained indices of nutritional plane. These could, on the one hand, be used as predictors of the animals' demographic performance, and on the other hand, as indicators of the range condition. This project recommends routine blood sampling and assay on experimental animals described in Projects 1, 2, 3, 5, and 8 to test the utility of these measures in describing ecological and nutritional characteristics.

Objectives

1. Systematically collect blood samples during habitat-interaction studies from cattle and horses for hematology and chemistry assays to provide independent evaluation of animal condition and to establish correlates with range-condition evaluations.
2. Systematically collect blood samples during range-nutrition studies and assay to establish correlates with condition and known levels of food intake and utilization.
3. Systematically collect blood samples from mares in the reproductive-performance study to establish correlates with condition, reproductive success, and mechanisms of reproductive suppression.

Methodology

1. At each sampling, extract 50 ml of blood from the jugular vein of animals that are roped and pole-restrained, immobilized in chutes, or drugged. The procedures are well-known and are commented upon by Kirkpatrick and others (1979a) in his article on restraint procedures for evaluation of stress. If drugs are used, they must be identified and specified, since the various immobilization drugs have an impact upon laboratory studies (excluding genetic studies). In particular, xylazine (Rompun®, Chemgro Corp.) should be avoided if the clinical metabolic studies for evaluation of condition are to be performed, since its administration results in a steady increase in blood urea and blood glucose for a period of 4 to 6 hours. It also would be desirable to collect the samples from the animals as soon after capture and handling as possible, and certainly before they are transported to more permanent holding facilities and fed..
2. Samples should be preserved until assay by a single laboratory to minimize interlaboratory variation. Procedures should be established to document quality control, including reproducibility and accuracy. A high degree of laboratory precision can be achieved in each of the assays listed below and excellent procedures and equipment are available for this purpose.
3. Approximately 2 ml of the sample should be drawn into a tube containing EDTA (ethylenediaminotetraacetate) as an anticoagulant for hematology, 5 ml into heparin for preparation of red cells and plasma for molecular genetic studies, 5 ml into Alsevier's solution for blood group typing, and the remainder into untreated tubes for preparation of serum.
4. The following blood assays should be evaluated for correlation with measures of animal nutritional condition, evaluation of range condition, measures of reproductive success, and estimation of the

presence of disease: serum urea, hematocrit and hemoglobin concentration, serum protein concentration, haptoglobin, creatine phosphokinase, triglycerides, uric acid, bilirubin, free fatty acids and ketones, white cell count and differential, transferrin, and various special clinical studies (serology).

Project 5. Demography of Wild Horses and Burros

Rationale

It is clear from the discussion on demography in the first part of this chapter that the particulars of this aspect of wild horse and burro biology are not well known. We have seen that the basic demographic parameters of (a) age-specific fecundity, (b) first-year survival rates, (c) adult survival rates, (d) age structure, and (e) sex structure are known only by the roughest approximation, and are often based on extremely small samples that make for an equally low precision of estimate. Even less well-known are the ranges of variation in these parameters and the role of such environmental variables as weather/climate, forage condition, nutrition, competition with other herbivores, and population density in producing this variation.

BLM officials have frequently accorded demography a high priority among the research needs on horses and burros. While we have not asked the reasons for this ranking, we surmise that the research is desired to dispel the disagreement over BLM's stated rates of population increase, and in general to resolve the question of population growth.

The relevance of demographic understanding to an equid management program depends on the level of management. At its least intensive, such understanding is not essential. Once a decision is made for a given tract of land on how much forage is to be allocated to equids, and on the population level that this implies, the population can simply be held at this level. Assuming that the census method is valid, the population can be counted annually, or at some other interval. As its numbers exceed the desired level, the excess can be removed periodically irrespective of what the increase rate may be. Another situation in which there is no need to know increase rates is if some populations are allowed to limit themselves, irrespective of their impacts on the ecosystem.

At a slightly more sophisticated management level, if the approximate rates of increase are known, then needed removal rates can be anticipated. Reduction operations can be planned well in advance.

A considerably more knowledgeable program would incorporate a thorough understanding of equid biology and of the relationships between environmental variables and demographic performance. The fact that performance would probably vary from herd to herd, and from year to year--as well as the causes of the variation--would be understood and anticipated. Such a program would result in a more insightful and sympathetic understanding of equid management. It would also have some predictive capability.

The Committee is divided on its own assessment of priority for demographic research. Those who accord it low priority do so on pragmatic grounds. A limited research commitment, in this group's view, would not add materially to what is now known. To refine by a few percentage points the survivorship estimates, or sharpen somewhat the fecundity parameters, would not alter the basic picture of increase rates developed in the earlier demography section. On the other hand, the mounting of a research program sufficient to delineate precisely the range of variation in these parameters that occurs between areas and years--as well as the functional relationships between that range and associated environmental causes--would entail a cost beyond the resources likely to be available for such research.

Those who assign high priority to demographic research contend that the parameters are too poorly known for workers to have any confidence in the present level of understanding of equid demography and in the various calculations of herd increase. Any increase in precision over what is now known would be a gain and worth the cost.

Among the parameters to be measured, there would appear to be some grounds for assigning priorities on the basis of (a) cost, (b) present level of understanding, and (c) the extent to which more information would contribute to the present level of understanding. Evaluations of these three measures are presented below for each parameter.

1. Age-specific fecundity

a. Least costly. Could be elucidated as outlined under "Methodology," below.

b. Inadequately known at present. Because it may be one of the parameters more sensitive to environmental factors, it may therefore be one of the more variable parameters, especially in burros.

c. An increased data base would refine the present estimates and could give some understanding of the range of variation and its relationship to environmental conditions.

2. First-year survival

a. Extremely costly, especially if designed to provide a good understanding of the range of variation and associated environmental causation.

b. Perhaps the least understood parameter at present, and one that is likely to be highly sensitive to environmental variation, especially in burros, and therefore highly variable within and between populations.

c. The value of an increased data base would depend on the scope of the research. Just to measure first-year survival for 1 or 2 years in a few populations would not add substantially to what is now known. We currently have a range of scattered, first-year survival estimates, crude though they may be. The next higher level of understanding will come when we have measured the range <u>within</u> each of an array of populations, along with measurements of the relevant environmental variables. Such a study would involve a commitment to several years of research in each of a number of populations, and would ultimately allow formulation of the functional relationships involved.

3. Adult survival.
   a. Costly.
   b. Poorly known, but one that is probably least sensitive to environmental variation and therefore least variable within and between populations.
   c. An increased data base would refine the present estimates, but would, in the opinions of some (but not all) members of the Committee, not add a great deal to present levels of understanding.

Objectives

The objectives of this project are to measure age-specific fecundity rates, first-year survival rates, and adult survival rates to two different levels of precision. The more definitive level will, of course, be the more costly.

Level 1: Obtain an array of measurements more precise than those currently available from a number of different populations.

Level 2: Obtain a series of measurements in each of a number of populations to determine the range of variation in each, and to correlate those with relevant environmental variables.
Methodologies for each of the three rates are described for Levels 1 and 2 in the following section.

Methodology

1. Age-Specific Fecundity Rates, Level 1: Determine pregnancy and corpus-luteum rates by rectal palpation of horses and burros captured in the course of herd-reduction efforts, or by autopsy of burros shot on national parks and monuments. Observations would need to be made in late winter or early spring in the case of horses and seasonally breeding burro populations, and perhaps again in the fall in burro populations breeding year-round.

2. Age-Specific Fecundity Rates, Level 2: Ideally, the range of variation between years--within and between populations--would be determined by rounding up the individuals within studied populations each year, palpating them, and releasing them. Level of precision--i.e., the confidence intervals around the estimates--would be decided upon before sampling, and this factor, along with prior measures of variability of the measured parameters, would dictate the sample sizes needed. Concurrently, weather records would be kept; the condition of the ranges occupied by the herds would be measured annually; blood assays (Project 3) would be taken of the sampled

animals; and the total populations would be censused to provide measures of population density. Numbers of potentially competing ungulates should be determined, along with total forage available and its allocation to all herbivores present. Properly, each herd should be studied in this way for not less than 5 or 6 years, and preferably 10.

If this ideal is not possible, then some level intermediate between it and Level 1 could be achieved by recording range condition, weather pattern in the 10 to 12 months prior to sampling, and population density for the locales in which each roundup providing animals for Level 1 studies is carried out. In addition, blood assays should be taken from the animals that are palpated and from males and young females in the herds. This collective information could not only give fecundity estimates that are more precise than those currently available, but could also provide background environmental information with which to relate them.

3. First-year survival rates, Level 1: Determine first-year survival rates by:

a. Rounding up samples of animals from within populations;
b. Palpating females in study design (1), above;
c. Placing radio transmitters on pregnant animals;
d. Releasing the telemetered mares, locating them periodically from the ground or air during the year after birth of their young, and determining which ones have foals surviving through the year; and
e. Predetermining sample sizes by deciding on the desired level of precision beforehand.

A scattering of 1- or 2-year studies in different populations should give some idea of the range of values for this parameter, and provide more precise estimates than are now available.

4. First-year survival rates, Level 2: Determine the range of variation within and between populations in first-year survival rates and the environmental causes of that variation by:

a. Measuring first-year survival rates as in study design (3) each year in each of several populations for at least 5 to 6 years, and preferably 10.
b. Recording each year the condition of the home range of each population; maintaining weather records; taking blood assays of the studied animals as they are caught, palpated, and telemetered; and censusing each population annually. Determine numbers of potentially competing ungulates, total forage available, and its allocation to all herbivores present.

5. Adult survival rates, Level 1: Determine adult survival rates by:

a. Rounding up samples of animals from within populations.
b. Placing radio transmitters on pregnant animals.

c. Releasing the telemetered animals, locating them periodically from the ground or air during the year, and determining which ones are still alive.
d. Predetermining samples sizes by deciding on the desired level of precision beforehand.

A scattering of 1- or 2-year studies in different populations should give some idea of the range of values for this parameter, and provide more precise estimates than are now available.

6. Adult survival rates, Level 2: Determine the range of variation within and between populations in adult survival rates and the environmental causes of that variation by:

a. Measuring adult survival rates as in study design (5) each year in each of several populations for at least 5 to 6 years, and preferably 10.
b. Recording each year the condition of the home range of each population; maintaining weather records; taking blood assays of studied animals as they are caught, palpated, and telemetered; and censusing each population annually. Determine numbers of potentially competing ungulates present, total forage available, and its allocation to all herbivores present.
c. Predetermining sample sizes by deciding on the desired level of precision beforehand.

7. Adult survival rates, a third approach: A great deal of age-structure data exists from the roundups. As shown in the demography discussion in the first part of this chapter, survivorship can be calculated from such data, although the method contains certain biases and demands large samples. A knowledge of population trend is also vital to its use. The available data should be explored further in populations that are censused annually, and ideally in those being studied by methodologies 5 and 6, so that results of the latter studies can be used as a check.

Project 6. Social Structure, Feeding Ecology, and Population Dynamics of Wild and Free-Roaming Horses and Burros

Rationale

Data on demographic patterns, feeding ecology, and population dynamics are important to determining what constitutes a healthy and viable breeding population of wild equids that will also permit maintenance of vegetation, soil, and water resources. Social structure, distribution and movement, and breeding patterns are particularly important to interpreting data on genetic variability and the potential effect of different cropping schemes on the genetic structure and viability of a population. Since activity levels determine part of nutritional requirements, enclosure studies will be insufficient for determining habitat preference and use, grazing impacts on range-plant communities, food-consumption rates and nutrition, and impact on riparian water quality of wild and free-roaming horses and burros.

In order to relate the findings on nutritional condition in the enclosure animals to those on the open range it will be essential to compare the level of activity between study groups, so as to make realistic generalizations concerning the feeding and nutrition experiments. If one is to understand the social effects of contraception in equids (see Project 18) it is necessary to have comparable measures of the behavior of experimental animals and wild animals. If there is a lack of comparability between studies, then the ability of researchers to generalize their experimental findings to wild populations will be severely limited.

A major point of controversy is the rate of increase in horses and burros. It is extremely important to document and integrate in free-roaming populations (a) population size and structure in terms of sex, age class, and social grouping; (b) daily activity pattern, feeding ecology, and energetics; (c) seasonal movements and home-range utilization; (d) nutritional level; and (e) age-specific reproduction and mortality.

Objectives

1. Determine the social structure, seasonal habitat preferences, and vegetation and water utilization of free-roaming equids on public lands.
2. Determine the daily activity pattern and dietary composition in relation to age, sex, physiological status (i.e., maintenance, gestation, lactation), and climate.
3. Assess nutritional status and general condition, and correlate these with activity, reproduction, and survival.
4. Determine age-specifc reproduction and survival.
5. Investigate the applicability of contraception as a means of managing wild equid populations.

Methodology

1. Establish three study areas each for wild horses and burros. In order to have the broadest possible application, research should be performed on populations that are not manipulated (i.e., cropped). One study area should be located in what is considered the most "marginal" habitat. Another area should be located in typical habitat, but be used to investigate the effect of contraceptive devices on social behavior, spacing, feeding ecology, and populaton dynamics of free-roaming equids.

2. For determining daily activity patterns and energetics, we recommend that at least the following data be recorded. Recorded information is to reflect activity states that provide data for calculating both energy budgets and social behaviors characterizing

the rates and directions of social interactions (i.e., who does what to whom). The following categories are to be scored: standing, standing eyes closed, lying down, walking, trotting, running, feeding, urinating, defecating, grooming, and social interactions. The term social interactions covers a multitude of what are often species-specific behaviors and which will require precise and common definitions across experiments. Researchers involved in these studies should be required to standardize these definitions after initial work has begun.

Point samples on these categories should be taken for 30 minutes each hour from 0600 to 1800 (light permitting), once every 2 weeks. Points are recorded every 2 minutes within the 30-minute sample. Two minutes has been chosen as being a sufficiently long period for a trained observer to record behaviors and identify individuals for a scan point sample of up to 5 or 6 focal animals, while providing a reasonable number of sample points. At the beginning and end of each 30-minute sample, interindividual spacing, location, habitat, and climatic data are to be recorded.

In horses, focal animals should include at least one dominant male, two females, one subordinate male, and one foal. Ideally, in horses, this group of focal-scan-point samples should be done on the same day, to provide daily profiles and to allow the determination of interdependence of behaviors within the day. For burros, whose groups are not as spatially coherent, samples cannot be simultaneous on different classes of animals. In burro studies, animals should include one territorial male, one nonterritorial male, two females, and one foal. In the contraception study (see below) one of the two females should be "contraceptive" and the other "normal."

3. The sampling scheme for monitoring detailed feeding behavior is to be a continuous focal-animal sample. Data are to be recorded on an animal in a continuous timed sequence. The schedule for sampling is identical to the FSP schedule. Data are recorded on one individual for 30-minute periods of each hour from 0600 to 1800. In these samples the onset, termination, and sequence of all behaviors (categories recorded for the FSP and reproductive behavior samples) are recorded on a real-timed record. The identity and size of all plants and plant parts eaten are recorded.

This detailed record is necessary to understand the basis of dietary selection in the horse and to measure changes in feeding response when inter- and intraspecific competition occurs. The detailed data on food intake are also necessary to estimate energy and nutrient balances in animals whose fecal output is collected. For both of these calculations it is necessary to know not only what is eaten, but to know specifically the rates at which forage species are eaten, the quantities ingested as a function of time, the sequence of ingestion through the day, and the diurnal patterns of gross intake rates.

Spacing data should be recorded at the beginning and end of each 30-minute sample. These data, coupled with displacement data collected as part of the continuous record, will allow dominance interactions to be related to feeding behavior.

Location, habitat, and climatic data should be recorded at the end of each 30-minute sample. Data should be recorded on the same focal classes of animals (N = 5) as were used for the scan-point sample.

4. Besides the activity and frequency of social behavior sampled by the FSP method, the reproductive behavior should be sampled in detail. Reproductive behavior can be divided into functional categories. These divisions are established because breakdown in the reproductive act can be attributed to either the mare or the stallion and the point at which the failure occurred can be assigned to a particular phase of the reproductive interaction. Proceptive behaviors are those that the female uses to make her estrous condition known to other animals. These behaviors include raising the tail, urinating at high frequency, urination stance, and approaching the male or altering her spacing relative to him. The male's responses to proceptive behaviors are called attraction behaviors. His approaches, spacing relative to the female, and mounting attempts signal his perception of her state. Her response to the male's attraction behavior is termed reception and is evinced in either acceptance or rejection of mounting attempts.

The object of the sample will be to monitor behaviors of "normal" and "contraceptive" females and their stallions to determine differences in each of these functional categories. Differences can then be related to failure of behaviors at particular stages of the reproductive sequence.

Samples should be continuous focal samples. The timing of the sample and its intensity can be determined by the researcher. The continuous samples will record the occurrence of sexual behaviors with a time record. From these samples the rates of behavior can be calculated and tested against estimates for wild populations.

Spacing observations give data on the distance between individuals of the groups. Such data can be taken at a point in time where the distances and the identity of the individuals is recorded. The samples should be taken at least at the beginning and end of all 30-minute FSP samples. Since spatial relationships often reflect social relationship, these data will allow a comparison not only of sexual states but also of dominance rank. Spatial displacements, usually a reliable indicator of relative dominance between individuals, will be recorded as part of the continuous focal samples.

5. Population size and sex and age-class structure should be monitored monthly. Age-specific reproduction and survival should also be monitored.

Project 7. Genetic Polymorphism

Rationale

Rational management of natural populations requires knowledge of the genetic structure of the population. In particular, it is necessary to ascertain the degree of genetic variation within and between populations. The amount of genetic variation in a population determines its "evolutionary potential," and hence must be preserved as the fundamental natural genetic reservoir of the species. The process of mutation may give rise to new genetic variations and may restore variants that have died out. However, the process of mutation is exceedingly slow--in vertebrates the typical rate at which a given allele at a given locus appears per generation is around one in a million individuals--and most new mutants are likely to be lost by random drift in the first few generations after their appearance even if they are adaptively favorable. Hence, it becomes important to preserve genetic variation in order to protect the welfare and evolutionary potential of the species.

The genetic variation of a group of populations may be present more or less equally in the various populations or each may have a different amount. Which of these situations obtains in a particular case must be ascertained, because each one leads to different strategies for the preservation of genetic variation. If several populations are nearly identical genetically, the preservation of any one population (subpopulation) is less important, because its genetic endowment will also be present elsewhere. On the contrary, if populations are genetically different from each other, the preservation of genetic variation requires that every one of the differentiated populations be preserved. In the case of wild and free-roaming horses and burros, it becomes important to study not only the wild populations but also the domestic breeds. For the reasons just mentioned, it must be ascertained whether or not the variation present in the wild populations is the same as the variation present in domestic animals. The comparison between domestic and wild populations may also make it possible to determine the ancestry of the wild populations.

None of the required information mentioned is presently available.

Objectives

1. Determine the amount and kind of genetic variation per population of wild and free-roaming horses and burros.
2. Determine the degree of genetic similarity among wild and free-roaming populations of horses and of burros.
3. Determine the degree of genetic similarity between wild populations and domestic breeds.

Methodology

1. Population Sampling. The information gained with a given amount of work is maximized if the populations are sampled in a "nested" fashion. The appropriate model to be followed should be coordinated with other projects, because blood (and tissue, if possible) samples from individual animals are needed. Ideally, one breeding wild group should be intensively studied (a sample of 50 to 100 animals might be sufficient, depending on the size of the group).

Two or three other breeding groups should be sampled within a given region, but fewer animals (10 to 20) would be needed from each group. In addition, one group from each of the other major regions (10 to 20 animals per group) in which the wild animals range should also be studied. This pattern of sampling should be followed for horses as well as for burros.

It will then be necessary to compare wild animals with domestic ones. About 10 animals for each of the main domestic breeds should suffice, although of course the more animals that are studied, the greater will be the amount of information obtained. The point is, however, that more information will be obtained by sampling a few animals from each of a number of breeds (or populations) than by studying a larger number of animals from fewer groups.

2. Genome Sampling. In order to obtain a valid estimate of the amount of genetic variation in a population, it is necessary to study a number of gene loci that are randomly selected with respect to how variable they are. That is, it is necessary that the probability of including a given locus in the sample be independent of how polymorphic the locus is.

Morphological traits (such as coat color) are generally useless for this purpose. The reason is that the genetics of morphological traits is determined empirically by traditional Mendelian methods; that is, by making crosses between individuals that manifest different phenotypes with respect to the trait. The pattern of segregation in the F_2 progeny allows one to determine whether or not genetic differences underlie the morphological differences, as well as to ascertain the number of genes involved. Thus, the only genes that can be studied with the traditional methods of Mendelian analysis are polymorphic genes; if a gene is invariant, such methods will not reveal it existence. It follows that use of such methods makes it impossible to obtain a random (with respect to variation) sample of the genome, because only polymorphic genes can be included in the sample (and usually the more variable a gene is, the more likely it is to be included in the sample because its existence is more easily detectable). The methodological handicap derived from the traditional Mendelian method of genetic analysis also applies to blood-group studies. As in the case of morphological variation, the study of blood groups depends on the detection of differences.

Obtaining a sample of genes that is random with respect to variation has become possible owing to the advances of molecular genetics. It is now known that genes consist of DNA and that (structural) genes code for proteins. It is possible to select for study a number of proteins, without having previous knowledge as to whether each protein is variable or how variable it is. If a given protein is found to be polymorphic, it can be inferred that the gene coding for it is also polymorphic. If a protein is found to be invariant, the inference is that the corresponding gene is also invariant. (Actually owing to the redundancy of the genetic code, not all gene variations result in protein differences; hence, the overall amount of variation is underestimated.)

The techniques of gel electrophoresis make it possible to study variation in a large number of proteins in a sufficient number of individuals without prohibitive investment of labor and money. Experience indicates that about 20 genes coding for proteins are sufficient to obtain acceptable estimates of genetic variation (Ayala and Kiger 1980), although 30 or more genes should be studied, if feasible.

3. Statistical Techniques. The amount of genetic variation is best measured by the heterozygosity per locus or per individual, although the proportion of polymorphic loci per population also provides useful information. The degree of genetic similarity can be summarized with standard measures, such as Nei's genetic distance. The formulae with which to calculate heterozygosity, polymorphism, and genetic distance and their significance can be found in recent textbooks (e.g., Ayala and Kiger 1980).

4. Biochemical Techniques. The techniques of gel electrophoresis and selective assay of enzymes are the most appropriate and least expensive with which to accomplish this project's objectives. Description of these techniques can be found in Ayala and others (1972). Information about a few specific enzyme assays as used in equids can be found in the references cited within "Genetic Polymorphism," in the first part of this chapter. Blood samples (a few cc per individual) can be used for the electrophoretic studies, although tissue samples (liver, in particular) should be used whenever available, because these make it possible to assay additional enzymes.

CHAPTER 3

EFFECTS OF EQUIDS ON OTHER ECOSYSTEM COMPONENTS

INFORMATION NEEDS

The Public Rangelands Improvement Act of 1978 clearly begins with an attitude of concern for the "unsatisfactory condition" of western rangelands, and for the need to improve that condition. In making lengthy provisions for research on, and management of, wild horses and burros, including authorization of the present study, it acknowledges that proper wild equid management must become part of the broader goal of improving and properly managing the rangelands.

As mentioned earlier, the repeated reference to "excess" animals in PL 95-514 requires some definition of the term, and one among its several connotations is the impact of wild horses and burros on other ecosystem components. Hence some consideration must be given to the ways in which these animals create impacts upon their surroundings, to the criteria by which those impacts are evaluated, and to the standards for the term "excess animals" derived from severity of impact.

Each land unit is capable of carrying some potential array of vegetative species if not excessively disturbed. As recognized and defined in PL 95-514, the "range condition" on a site at any point in time is "the present state of vegetation...in relation to the potential plant community for that site, and the relative degree to which the kinds, proportions, and amounts of vegetation in a plant community resemble that of the desired community for that site." To establish and maintain some level of range condition would appear to be a desirable management goal for each land unit. What that level should be is a policy decision, but presumably it would at the least ensure perpetuation of the basic vegetation, soil, and water resources.

Since vegetation has evolved with herbivory, it is capable of sustaining some level of herbivorous removal while maintaining itself in some equilibrium state. This state may vary between years and be highly dynamic, but it will vary around some long-term, constant average over a period of time. Maintaining the vegetation at some decided-upon state implies that herbivorous removal must be maintained at a level that will perpetuate the equilibrium. One definition of "excess" horses or burros could be that number which, when exceeded, causes the range--including its vegetation, soil, water, and wildlife--to decline from the desired condition.

Hence, the information needed to determine when equids are in excess includes knowledge both of their forage preferences and consumption rates, and of the effects of that consumption on their ecosystems, including vegetation, soil, water, other wild animals, and livestock. Forage preferences and consumption rates were considered in Chapter 2. The ecosystem factors will be reviewed in this chapter.

STATE OF KNOWLEDGE

Information Sources

The search for information on ecosystem effects was concentrated in four areas:

1. Impacts on range-plant community created by wild, free-roaming horses and burros and associated livestock.
2. Indications of competitive pressures by wild equids on other wild animals.
3. Impacts on watersheds created by wild equids and domestic grazers.
4. Impacts on range nutrition and feeding ecology created by wild equids and associated domestic and native ungulates.

Major attention was given to published, peer-reviewed literature, but considerable unpublished information (internal reports, consultant's reports) was obtained from files of the BLM, USFS, and NPS. Duplicate copies of these reports are on file at New Mexico State University and Utah State University.

Range-Plant-Community Impacts

In general, wild and free-roaming horse and burro populations in the western U.S. can be discussed in the context of the following vegetation types: pinyon-juniper, sagebrush-bunchgrass, salt-desert shrub, ponderosa pine, and hot-desert shrub, the last being primarily the domain of burros. While this geographic classification is general and considerable physical, climatic, and vegetational variation may exist within a particular type, it offers, at least, a general scheme for discussing and analyzing the problems on an ecological basis. Recent symposia and state-of-the art publications have dealt with the ecology and management of several of these areas (e.g., Clary 1975, Currie 1975, Gifford and Busby 1975, Springfield 1976, USU/CNR 1979). Such publications provide a broad foundation of information upon which to build an analysis of horse and burro ecology.

Considering the scope and alleged severity of grazing impacts by horses and burros on western rangelands, the problem has been studied surprisingly little. General statements by recognized range management experts warn of a severe and ever-growing problem. For example, Box (n.d.) observed that: "In many areas ranges are seriously overgrazed and the environment degraded." He further cited specific cases of burros in the Death Valley area and wild horse herds in the Rock Springs, Wyoming area posing threats to the range of native ungulates. Similarly, Cook (1975) suggested that under the Wild and Free-Roaming Horse and Burro Act of 1971, horses and burros living in areas where a year-round forage supply was unavailable would cause serious range deterioration that would lead to reduced grazing capacity for wild ruminants and domestic livestock.

Subjective observations such as the foregoing are generally based on years of professional experience and may possibly depict the reality of the horse and burro problem. However, the regrettable fact remains that few pertinent empirical data are generally available for scrutiny and evaluation. Until such data can be procured, professional judgments, whether made by scientists or practicing range managers, are certain to remain controversial.

Empirical studies on grazing impacts by either horses or burros are few in number. Most of the studies that do exist deal with burros. Hanley and Brady (1977) reported that burros in the lower Colorado River Valley of California and Arizona overgrazed ranges near the river, but that plant utilization, principally on browse species, decreased to light or moderate rates at distances greater than 2.5 km from water. They found that: "Overgrazing decreased the canopy cover of *Ambrosia dumosa* from about 2.26 to 0.04 percent and decreased total canopy cover for all species from 8.64 to 2.80 percent." They further observed that no particular plants acted as increasers or invaders under heavy burro use. The same general trend of heavy impact adjacent to water sources is evident in a report by Fisher and others (1973), who worked in the Panamint Range. However, at an exclosure of 2 km from the water source, measurement of species density and volume showed higher biomass *outside* than inside the exclosure. Annual densities and species diversity were higher outside the exclosure, but a bunch grass--*Stipa* sp.--was more abundant inside the exclosure.

Carothers and coworkers (1976), who performed studies in the Grand Canyon area, reported that their results "demonstrate conclusively that the feral ass has a negative effect on the natural ecosystem of the lower reaches of the Grand Canyon." They showed that the total vegetative cover of the Mojave Desert scrub type was reduced from 80 percent on a control plot to 20 percent on an impact plot, and that the total number of vascular species present was reduced from 28 to 19.

A later study by the same research group (Phillips and others 1977) was much expanded to include the three major vegetation types in and along the Grand Canyon where burros were considered a problem. These included the pinyon-juniper type, the blackbrush (*Coleogyne ramosissima*)-grass type and the Mojave Desert scrub type of the inner gorge of the canyon. These authors concluded that burros had had great impacts on all three community types. In the pinyon-juniper and blackbrush-grass types, the major trend appeared to be replacement of palatable grasses such as galleta (*Hilaria jamesii*) and squirreltail (*Sitanion hystrix*) by unpalatable shrubs such as broom snakeweed (*Xanthocephalum sarothrae*) and brittle bush (*Encelia farinosa*). The inner gorge sites sustained the greatest amount of disturbance, attributed to a concentrated use by burros, the "inherently fragile nature of the arid desert flora," and a relatively low species diversity. Also noted was a "severe" impact on crustose mosses and lichens. The authors observed that the pattern of plant-community response to heavy grazing by burros was essentially similar to that widely documented under heavy grazing by livestock.

Koehler (1974) studied burros in Bandelier National Monument and concluded that foraging by a population estimated to number from 107 to 120 individuals had led to degradation of some 4,000 ha of rangeland. He postulated the following order of disappearance of perennial grasses in pinyon-juniper communities overgrazed by burros: (1) Lycurus phleoides and Oryzopsis hymenoides, (2) Stipa neomexicana and Koeleria cristata, (3) Sporobolus airoides, (4) Festuca arizonica, (5) Bouteloua eriopoda and B. curtipendula, (6) Stipa comata, (7) Sporobolus contractus, (8) Sitanion hystrix, (9) Hilaria jamesii, (10) Bouteloua gracilis and B. hirsuta, (11) Aristida sp., and (12) Muhlenbergia torreyi. In addition to providing a basis for predicting community change, this sequence allows insight into the relative preferences by burros for the grass species listed. Generally, the most preferred species in a community are the first to be reduced by improper grazing practices (Stoddart and others 1975).

A later study in the same area by Potter and Berger (1977), conducted after the burro population was reduced in 1975, reported forage utilization levels on individual grass species. "Severe" levels of utilization were still noted on several grass species, averaging 61 and 50 percent for winter and summer periods, respectively. Some use of the unpalatable shrub called broom snakeweed was also noted and was interpreted as an indication of overutilization of the preferred grasses. These authors also observed heavy use of mountain mahogany (Cercocarpus montanus) by burros during periods of winter forage stress.

Feral burros have also been studied in Death Valley National Monument by several investigators. Moehlman (1974) observed that animals in the Wildrose-Emigrant area were primarily browsers, seemingly due to a low availability of herbaceous species. Working in the Wildrose Canyon area at a later time, Douglas and Norment (1977) observed that browsing pressure by burros on the shrubs Acamptopappus shocklei and Ambrosia dumosa was probably severe enough to threaten removal of these species from the community. They further postulated that the level of use of Artemisia spinescens and Dalea fremontii, while lower than that of the preceding two species, was nonetheless severe enough to cause concern.

In contrast to the studies just described, burros in two locations (Granite Wash and Temple Bay) in Lake Mead National Recreation Area apparently did not cause major impacts on vegetation (O'Farrell 1978), even though estimated animal densities were considerably greater than those in the Wildrose Canyon area of Death Valley. This lack of impact was attributed to above-average precipitation in the area during recent years, leading to a greater-than-normal level of primary production and grazing capacity for burros. O'Farrell's (1978) preliminary report was based on a small number of samples, and judgment should await a final report.

Although several management-level studies and inventories have led to subsequent population reduction of horse herds over the West, little controlled research has been done on specific grazing impacts by horses. The number of such reports in the literature is certainly less than that for burros. These data for horses seem especially meager in light of the extensive land area and the great number of animals concerned. Apparently much of the management that has been applied to horse ranges over the past 3 to 4 years has proceeded from experience and judgments exercised by the agency range managers.

This problem will be discussed later under "Review of Range Survey Methodology" in Chapter 5. It is mentioned here, not for the purpose of criticizing previous horse management work, but rather to reemphasize the need for information on range trends, forage utilization, and associated environmental impacts--as they relate specifically to horses--to serve as a basis for future management actions. Research in this area is needed to assist the manager in distinguishing forage utilization and range impacts by horses from those of other sympatric ungulates, and to determine whether horse impacts differ from those of cows or sheep. There is also a need to monitor range impacts with greater sensitivity than is presently possible with existing techniques, which were developed largely for use with domestic livestock.

Since scientific information on specific grazing impacts by wild horses and burros is scarce, additional perspective may be gained through exploration of the relatively extensive literature on grazing impacts by livestock. This literature has further importance: it forms the basis of existing management programs for wild horses and burros.

The benchmark review monograph by Ellison (1960) throughly covered the pertinent literature up to 1960. Some 260 references are cited in that paper, and discussion is organized on the basis of plant-community types, including those pertinent to wild horses and burros. One of Ellison's major conclusions is that successional trends in plant communities are roughly proportional to grazing intensity: they are pronounced under severe grazing pressure, and in some instances difficult to distinguish at light or moderate levels (Ellison 1960:45). This conclusion has generally been sustained by the vast majority of long-term grazing experiments conducted throughout the western United States, and it is the fundamental assumption underlying contemporary grazing-management practices. The following perspective on grazing intensity presented by Ellison in his 1960 paper remains germane to the present question and is worthy of consideration when reviewing results of grazing studies or when evaluating effects of animals in a management context:

> Degrees of grazing are not easily defined. The range that will support a given number of animal months during one period of years may be capable of supporting twice as many during a wetter period or perhaps only a third as many during

> a drier period. A depleted range may be heavily utilized by the same number of animals that would make only light use of the same range in good condition. The terms "lightly", "moderately" and "heavily" grazed are not only restricted in significance by being relative instead of absolute, but, unless production of forage and numbers of animals are specified, they are highly subjective. What one author means by "light" grazing may very well be "moderate" or even "heavy" grazing to someone else. (Page 5)

As a means of providing more recent information on the relationship of grazing intensity to plant-community change, the data in Table 3.1 were assembled. This table summarizes a small sample of long-term grazing experiments that have either been conducted in plant-community types where wild horses now occur, or that have focused on plant species locally important elsewhere on wild horse ranges. No comparable studies were found that dealt with the blackbrush-grass or Mojave desert scrub vegetation types now occupied by feral burros. One of the studies presented in the table (Hutchings and Stewart 1953) was discussed in the Ellison (1960) treatise. The rest have been published since then.

The table is incomplete in that it focuses mainly on the impacts of "heavy" grazing. This emphasis was prompted by the concern of the land-management agencies over the question of excess numbers of animals. Since major and enduring environmental change is a possible consequence of excess numbers of either wild or domestic ungulates, this emphasis appears necessary to provide perspective for designing research specifically related to horses and burros and to provide an interim management perspective pending the completion of that research. The specific data relating stocking rates to plant-utilization levels and subsequent changes in range-plant communities or particular plant species should prove useful in that regard. An important assumption underlying our analysis of such studies is that properly managed grazing, which takes into account the species and number of animals as well as their season and distribution of grazing, can in most cases be harmonious with most resource needs and values.

The general conclusion from studies summarized in Table 3.1 is the same as that drawn earlier by Ellison (1960): heavy grazing promotes accelerated plant-communitity change that has generally been interpreted as deteriorating range condition. Apparent deviations from, or variations on, this general statement can be seen in the studies of Hyder and others (1975), Skovlin and others (1976), and Hutchings and Stewart (1953). These questions are addressed below.

Range dominated by the shortgrass species blue grama and buffalograss appear relatively resistant to grazing-induced change. The study by Hyder and others (1975) summarized in Table 3.1 led to the conclusion that there was no ecological basis for relating changes in range condition (i.e., plant-community composition) to severity of grazing as separate and distinct from changes promoted by variable weather conditions from year to year. This opinion appears to

TABLE 3.1 Summary of Six Long-term Grazing Studies Measuring Utilization Rates and Community Responses to Heavy Stocking

Plant Association	Location/Animal Species/Study Duration	Annual Precip. (in.)	Season of Use	Stocking Rates (AUD/acre)[a] Light	Moderate	Heavy	Key Forage Species	Plant Utilization Levels (%) Light	Moderate	Heavy	Major Community Responses to Heavy Grazing	Study
Shortgrass	Colo./heifers/ 7 years	12.3	Monthly Year-round	--	--	24	Bouteloua gracilis	100 lb/acre of ungrazed herbage remaining and considered "very heavy" use.			Thinning of blue grama stand; heavy grazing in April, May, & June reduced cool-season perennials. Changes in community botanical composition more a function of weather than of months of repeated heavy grazing.	Hyder and others (1975)
Ponderosa pine-bunch-grass	Colorado/ heifers/ 18 years	15.4	June-Oct.	5.0	9.0	10.2	Festuca arizonica	20	38	74	Reduction of plant cover and increase in proportion of undesirable species such as Antennaria parvifolia. Decrease in root depth, weight, and branch rootlets Delayed early season growth and retarded later growth. Erosion rates increased 2- to 4-fold over light grazing.	Smith (1967)
		--	--	--	--	--	Muhlenbergia montana	17	36	70		
Ponderosa pine-bunch-grass	Oregon/cattle/ 11 years	20	Summer	3	4	6	Agropyron spicatum	34	49	55	Slight increase in production of A. spicatum and no change in P. sanbergii, both occurring in open grassland situations. Carex sp. occurring under tree stands reduced production by 50%. Elk use was decreased.	Skovlin and others (1976)
			--	--	--	--	Poa sandbergii	7	16	21		
			--	--	--	--	Carex geyeri	15	24	32		
Salt-desert sagebrush-pinyon-juniper	Utah/sheep/ 12 years	6.7	Winter	2.0[b]	2.8[b]	3.4[b]	Ceratoides lanata	49	55	66	Total herbage production increased 54, 46, and 34% for light, med. and heavy grazing over course of 12-yr. study. Major contributors to this increase were C. lanata and A. confertifolia.	Hutchings and Stewart (1953)
		--	--	--	--	--	Atriplex confertifolia	20	21	28		
		--	--	--	--	--	Hilaria jamesii	25	49	67		
		--	--	--	--	--	Oryzopsis hymenoides	65	76	88		
Sagebrush-bunchgrass	Idaho/sheep 13 years/	--	May	--	--	8[b]	Agropyron spicatum	--	--	20 to 40	Range condition declined from good to poor in 13 yrs. Sagebrush increased 78%. Total grass production declined 73%. Bluebunch wheatgrass decreased 48%.	Laycock (1967)
		--	Nov.-Dec.	--	--	12[b]	Agropyron spicatum	Variable, but relatively heavy (6-19%) use on sagebrush.			Bluebunch wheatgrass and Poa nevadensis increased 47%. Sagebrush production decreased 20%. Heavy use on shrubs while grasses were dormant led to community progression.	
Crested wheatgrass artificial seeding	Utah/cattle/ 10 years	12.9	Spring	13.4	16.6	20.2	Agropyron cristatum	53	65	80	Reduced basal area of grass plants 18% in comparison to moderate grazing. Reduced grass yields from 433 lb/acre for moderate grazing to 325 lb/acre for heavy grazing. Accelerated invasion of sagebrush and rabbit brush.	Frischknecht and Harris (1968)

[a] An animal unit day (AUD) is the grazing pressure exerted by a 454-kg (1,000-lb) cow, an animal unit, or her equivalent during a 1-day period. Thirty AUD = an animal unit month (AUM).

[b] Calculated on the basis of 5.0 sheep days = 1.0 AUD.

conflict with earlier conclusions from a study on the same site (Kipple and Costello 1960) that heavy grazing reduced vigor and yield of the important forage species and led to a deterioration of range condition. However, Hyder and others (1975) attributed the results of the earlier study to improper classification of site differences as differences in range condition.

The Oregon study on ponderosa pine-bunchgrass range (Skovlin and others 1976) did not show the drastic decline in range condition under heavy grazing that the Colorado study (Smith 1967) showed in a similar plant association (Table 3.1). However, stocking rates in the Oregon study were considerably lower than those in the Colorado study, while annual precipitation in Oregon was roughly 30 percent greater than that in Colorado. Given comparable stocking rates, differences in precipitation notwithstanding, declines in range condition in the Oregon study would likely have been larger. Even with the prevailing conditions observed, the important species elk sedge (Carex geyeri) declined 50 percent in the forested habitat, and this was viewed as a serious consequence. This decrease was associated with, but not necessarily the direct cause of, a 20 percent decline in livestock grazing capacity over the 11-year study in the forested habitat.

Total herbage production, and presumably grazing capacity, increased over the course of a 12-year winter grazing study at the Desert Experimental Range in southwestern Utah (Hutchings and Stewart 1953), where salt-desert shrub, sagebrush-grass, and pinyon-juniper vegetation types were all represented (Table 3.1). Even though the increase was smaller under heavy grazing than under either moderate or light grazing, the general trend is not entirely consistent with that propounded by Ellison (1960). A reason for this response can be proposed. The ranges where the study was conducted were in a generally depleted state at the outset, due to excessive grazing and drought. Therefore, control of animal numbers, even though they were allowed to graze "heavily," apparently allowed some degree of range recovery. Furthermore, subsequent studies on physiological responses of desert plants to season and intensity of defoliation (Cook 1971) have shown that herbage removal during winter is considerably less detrimental than spring or summer defoliation. Thus, control over season of grazing--so that use was confined to winter--probably contributed to range recovery.

The general pattern of plant-community change under heavy grazing in the Great Basin has been described by Young and others (1976) as: (a) an increase in native shrubs undesirable for browsing, (b) a reduction in perennial grasses and forbs, and (c) exploitation of these voids by alien annual weeds such as cheatgrass that are highly adapted to intensive grazing. From the standpoint of soil and water conservation, communities dominated by annual species are unpredictable from year to year as far as how much soil cover they will provide, and their soil-binding root masses are small. A later section in this report deals specifically with soil-plant-watershed relationships under grazing pressure. The most extreme change in this regard has been the dessication of upland meadows caused by accelerated erosion and stream-channel cutting (Cottam and Stewart

1940). Young and others (1976) state that a cycle of geologic erosion and deposition would be required to restore these meadows to their past condition.

From a standpoint of forage values, communities dominated by stands of relatively unpalatable shrubs (e.g., sagebrush) and by annual weeds (e.g., cheatgrass) offer relatively little to livestock (Cook and Harris 1968). Although specific data are scarce, the same is probably true for horses. Table 2.22 strongly suggests that horses make little or no dietary use of shrubs. Exotic annuals may be highly palatable and nutritious during their growing season (Cook and Harris 1968), but this is generally restricted to a brief period in the spring and early summer of favorable years. In years when precipitation is scarce, yields of forage from annual-dominated ranges may be negligible.

As previously mentioned, responses of plant communities to grazing are greatly complicated by the effects of season and frequency of grazing. For example, Laycock (1967) showed that heavy spring grazing of sagebrush-bunchgrass range by sheep in Idaho led to a deterioration of range conditions, including replacement of bluebunch wheatgrass (Agropyron spicatum) by annual cheatgrass (Bromus tectorum) and sagebrush (Artemisia tripartita). In contrast, heavy grazing of similar range in autumn after the herbaceous understory plants had entered dormancy led to increased grazing pressue on sagebrush and an improvement in range conditon. Such differential responses of individual plant species to season of grazing form the basis for the specialized "rotational" grazing systems now in common practice over much of the western range (reviewed by Herbel 1974).

Controlled studies concerning the effects of plant defoliation on subsequent vigor and production (Cook 1971) showed that desert shrub and grass species are highly sensitive to season of herbage removal. Species included in the studies were black sagebrush (Artemisia nova), big sagebrush (A. tridentata), shadscale (Atriplex confertifolia), winterfat (Ceratoides lanata), Nuttall saltbrush (Atriplex nuttallii), Indian ricegrass (Oryzopsis hymenoides), and squirreltail grass (Sitanion hystrix). A 50-percent winter utilization of these species maintained vigor and yield, but the same level of use during late spring and early summer was detrimental, particularly for the shrub species. No more than a 25-percent use could be safely tolerated by most species in late spring.

The implications of these studies for the management of wild horse ranges are clear. If maintenance of a stable range condition is a desired management objective, control of grazing season may be equally as important as control of animal numbers. This type of control may prove particularly difficult in some areas where options are limited to regulating movement patterns and distribution of animals over the range.

Year-to-year variability in precipitation (both in amount and monthly distribution) can radically alter the composition of plant communities and influence the pathway of either secondary succession or retrogression. This has already been emphasized in discussing the findings of Hyder and others (1975). Precipitation seems to be an overriding factor in most range ecosystems, but especially in the more arid ones. On the basis of a 10-year study of semi-desert range in southern Arizona, Martin and Cable (1974) concluded that year-to-year variation in precipitation influenced short-term changes in vegetation more than any other single factor, including season and intensity of grazing. The periodic stresses imposed by droughts, coupled with stress imposed by heavy grazing, have often interacted to produce profound changes in range conditions. In fact, many of the grazing studies discussed above pointed out that much of the change measured over the duration of a particular study actually occurred during periodic drought periods, rather than as a gradual, continuous process.

Range grazing capacity is also subject to the vagaries of annual precipitation. Close positive relationships have been demonstrated between annual precipitation and forage production (hence, grazing capacity) for many areas (Pechanec and Stewart 1949, Hutchings and Stewart 1953, Dahl 1963, Currie and Peterson 1966, Martin and Cable 1974, Duncan and Woodmansee 1975). Variations in precipitation greatly complicate the decision regarding the number of animals an area can sustain on a long-term basis. Even with domestic livestock that are subject to a relatively high degree of managerial control, yearly adjustments of animal numbers in accord with the prevailing forage conditions are not practical. Such control is presently out of the question for wild horses and burros. Stoddart and others (1975) state that 65 to 80 percent of the long-term, average forage production base is usually a realistic starting point for calculating grazing capacity. However, they emphasize that under no plan of constant stocking will it be possible to prevent excessive use in dry years, and underuse in good years. If there is to be a temporary imbalance it should favor the plants rather than the number of animals, because ranges are slow to recover from overuse. For example, in studies by Cook (1971) cited above, shadscale, squirreltail grass, and black sagebrush had not fully recovered from the effects of heavy (75 percent) utilization after 7 years of rest.

Year-to-year fluctuations in forage production are even more serious on ranges in poor condition, where much of the forage supply is based on annual species. For example, Murray (1971) compared grazing capacities of native bunchgrass in southern Idaho to those of cheatgrass ranges in the same vicinity. During wet years, grazing capacities of the two ranges were similar, but in dry years, they were 60 percent less on the cheatgrass range. Thus, maintenance of plant communities with a major component of perennial vegetation appears desirable not only from the standpoint of long-term site stability, but also from the viewpoint of a dependable forage supply for grazing animals.

Competitive Effects on Other Animals

Interspecific Competition as a Population-Limiting Influence

The question of competitive effects of equids on other animals raises once again the difficulties discussed in Chapter 2 in demonstrating the existence of competition. Interspecific competition occurs when (a) two different species use the same resources, (b) they reduce them to the point of short supply, and (c) the populations of one or both are constrained in the process. Two species may use exactly the same resource but not be in competition if their combined use does not reduce it to the point of population limitation.

A population effect, the acid test of competition, is often difficult to demonstrate. If two species have been coexisting for some period of time and one is declining, it is risky to assume cause and effect. Many environmental variables change over time, and the decline of a species could just as well be prompted by one or more of them as by a suspected competitor. Competition is best demonstrated by an experiment in which one species is increased or reduced, and the response of the other observed. Properly, such treatments should be replicated.

In the absence of population tests, at least a preliminary indication of competition can be obtained by measuring the resource in question and calculating the resource need of the two species suspected of competition. If the combined need is greater than the amount of resource available, it is at least presumptive evidence that competition may be occurring. Even where a population effect can be observed, the case for competition is strengthened by measuring the resource and demonstrating its depletion and shortage.

It is not stretching the correspondence between concept and reality too far to suggest that interspecific competition can be created by administrative fiat. If the decision is made to limit the number of grazing animals on a given tract of land to a certain number of animal unit months (AUM: see Table 3.1 for definition) and a portion of these is allocated to equids, then the numbers of livestock must be limited to the remainder. In a real sense, livestock populations are held at lower levels than they would be in the absence of equids, and the latter therefore exert competitive pressures on the domestics.

Feral Asses

The most commonly inferred competition of equids with wild species is that of burros with desert bighorn sheep, and it has been reported to involve three resources: water, vegetation, and space. The evidence for water resource competition is conflicting. Numerous authors (Dixon and Sumner 1939, Sumner 1952, Russo 1956, Weaver 1959, Thomas 1979) have reported for years that in areas where burros are numerous and water scarce, the equids foul or completely use up the water so that sheep cannot drink it. But other investigators studying burro watering behavior have failed to find the fouling problem (Welles and Welles 1961a, b; Moehlman 1974; Golden and Ohmart 1976). Observations on watering behavior of the two species vary, but there may be a tendency for bighorns to water by day while burros are more inclined to water at night (Welles and Welles 1961a, b; McMichael 1964; Farrell 1973; Moehlman 1974; Woodward 1976). Welles and Welles

(1961b) reported that "thriving bighorn populations have been watering at the same springs with thriving burro populations since before 1937." The question may revolve around the abundance of water: problems may arise where it is quite scarce, and its use is intensive.

The problem of competition for forage has been given more attention, but also lacks conclusive resolution. It is quite clear that many forage species are shared by burros and desert bighorns (McMichael 1964; St. John 1965; Hansen and Martin 1973; Seegmiller and Ohmart 1975, 1976, 1980; Seegmiller 1977; McQuivey 1978; Walters and Hansen 1978). Burros appear to have a competitive advantage, since they utilize a wider array of plant species and plant parts (McKnight 1958) and can range farther from water sources (Seegmiller and Ohmart 1980). However, as discussed above, mutual use of the same resource does not necessarily imply competition.

The important point may be whether sheep are sufficiently wide-ranging to be unaffected by the burro vegetation damage close to water holes (which most authors agree takes place), or whether vegetation consumption and alteration extend far enough out from water holes to affect appreciable fractions of sheep home ranges. Some authors (e.g., McMichael 1964) have suggested that the vulnerable point in the sheep life cycle may be the food needs of the lambs, especially at weaning time (Thomas 1979:183) during the dry season, when they are confined to a narrow radius around the water holes.

The question of the space resource involves social encounters between the two species. McKnight (1958) suggests an implicit dominance of burros over sheep. Thomas (1979:183) describes observations made during a joint BLM, NPS, and California Department of Agriculture study in which sheep invariably waited to drink at a spring until after burros had vacated the area. Such nonovert submissive responses have been reported for other large herbivores. McCullough and Schneegas (1966) speculate on the behavioral incompatibility between livestock and Sierra Nevada bighorns. Jeffery (1963) and Mackie (1970) reported that elk vacate areas occupied by cattle.

Despite all of this indirect evidence, experimental observations on population effects are few and equivocal. Several cases have been reported of thriving sheep populations in areas without burros, and a lack of sheep in areas occupied by the equids. Thomas (1979) describes a number of such cases, including situations on two military bases in San Bernardino and Inyo Counties, California. The Avawatz Mountains on Fort Irwin have abundant perennial grasses, a thrifty sheep population, and no burros. The Argus Mountains on the Naval Weapons Center have a large burro population, show signs of heavy grazing and absence of perennial grasses, and have a declining herd of fewer than 15 sheep. McKnight (1958) reported that in the 1950s the Panamint Mountains on the west side of Death Valley were heavily utilized by burros and were practically devoid of sheep. The ranges on the east side of the valley contained no burros and had sizeable sheep populations. Of course the question always arises as to whether these negative correlations involve cause and effect, or whether other variables are involved.

Dixon and Sumner (1939) and Brandt (as cited in McKnight 1958) reported a sequence of changes at Willow Spring in Death Valley that constituted an inadvertent experiment. In 1935, the spring was being used by a local sheep population, and was clean; apparently there were no burros. In 1938, the spring was trampled and muddied by burros, and no sheep could be found in the vicinity, according to Dixon and Sumner. By 1957, burros had been trapped out of the area and it once again supported a thriving sheep population. Despite the absence of conclusive data, the problem has been alluded to so repeatedly by experienced observers that one must suspect its reality. Thomas (1979) marshalls an impressive array of unpublished and published information on the subject.

Morgart (1978) reported year-round coexistence between burros and mule deer on the same range at Bandelier National Monument. In addition, deer numbers were greatly augmented in winter by migrants. Deer were almost entirely browsers while burros were mainly grazers, but in winter a third of the burros' diet was browse. Since the browse was overused, and therefore at or below the amounts needed by both species, there was some possibility of competition in Morgart's opinion.

Several authors have investigated possible effects of burros on small mammal populations. Moehlman (1974) counted rodent burrows along transects placed to sample areas with different feral ass densities, and found no difference in burrow numbers in the different areas sampled. Other authors, however, have found rather different results. Carothers and coworkers (1976) and Czaplewski and others (1977) investigated the abundance of small mammals in three different habitat types in Grand Canyon, each with different burro densities, and each with areas subject to burro use and control areas protected from burro use. In the pinyon-juniper vegetation type on the Canyon rim, where burros are scarce, no differences were evident between rodent populations in "impact" and "control" areas. In the desert scrub vegetation of the Tonto Platform and Rampart Cave area, where burro use was intermediate, rodents were more numerous in the impact than in the control area, and were composed in large part of disturbance species in the family Cricetidae. In the riparian-plant community of the canyon's inner gorge, where burro use was heavy and vegetation damage extreme, rodent populations in the impact areas were far smaller than those in the control plots.

Douglas and Norment (1977) conducted similar investigations in two areas of Death Valley, one heavily affected by burro use and the other free of use. Efforts were made to select plots with similar elevation, slope aspect, and plant communities. The density of small mammals in the burro-free area was more than 3.5 times as great as that in the burro-inhabited area. Species compositions also differed. The authors acknowledged, however, that since the two areas were not adjacent to each other, the possibility existed that variables other than burro populations were partially or wholly responsible for the difference. Guthrie (1978) compared rodent densities of areas with and without heavy burro use in pinyon-juniper woodlands of Bandelier National Monument. Rodents were less abundant in areas used by burros.

Other authors have marshalled evidence to suggest reductions in bird populations (McKnight 1958, Wauer 1978, Thomas 1979) and desert tortoise where burros range (NPS 1979).

Feral Horses

The attention given to, as well as the attempts made to evaluate, horse competition with other wildlife is much more limited than are burro investigations. Some studies (Hansen 1976, Hubbard and Hansen 1976, Hansen and Wolsen 1977, Hansen and others 1977, Thomas 1979) have been conducted to assess the degree of dietary overlap between horses, cattle, and several species of wildlife (elk, mule deer, pronghorn antelope, and bighorn sheep). All overlap to varying degrees at one time or another, and in one area or another.

Overlap tends to be greatest between horses, cattle, elk, and bighorn, all of which are primarily grazers in the more northerly portions of the western United States. In the Challis region of Idaho, bluebunch wheatgrass (*Agropyron spicatum*) is a preferred species for horses, elk, and bighorn (Peek as cited in Thomas 1979:193). This is a climax species that often recedes under any material grazing pressures, and its full utilization by cattle has been reported by Morgan (1971) to pose genuine competitive pressure on bighorn populations in the nearby Salmon River wilderness area.

Peek also reported that horses turn to sagebrush to some degree in winter in the Challis area, and at this point may compete with mule deer for limited winter browse. A similar situation in eastern Oregon was reported to us by Forrest Sneva (USFS, personal communication, 1980). In general, several species of sympatric large herbivores may partition resource use when the resource spectrum is broad and utilization is low. But if their populations and feeding pressures increase to the point where preferred food species are reduced, their food selection may converge and the risk of competition will increase (Wagner 1978).

Thomas (1979:194) describes a situation in the White Mountains on the California-Nevada border. Up to 25 years ago, when wild horses were scarce in the region, bighorn sheep occupied all parts of White Mountain Peak, which rises to 14,000 feet, including the foothills on the east side of the mountain. In recent years a growing horse population occupies the eastern slopes of the mountain. Sheep are now found only on the west side and the crest.

All of this is again circumstantial and not firm evidence of competition. But it would be a mistake to dismiss the possibility that competition does occur simply because the data are equivocal. The question remains open.

Effects of Equids on Range Hydrology

Hydrologic impacts are generated by activities that, in one way or another, affect quantity, quality, or timing of water yields. Impacts may be measured either on or off site, at upland locations, or directly in a channel.

The grazing animal influences watershed behavior through removal of protective cover and through trampling disturbance. Resultant impacts may include altered water-quality parameters (coliform counts, nutrients, water temperatures, sediment, dissolved oxygen, and total dissolved solids), reduced stream-channel stability, increased overland flow, reduced soil moisture, and increased erosion.

Currently, no information is available in scientific journals that attempts to quantify the impacts of wild equids on quantity, quality, or timing of water yields. However, numerous anecdotal comments have appeared from time to time, and some limited in-house reports have been issued by various federal agencies that purport to identify the hydrologic impacts of wild equids.

These reports suggest that wild equids may adversely impact range hydrology by: (a) compacting the soil surface, (b) developing trails in steep terrain that accelerate erosion, (c) overgrazing their habitat, (d) competing with livestock and big game for forage and water, and (e) polluting water holes (Dixon and Sumner 1939; McKnight 1959; Weaver 1959; Welles and Welles 1959, 1960, 1961b; Buechner 1960; Koehler 1961, 1974; Fisher 1975; Stoddart and others 1975; Woodward and Ohmart 1976; Carothers and coworkers 1976; Norment and Douglas 1977; Zarn and others 1977a; O'Farrell 1978; Hansen n.d.; Jones n.d.; NPS n.d.). These impacts are somewhat localized, highly dependent on local population and climatic trends, and often confounded by other effects (e.g., present livestock grazing, past grazing history, wildlife, and hikers).

The existing knowledge about the impacts of wild equids on range hydrology is scanty at best. However, information is available on livestock grazing impacts, which should be similar to those wild equids. The following review deals with the influence of livestock grazing on vegetation, soil, infiltration, and water-quality parameters.

Vegetation and Cover Factors

Vegetational Factors. Impacts on vegetation caused by the grazing of wild equids and livestock on range-plant communities were reviewed in an earlier section of this chapter ("Range-Plant-Community Impacts"). As pointed out in that review, grazing animals can drastically influence plant communities, and it is the removal of vegetation that has the largest potential impact on watershed behavior. Overgrazing for extended periods may result in vegetational changes that will: (a) reduce protective cover, thus increasing the impact of raindrops; (b) decrease soil organic matter and soil aggregates; (c) increase surface vesicular crusts; (d) decrease infiltration rates; and/or (e) increase erosion (Blackburn 1975; McGinty and others 1978; Wood and others 1978a, b; Wood 1979; Knight and others 1980). The end result of overgrazing may be to lower site potential. Excessive removal of vegetation for short periods may:

(a) reduce the protective cover, thus increasing raindrop impact; (b) break down soil aggregates; (c) decrease infiltration rates; and/or (d) increase erosion. Usually these impacts can be reduced by adjusting stocking rates and/or applying proper grazing management (McGinty and others 1978, Wood and others 1978b, Wood 1979).

Grazing usually lowers the standing crop when compared at any one point of the grazing cycle (Lodge 1954, Johnston 1962, Rauzi 1963, Rhoades and others 1964, Rauzi and Hanson 1966, Hazell 1967, Hanson and others 1970). Knight and others (1980) found midgrass standing crop to be similar on moderately, continuously grazed and short-term grazed pastures (Figure 3.1). Standing crop on a very heavily grazed pasture was significantly smaller than that on pastures grazed moderately and continuously or on a short-term basis. Some authors report a stimulating effect of grazing on vegetation production that is similar to that seen in an exclosure or lightly grazed area (Rauzi and Smith 1973, McGinty and others 1978). Reardon and Merrill (1976), working in Texas, reported that only heavy grazing showed a decrease in plant production when compared to a livestock exclosure and a four-pasture, deferred-rotation system.

Mulch. Although mulch is usually reduced by grazing (Johnston 1962, Rauzi and Hanson 1966, Hanson and others 1970, Wood 1979), it was not reduced by moderate, continuous grazing below levels found under light, continuous grazing or in exclosures during two studies (Rauzi and Smith 1973, McGinty and others 1978). Reardon and Merrill (1976) suggested that exclosure vegetation on the Edwards Plateau, Texas needed the stimulation of grazing to keep producing mulch at levels comparable with that of grazed areas.

In a South Dakota study, more mulch cover occurred on a moderately, continuously grazed pasture than on a heavily or a lightly, continuously grazed pasture (Sharp and others 1964). Lusby (1970) reported that a heavily grazed pasture at Badger Wash, Colorado displayed a decline in mulch cover when compared to an ungrazed area.

Bare Ground and Rock Cover. Lusby (1970) reported that bare soil and rock cover increased with heavy grazing in a paired watershed study (Badger Wash, Colorado) that compared heavy and no grazing. Heavy grazing and short-duration grazing increased the percentage of bare ground cover at Rolling Plains in Texas (Wood 1979). Several studies have shown that 60 to 75 percent plant and mulch cover is needed to control surface runoff and erosion adequately (Meeuwig 1970a, Orr 1970, Packer 1951, Marston 1952). Many areas where wild equids are found do not have the potential to produce that much plant and mulch cover.

Soil Factors

Physical properties of soil change more slowly than does vegetation, although the two may be related (Rauzi and others 1968).

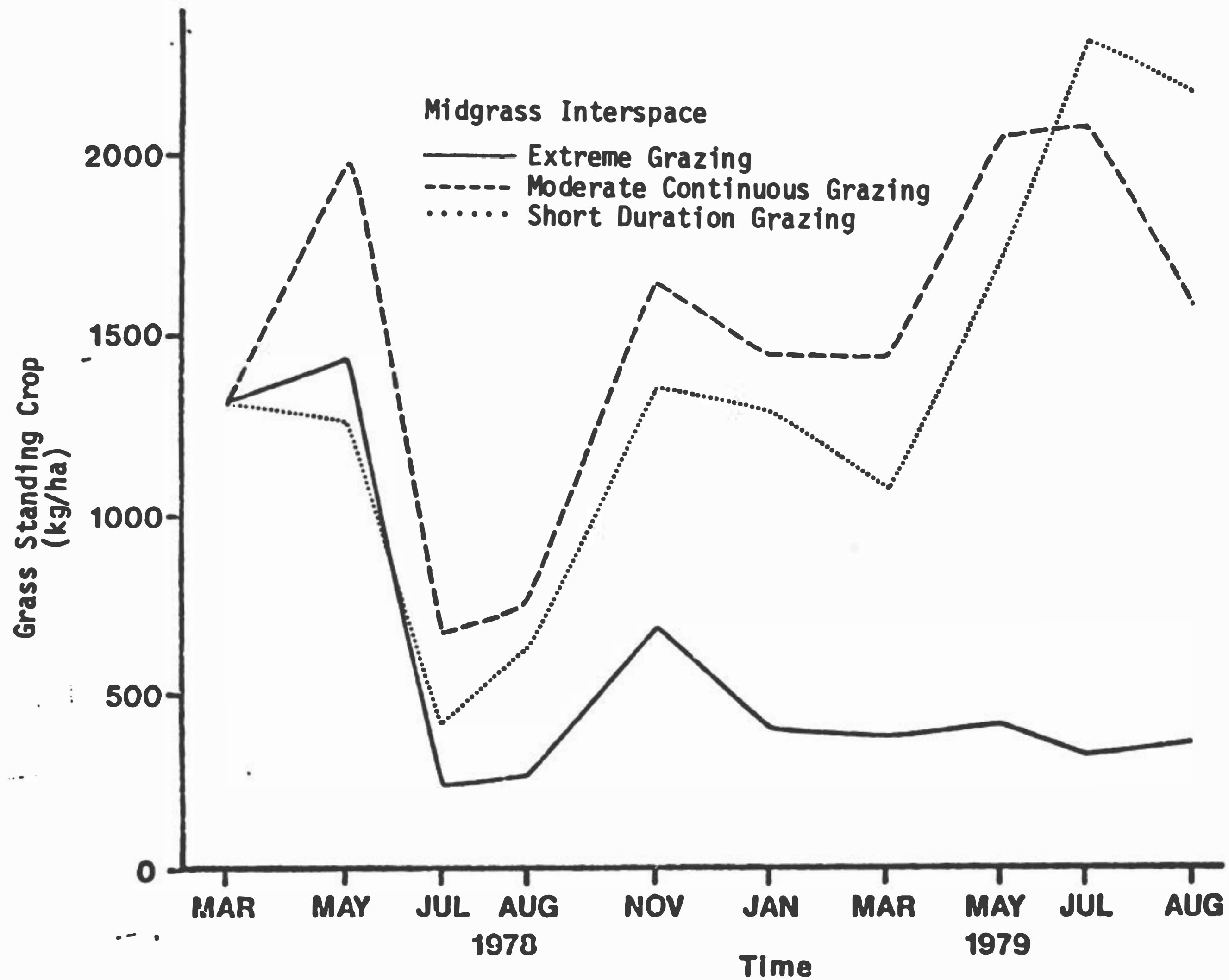


Figure 3.1 Midgrass standing crop as influenced by livestock grazing, Edwards Plateau, Texas.

The soil factors that may be altered by livestock grazing may also change infiltration and erosion rates.

Bulk Density. The soil-compacting effects of grazing animals appear to be most pronounced in the first 2.5 to 5 cm of soil surface (Alderfer and Robinson 1947). No significant increases in bulk density due to moderate, continuous grazing were reported by Meeuwig (1965), Rauzi and Hanson (1966), and Skovlin and others (1976).

However, Klemmedson (1956) reported that grazing-induced changes in range condition also changed the bulk density of the soils. The bulk density tended to decrease as range condition improved, although no statistical tests were reported. Unrestricted grazing of stream bottoms in the Black Hills caused increases in bulk density in the top 5 cm of soil at three out of four sites (Orr 1960). Similarly, unrestricted grazing of the Southern High Plains caused increased bulk density of the surface soil (Brown and Schuster 1969). In northern Utah, Laycock and Conrad (1967) showed that seasonal changes in bulk density were greater than those that could be attributed to grazing.

Rhoades and others (1964) and Linnartz and others (1966) reported increased bulk density due to grazing down to 40 cm below surface or deeper. These findings are contrary to other studies that found grazing impacts to be minimal--restricted to the upper 5 cm of the surface. It is possible that different soil types were compared between the grazed and protected areas. Rhoades also reports that numerous rodent and insect burrows in the protected area may have caused the lower bulk density.

Organic Matter/Aggregate Stability. No differences in percentage of organic matter were found between soils of grazed and protected areas by Lodge (1954), Klemmedson (1956), Rhoades and others (1964), and Meeuwig (1965). Wood's (1979) study in Rolling Plains, Texas reported organic matter to be highly correlated with infiltration rates and sediment production, but found little difference due to grazing treatment. McGinty and others (1978) showed the percentage of organic matter in two grazed pastures to be lower than that of a nongrazed area.

Wood (1979) reported that the percentage of water-stable aggregates was lower in a heavily grazed pasture than it was in one 20-year-old exclosure, but not significantly lower than that in another 20-year-old exclosure. He also found aggregate stability to be highly correlated with infiltration rates.

Infiltration

Studies relating livestock grazing practices directly to runoff are rare, in part because most hydrologic concern has been directed toward the recharge of soil moisture for growing forage in arid and semi-arid environments. Most studies have concentrated on infiltration as an indicator of range hydrology, and there exists a modest amount of literature on the subject. Unfortunately, this information presents several different descriptors, and infiltration is measured with a variety of instruments (Gifford and Hawkins 1978). Ideally, infiltration should be measured using rainfall, either natural or simulated, and calculated as the difference between input rainfall and output runoff. As a refinement, initial surface retention and temporary storage may be quantified. Flooding infiltrometers have been used, but represent unnatural conditions: the impact of raindrops is eliminated and exceptionally high infiltration estimates result from the ponded head of water.

Data dealing with the impacts of livestock grazing on infiltration rates have been summarized in Table 3.2. Several conclusions can be drawn from these studies.

1. The results are often confounded by range-improvement activities, past grazing history, and/or climatic fluctuations.
2. Results may be very site specific.
3. There is usually little difference between light and moderate grazing. On some sites there may not be a difference between no grazing and light or moderate grazing.
4. Heavily grazed areas almost always exhibit a lower infiltration rate than areas grazed lightly, moderately, or not at all.
5. These studies were conducted by sundry methods, mostly on year- or season-long, continuously grazed pastures with varying stocking rates.

Infiltration data listed in Table 3.2 that met the following conditions were analyzed statistically: (a) terminal rates, (b) measured with either natural rainfall or a sprinkling infiltrometer, and (c) grazing intensity identified. These data were also used in developing a deterministic model for predicting infiltration rates under various livestock grazing regimes (Gifford and Hawkins 1978, Hawkins and Gifford 1979). The authors cited were unable to differentiate between the influences of light grazing and moderate grazing, and considered them to be identical. Statistical analyses indicated that there was a difference between infiltration rates associated with moderate/light, heavy, and no grazing. These data were also subjected to regression analyses using the three categories of light/moderate, heavy, and no grazing (Figure 3.2). From these calculations the following conclusions were drawn: (a) "There is an influence of grazing on infiltration;" (b) "There is a distinct impact from heavy grazing which is statistically different from that of light/moderate."

The model developed by Gifford and Hawkins (1979) used an average infiltration recovery time from grazing of 4 years. This figure was based on limited data presented by Dortignac and Love (1961) and Thompson (1968). They contend that the recovery period is certainly longer than 1 year, a factor that reduces the potential of improving watershed conditions through improved grazing management systems.

The existence of this long recovery period is not supported by McGinty and others (1978) and Wood and others (1978b), who studied several different grazing systems in Texas. The results of these two

TABLE 3.2 Summary of Livestock-Grazing/Infiltration Studies (Taken from Gifford and Hawkins 1978 and Wood, and others 1978).

Site	Equipment	Infiltration Rate (inches/hour) by Grazing Intensity				Remarks
		Ungrazed	Light	Moderate	Heavy	
'Slick' or 'Semislick' soils, Montana [Branson et al., 1962]	tube-type sprinkling infiltrometer	0.5	0.1		0.2	unfurrowed
		0.1			0.3	unfurrowed dry plots in 1958
		0.3	0.5		0.3	furrowed and seeded in 1948
		2.6	1.5		0.6	furrowed and seeded in 1948
		0.4	0.2		0.6	unfurrowed
			0.3		0.3	unfurrowed moist plots in 1959
		0.4	0.1		0.5	furrowed and seeded in 1948
		1.5	1.5		0.4	furrowed and seeded in 1948
Sandy loam soils, Utah, chained P-J site [Gifford et al., 1976]	Rocky Mountain infiltrometer	2.3 2.6		1.9 2.3		ungrazed (natural woodland), protected since 1968
		2.9 2.5		2.4 2.6		grazed (chained with windrowing), seeded, grazed since 1974, ungrazed 1968-1973
		2.5 1.3 1.5		1.6 1.3 1.2		chained and windrowed, seeded in 1964, ungrazed since 1971
		1.4 2.0		1.9 1.2		ungrazed (exclosure on chained with windrowing) seeded site, protected since 1968
		1.4 1.1		1.8 1.0		moderately grazed area since 1974 ungrazed 1968-1973
Loams to clay loams, southwestern Alberta [Johnston, 1962]	mobile infiltrometer		2.5	2.0	2.0 1.7	treatment age, [illegible]0 years
Loamy fine sand, Oklahoma [Rhoades et al., 1964]	sprinkler infiltrometer double ring infiltrometer	5.3 12.2	2.2 5.8	1.8 5.0	1.6 3.3	treatment age, 20 years
Silty clay over clay, South Dakota, 2-acre watersheds, rainfall minus runoff [Sharp et al., 1964]			1.2 0.4	0.8 0.3	0.8 0.3	storm of May 30, 1963 composite data
Gravelly loam, Arizona [Trumble et al., 1974]	rainfall simulator	1.6			1.2	ungrazed, protected 9 years: heavy grazing utilized 75%
Silty clay loam (loessal material), Kansas [Knoll and Hopkins, 1959]	single-ring infiltrometer	1.3		1.0	0.8	ungrazed, protected 13 years

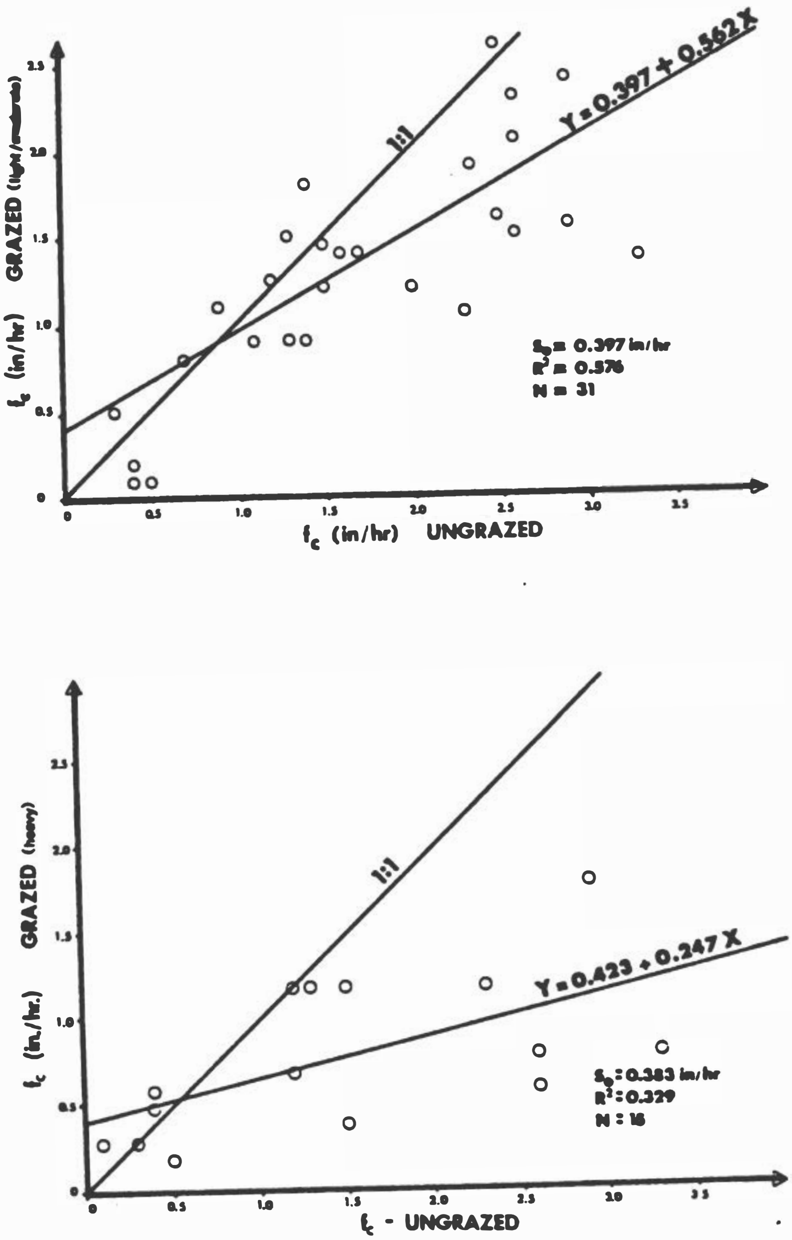
Granitic alluvium, Colorado [Dortignac and Love, 1961]	Rocky Mountain infiltrometer	2.0				grassland, ungrazed beginning 1941
		2.3	0.9	1.2	1.2	
		3.3	1.3	1.4	0.8	
		1.6				ponderosa pine grassland, ungrazed beginning 1941
		2.9	1.5	1.6	1.8	
		2.6	1.8	2.3	0.8	
Silty clay, South Dakota [Rauzi and Hanson, 1966]	mobile infiltrometer		3.0	1.7	1.0	dry, treatment age 22 years
			1.3	0.7	0.5	wet, treatment age 22 years
Sandy loam and loams, Colorado [Rauzi and Smith, 1973]	mobile infiltrometer		1.8	2.0	0.8	sandy loam, treatment age 30 years
			1.0	0.9	1.0	sandy loam, treatment age 30 years
			1.8	2.2	1.2	loam
Various soils, North Dakota [Whitman et al., 1964]	probably ring infiltrometer		6.0	3.1		average values over seven major range soil types
Shale-derived soils, Colorado [Thompson, 1968]	Rocky Mountain infiltrometer	0.7		0.8		study began 1953 (first year of protection)
		0.9		1.1		
		0.7		0.8		
Silt loam, Wyoming [Rauzi, 1956]	mobile infiltrometer		1.2		0.9	treatment age 5 years
Silt loams, North Dakota	mobile infiltrometer	4.3		2.4	1.5	treatment age: heavy 44 years, moderate 46 years, ungrazed 21 years
Various soils, Montana [Reed and Peterson, 1961]	single ring infiltrometer	7.3	4.4	4.3	2.8	sandy loam
		4.8			2.2	clay soils, average of all data
		4.3			1.4	clay soils, buffalo grass sod
		4.8			2.5	clay soil, western wheatgrass
		6.7			2.6	silty clay soil, average of all data
		4.5			0.8	silty clay soil, buffalo grass sod
		6.8			3.8	silty clay soil, western wheatgrass
						age of treatment: 7 years ungrazed, all else 14 years
Silty loam, Idaho (G. F. Gifford, unpublished data, 1977)	Rocky Mountain infiltrometer	1.7		1.4		plowed big sagebrush site, ungrazed 1975-1976, moderate since 1970; plowing and seeding in 1968
		1.6		1.4		
		1.1		0.9		
		1.3		0.9		
Clay loams and sandy loams, Pennsylvania [Alderfer and Robinson, 1947]	type F rainfall simulator			1.1	0.4	clay loam, bluegrass-clover; heavy, 50-60% cover, moderate, 90% cover
			1.4		0.8	clay loam, bluegrass-clover: heavy, 80-85% cover, light, 100% cover
				0.7	0.8	sandy loam soil treatment age for both soils 10 years

TABLE 3.2. (cont.).

Site	Equipment	Infiltration Rate (inches/hour) by Grazing Intensity: Ungrazed	Light	Moderate	Heavy	Remarks
Silt loam, Wyoming [Rauzi, 1954]	mobile infiltrometer	1.3	1.7	1.3	1.2	ungrazed for 2 years
		1.2			0.7	ungrazed for 13 years
Fine gravelly loams and silt loams, Wyoming [Rauzi, 1955]	mobile infiltrometer	1.2	1.2	1.3	1.2	fine gravelly loams, ungrazed for 3 years
		1.5	1.5	1.4	1.2	silt loams, ungrazed for 3 years
Silt loam, Louisiana [Linnartz et al., 1966]	double-ring infiltrometer	1.8		1.1	0.7	treatments 10 years old (spring and summer grazing); mostly Andropogon spp. on clearcut long-leaf pine forest site; moderate grazing, 47% utilization; heavy, 67% utilization
Cecil, Madison and Durham soils (texture not given), South Carolina [Holtan and Kirkpatrick, 1950]	type F infiltrometer		1.2	0.7	0.6	probably improved pasture situation, exact conditions not given.
Clay-skeletal, Texas [McGinty, 1978]	mobile infiltrometer	4.1		4.0[1]	1.7	ungrazed for 28 years
Clay, Texas [Wood et al., 1978b]	mobile infiltrometer	6.0[2]		5.3[1]	3.2	midgrass sites, ungrazed for 20 years
MEAN		2.6	1.7	1.7	1.2	

[1] Merrill 4-pasture deferred-rotation grazing system.

[2] Mean of two livestock exclosures.



SOURCE: Gifford and Hawkins (1978).

FIGURE 3.2 Relationships between infiltration rates (f_c) on grazed and ungrazed areas.

studies showed no difference between infiltration rates in pastures that were grazed with a Merrill deferred-rotation system and in livestock exclosures that had been ungrazed for 20 to 30 years. However, there was a significant difference between heavily stocked, continuously grazed pastures and ungrazed exclosures or Merrill deferred-rotation pastures.

Knight and others (1980) studied the impact of short-term; moderate, continuous; and very heavily stocked grazing systems on infiltration rates (Figure 3.3). These rates were lowest in winter and peaked in late spring and early summer, fluctuations that corresponded very closely with vegetation growth. Generally, there was no difference between the moderate, continuous and short-duration grazing systems. The very heavily stocked system resulted in significantly lower infiltration rates than the moderate, continuous or short-duration systems, except for January 1979.

The impact of grazing on infiltration rates will vary depending on range condition. Generally, infiltration rates of a site improve as the site's range condition improves (Osborn 1952, Rauzi and others 1958, Leithead 1959, Rauzi 1960, Johnston 1962, Rhoades and others 1964). Several researchers (Packer 1951, Marston 1952, Orr 1970, Meeuwig 1970a) have recommended that somewhere between 60 and 75 percent of plant and litter cover is required to control surface runoff. Recently Dadkhah and Gifford (unpublished manuscript), found that trampling may have a much greater impact on infiltration rates than does plant cover (Figures 3.4 and 3.5). Generally, a plant cover maintained at approximately 50 percent is just as good as an 80 percent litter cover in controlling infiltration rates on slopes of at least 15 percent. As slopes become steeper, increased plant cover is required to control infiltration.

Water Quality

Grazing is a diffuse activity and thus is a potential source of nonpoint pollution. Available literature indicates that sediment and bacterial water-quality indices are the parameters of greatest importance with wild equids.

Sediment from Upland Sites. Lusby (1970) reported that an ungrazed watershed produced 45 percent less sediment than a heavily grazed watershed. These comparisons were based on a paired watershed approach, but the two were not calibrated against one another before the grazing treatment was applied. Lusby assumed the watersheds were similar before treatment. Studies conducted in a Louisiana forest (Duvall and Linnartz 1967) and on a Canadian grassland (Johnston 1962) did not show an increase in sediment production from heavy grazing.

A study on the Manitou Experimental Forest, Colorado found no difference in sediment production between moderately, continuously grazed and nongrazed areas (Dunford 1954). Similar results were reported by Rich and Reynolds (1963) in a study conducted on the chaparral lands of Arizona. However, moderate grazing of a subalpine

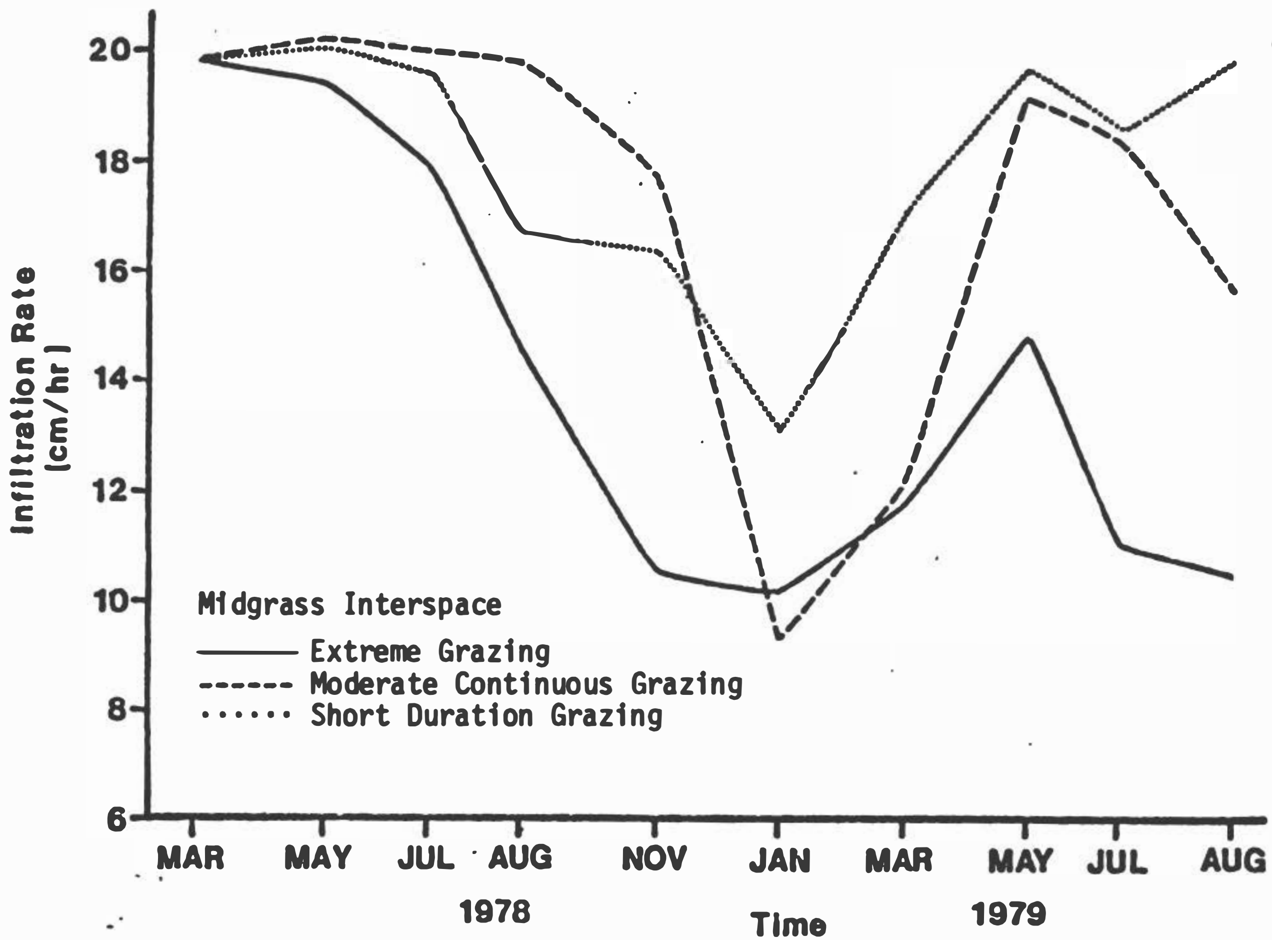
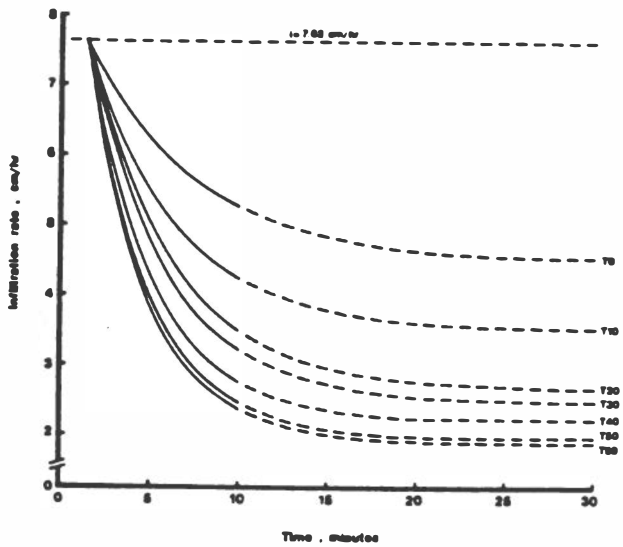


FIGURE 3.3 Terminal infiltration rates on midgrass interspace as influenced by livestock grazing, Edwards Plateau, Texas.



SOURCE: Dadkhah and Gifford, unpublished manuscript.

FIGURE 3.4 Infiltration rate curves for different soil compaction treatments. Dotted portions of each curve represent time periods after 10 minutes when an interaction between rock cover and trampling existed.

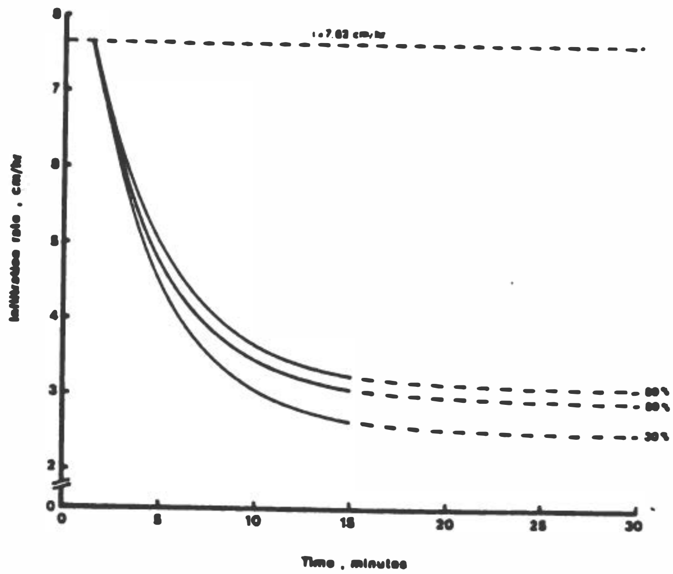


Figure 3.5 Infiltration rate curves for different percentages of grass cover. Dotted portions of each curve represent time periods after 15 minutes when an interaction between grass cover and trampling existed. (From Dadkhah and Gifford, unpublished manuscript.)

range in Utah increased sediment production over that of nongrazed areas (Meeuwig 1965). Meeuwig emphasized the need for proper management to reduce grazing impacts. A change in grazing management on part of the upper Rio Grande Basin from heavy, continuous grazing to moderate, summer-deferred grazing resulted in sediment being decreased from 1.72 to 0.54 metric tons/ha (Aldon and Garcia 1973). Buckhouse and Gifford (1976a) reported that 2 weeks of heavy grazing on a chained pinyon-juniper site in southern Utah did not increase sediment production over that of an ungrazed area.

Heavily, continuously grazed pastures on the Edwards Plateau, Texas produced more sediment than a pasture grazed under a four-pasture, deferred-rotation system, but was not different from an exclosure that had not been grazed for 28 years (McGinty and others 1978). Wood and others (1978b) measured sediment loss from three vegetation areas in eight different grazing treatments on the Rolling Plains, Texas. In shrub zonal areas, heavy, continuous grazing did not increase sediment production over that of nongrazed zonal areas. Heavily, continuously grazed midgrass-interspace areas produced more sediment than did the four-pasture, deferred-rotation system or a 20-year-old livestock exclosure.

Knight and others (1980) studied the influence of short-term; moderate, continuous; and very heavy, continuous grazing on sediment production at Edwards Plateau, Texas. He found no difference in sediment production between moderately, continuously grazed pastures and those grazed for a short amount of time (Figure 3.6 and 3.7). However, there was a large increase in sediment production from the very heavily, continuously grazed pasture as compared to the other two levels of grazing intensity.

As previously indicated, soil compaction by livestock has a major impact on infiltration rates. Trampling also has some impact on sediment production, but the overwhelming influence is through plant-cover manipulation. Dadkhah and Gifford (unpublished manuscript) have found that trampling (up to perhaps 30 percent disturbance) has a major impact on sediment production from bare and sparsely vegetated loam soils. However, as plant cover increases beyond perhaps 15 to 20 percent, it dominates control of sediment yield. Once cover extends over approximately 50 percent of the land, sediment production is statistically the same minimal value, regardless of the trampling disturbance. These findings conflict with the suggestions of Meeuwig (1970b) and Meeuwig and Packer (1976), which were based simply on a visual inspection of regression relationships, that 65 to 75 percent cover is required to minimize sediment production. This broad range obviously provides latitude for management recommendations, and the sediment issue becomes especially critical on rangelands that are only capable of supporting 50 percent cover at best.

To summarize, most studies show little or no difference in sediment production between lightly and moderately grazed pastures. Likewise, many of these studies show no difference between nongrazed areas and lightly or moderately grazed pastures. However, they almost always show an increase in sediment production from heavily grazed pastures as compared with lightly, moderately, or ungrazed pastures.

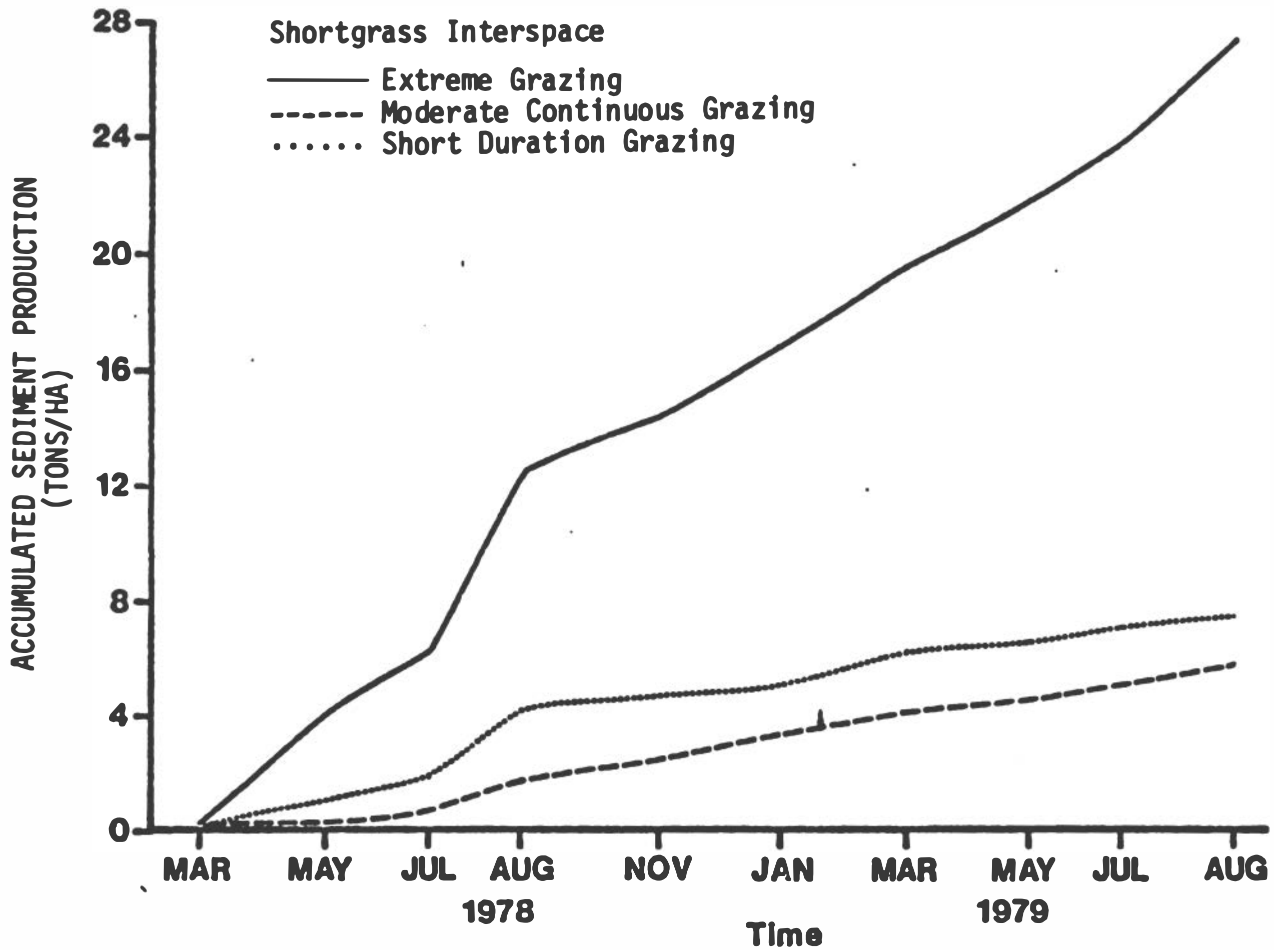


FIGURE 3.6 Accumulated sediment production from shortgrass interspace as influenced by livestock grazing, Edwards Plateau, Texas.

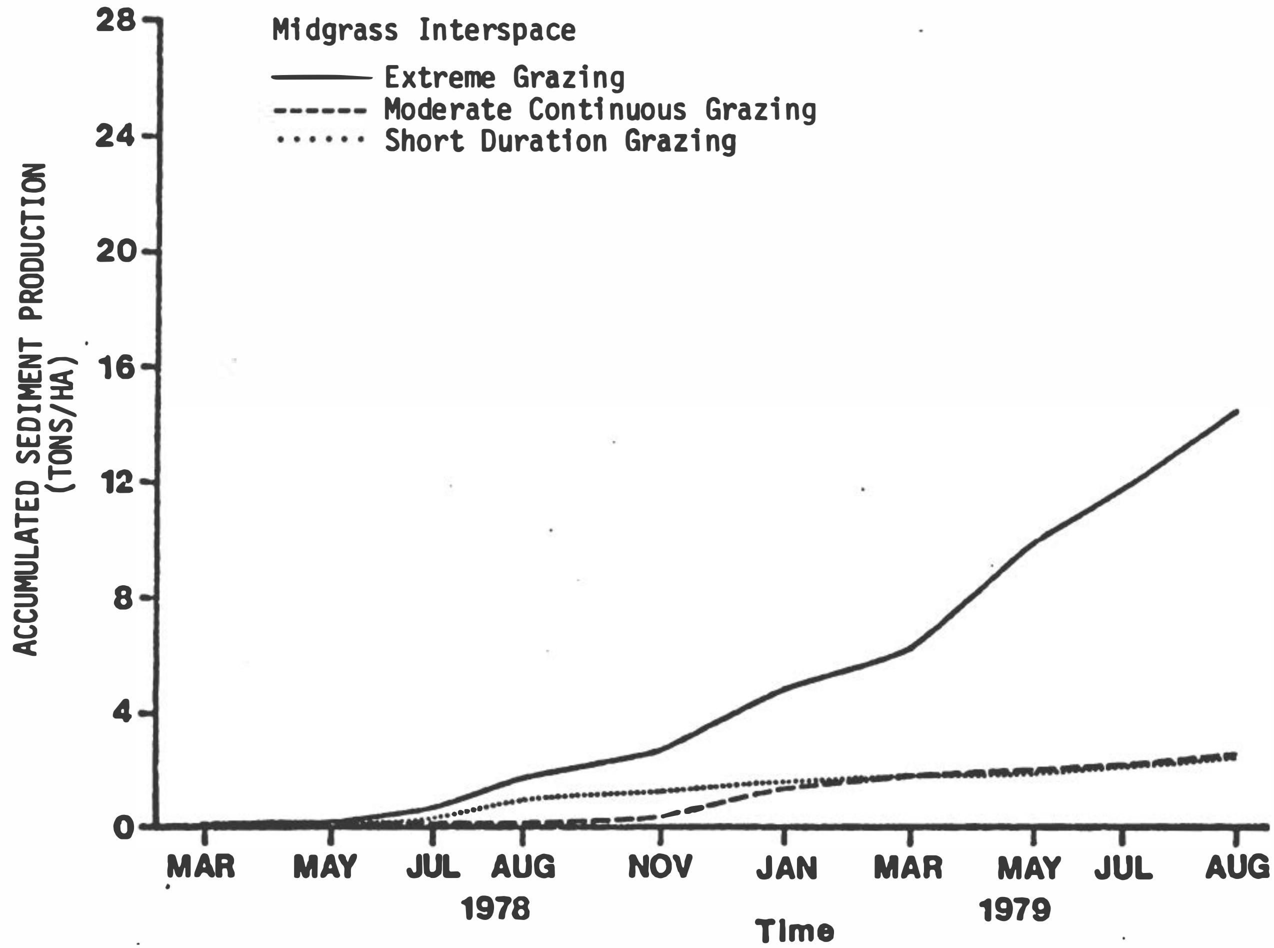


FIGURE 3.7 Accumulated sediment production from midgrass interspace as influenced by livestock grazing, Edwards Plateau, Texas.

Sediment from Riparian Zones. Sediment production within the riparian zone is often a serious matter, as problems with bank stability are often encountered. The bank-stability problem is often a combination of such things as destruction of vegetation, mass wasting, and bank cutting. In general, natural, stable, well-vegetated stream banks help maintain stream-channel integrity (Ames 1977, Davis 1977, Glinsk 1977, Kennedy 1977). Knight (1978) studied the influence of deferred rotation; rest rotation; moderate, continuous grazing; and no grazing on riparian habitat in the Blue Mountains, Oregon. He found that overwinter effects were more extreme than could be accounted for by livestock grazing. However, several recent papers (e.g., Cooper 1978) suggest that there is very little scientific information available on the relationships between grazing and riparian habitat management. Much of the available information is based on observations and a few case studies.

Bacteriological Quality. Stephenson and Street (1978) investigated both limited and intensive grazing systems at Reynolds Creek Watershed in Idaho. Results indicated that fecal coliform counts in the waterway increased after the cattle were introduced and remained at elevated levels for a period after the cattle were removed. No correlation was found between fecal coliform and stream discharge, but there was a correlation between total coliform and stream discharge ($r = 0.85$).

Sites subjected to summer grazing followed the same general pattern, with dilution and other inhibiting factors reducing concentrations as sampling progressed downstream. Inconsistencies were attributed to the tendency of cattle to congregate around trees for shade and the creation of a holding area for the fall roundup near the channel. This latter situation possibly resembled a feedlot.

On winter range sites, total and fecal coliform counts were dominated by runoff events. Again, counts increased when cattle were returned in the fall, and a partial snow cover and frozen ground allowed runoff and flushing during the winter. Irrigation return flow washed the bacteria into the stream from April to August, when the cattle were no longer on the pasture.

An attempt was made in the Reynolds Creek study to use a proposed BLM allotment plan to study fecal contamination, but incomplete construction of fences allowed cattle to move back into previously grazed allotments, thereby confounding the results. Counts increased as cattle were moved onto the allotments and fell after they were removed. An intense storm 3 weeks after the cattle were removed from both allotments caused considerable increases in counts (between 200 and 2,000 percent).

Johnson and others (1978) studied the effects of flood-plain grazing by 150 cattle in the Colorado Front Range. An 85-ha pasture bisected by a perennial stream was grazed from early April to mid-June, 1977. Six samples were taken prior to, and after, the removal of cattle. Sampling did not begin until early June. Results indicated significant increases in both fecal coliform and fecal streptococci counts over an upstream control. Within 9 days after removal of the cattle, neither type of bacteria was statistically different from its counterpart in the control.

Darling (1973) investigated cattle and sheep grazing on allotments in the Logan River Basin. Fecal coliform were monitored at low levels (<10 counts/100 ml) before the cattle and sheep were moved onto the allotments; after they moved in the fecal coliform count rose, but so did that in the control watershed. Fecal streptococci counts showed much variation, but differences were significant for all indicator bacteria when compared with an ungrazed watershed.

The influence of various land-use practices on bacterial water quality in a humid region was investigated by Kunkle (1970). The land-use categories included forest, pasture, barns, village, and a composite, and the quality of water stemming from the forested area was considered the control. Fecal coliform counts were closely related to stream discharge levels in the grazed area. Also, counts exhibited a hysteresis loop with stream flow much like suspended sediment on the same watershed. The author also found that bacteria were stored at the bottom and bank areas of the streams, and if agitated, became part of the stream load. By wading a reach of the channel, Kunkle found an increase in fecal-coliform concentration 30 m downstream and concluded that a floodwave could disturb these storage areas and release the bacteria. The influence of channel storage and lack of overland flow on the watershed led to the conclusion that very few bacteria were flushed during the events originated on upland areas. The channel and zones adjacent to the channel where overland flow was observed were cited as source areas for the bacteria.

A grazing study conducted outside the channel to determine bacterial pollution was reported by Buckhouse and Gifford (1976b). The study site was a chained pinyon-juniper community in southeastern Utah. The slash was windrowed and seeded to crested wheatgrass (Agropyron cristatum), and part of it was grazed at a rate of 2 ha/AUM. Data were generated with a simulated 28-minute rainfall. Results indicated no statistically significant difference between grazed and ungrazed aras. Analysis of source material revealed that sufficient numbers of bacteria existed for several weeks after deposition. Therefore, low counts were attributed to the low density of fecal material, which at this stocking rate covered approximately 0.2 percent of the area.

Doran and Linn (1979) monitored runoff from a Nebraska pasture grazed by cows and calves for total coliform, fecal coliform, and fecal streptococci during 1976, 1977, and 1978. Bacteriological counts in runoff from both grazed and ungrazed pastures generally exceeded recommended water-quality standards. Runoff from the grazed pasture contained 5 to 10 times more fecal coliform than runoff from the ungrazed pasture. The authors reported little difference in total coliform counts between the grazed and ungrazed areas, but fecal streptococci counts were higher in runoff from the ungrazed pasture and reflected the contributions from wildlife. They found the fecal coliform/fecal streptococci ratio in pasture runoff useful in identifying the relative contribution of cattle and wildlife. Ratios below 0.05 were indicative of wildlife sources and ratios above 0.1 were characteristic of cattle.

Buckhouse and others (1979) studied the influence of livestock grazing on the bacteriological quality of Meadow Creek in the central Blue Mountains of eastern Oregon. They found no detectable increase in coliform counts due to livestock grazing. Observed increases in bacteriological counts were due mainly to natural causes.

NEEDED RESEARCH

Overview

The Committee recommends that studies on habitat selection, food preferences and consumption rates, plant responses to grazing, animal population responses, and hydrologic effects be paralleled with empirical observations on ecosystem responses to grazing by different numbers of equids, with and without other herbivores. We accord first priority to studies of horses with and without cattle for several reasons.

1. Horses are more numerous and widespread than burros.
2. Dietary data indicate that horses are more likely to compete with cattle than with sheep.
3. Burro-livestock overlap and possible competition are potentially less extensive, if for no other reasons than that burros are more limited in distribution and the desert areas they occupy have a limited carrying capacity for livestock.
4. The following research designs will make it clear that the facilities and numbers of replications needed to study horse-cattle interactions alone will be demanding of personnel, space, and finances. Adding the study of sheep would double these demands. Horse-sheep interactions need to be investigated, but in our view not until horse-cattle studies as well as some of the other research advocated in this report have been provided for adequately.

Impacts on wildlife need attention, but we are not recommending formal studies at this time for two reasons:

1. The possible combinations of interactions are too numerous to be studied at present, given the amount of resources that are likely to be provided: horse-elk, horse-bighorn, horse-pronghorn, horse-deer, burro-desert bighorn. Such a large number of controlled studies seems out of the question for now.
2. Experimental controls of the sort advocated in the horse-cattle studies are difficult to establish for wild ungulates, particularly when replication is demanded.

What we do urge is that the federal and state agencies be alert to the possibility of doing before-and-after censuses on wildlife populations in areas where horse or burro herds are to be reduced. If several desert bighorn populations, for example, could be censused before planned burro reductions and for several years afterward, these counts could serve as experiments. If, in addition, a number of populations in nearby areas where burro reductions were not undertaken could be similarly counted, the overall result would be a roughly controlled experiment that hopefully would give more accurate answers than we now have on burro-sheep competition. Similar opportunities involving horses and wild ungulates should also be exploited.

Accordingly, we propose the following three projects, which concern horse-cattle impacts on vegetation, range hydrology, and riparian zones.

Project 8. Grazing Impacts of Equids and Cattle on Range-Plant Communities

Rationale

PL 95-514 requires that a program of research be developed that defines what constitutes excess numbers of animals. "Excess" can be interpreted from both the standpoint of animal population welfare and welfare of the range. On the latter point, there appears to be little quantitative documentation in the published literature of grazing use by either horses or burros. Several studies have documented plant utilization levels by both burros (Koehler 1974, Carothers and coworkers 1976, Hanley and Brady 1977) and horses (Salter and Hudson 1979), but grazing by other ungulates using the same range has often confounded the results, and the attribution of specific levels of defoliation to specific numbers of animal days of grazing use has not generally been done. Protracted studies (>5 years) on range trend are quantitatively needed to document adequately the effects of horses on plant communities. However, in view of the immediacy of the question and the brief amount of time available to conduct the required studies, quantitative data on plant utilization levels can be used to arrive indirectly at an approximate definition of "excess" from the standpoint of range-plant community use and stability.

It is quite apparent that herbivores affect the physical structure and botanical composition of the plant communities upon which they graze. However, for a given stocking rate or level of herbage removal, the grazing effect is not uniform across animal species because various animals possess different forage preferences, dietary habits, and grazing behaviors. To plan effective grazing management programs, the range manager needs to know more than merely which plant species are consumed or preferred by his grazing animals and the extent to which their diets overlap. He must also understand the temporal and spatial patterns of such grazing use, the relative degree of foliage removal on the major forage plants in the community, and the parts of various plants that are consumed. All of these factors contribute to the persistence or the demise of individual plants in a community and, ultimately, to shifts in competitive relationships and community succession. These relationships have been studied relatively well under cattle and sheep grazing regimes, but have received little attention where equids graze, either alone or in combination with other large herbivores.

Ideally, such studies should endure for more than 5 years, so that successional changes in plant communities could be directly evaluated. However, it is possible to draw inferences from short-term studies in which utilization patterns on individual plants are carefully monitored and related to published information on the physiological responses of these plants to various levels of defoliation. Such studies would also form the beginnings of longer term investigations where successional change is monitored.

Emphasis is given here to horse-cattle impacts because they appear to constitute the most prevalent problem all over the West. However, we are not implying that other domestic animals (e.g., sheep) should not be considered if they are important locally. Nor do we imply that burro-livestock or burro-wildlife interactions should not be considered.

Objectives

1. Determine grazing distribution patterns (habitat selection) of horses and cattle when grazed as single species or in combination. This objective is to be addressed in Project 1 (see Chapter 2).
2. Within important habitat segments, determine for the major forage species:

    a. Temporal level of utilization (percentage of production removed during current year)
    b. Use of standing dead or previous year's (in the case of shrubs) plant material
    c. Plant parts utilized
    d. Frequency and timing of defoliation
    e. Production of forage regrowth and its utilization.

Methodology

1. In contrast to Project 1, this grazing-impact study should be conducted in large paddocks, say from about 100 to 320 (40 to 130) acres in size. These can be set up in small temporarily or permanently fenced pastures so that local environmental variation can be adequately controlled. The actual size of these pastures will depend upon the present grazing capacity of the areas selected for study and the seasons and durations of the grazing periods.
2. Domestic horses generally representative of the locale's wild types might serve as experimental models in studies of plant utilization patterns and rates, daily forage-consumption rates, dietary nutritional value, and--to a partial extent--forage preferences. Representation of social units and sex-age structures typical of wild herds will obviously not be possible in such small-scale, highly controlled studies. However, major attention should be focused on the reproductive female. Domestic cattle used in these studies should represent local conditions in terms of breed,

sex, age, and reproductive status. For example, steers should not be used to represent lactating cows simply for the sake of technical expediency.

3. The season(s) of grazing should also represent local conditions. For example, if existing conditions include year-long use by horses of sagebrush-bunchgrass range, with typical spring use by cows and calves, the small-scale pasture studies should be designed to adequately represent and sample these conditions.

4. The treatments in this project should be the same as those in Project 1:

a. Grazing by equids at carrying capacity
b. Excessive grazing by equids
c. Grazing by cattle (or sheep) at carrying capacity
d. Excessive grazing by livestock
e. Grazing by equids and livestock at carrying capacity
f. Excessive grazing by equids and livestock.

In addition, there should be control pastures with no grazing by either class of animals. The stocking rates should be determined through consultation with professional range managers and scientists (BLM, USFS, Soil Conservation Service [SCS], and university scientists and extension specialists) who are familiar with problems and conditions of the particular study area. The combination treatment should be stocked so that the year-long level of grazing use is on an equivalent AUM basis for the two animal species concerned.

5. Where possible, grazing use by native ungulates should be incorporated into the design. This factor might be treated as a separate main effect with appropriate blocks for combinations of horses (burros), domestic livestock, and native ungulates, or it might be analyzed through an alternate experimental design (e.g., split-plot) in which separate blocks are not considered. The use of tame, hand-reared animals in either of these design contexts would provide an avenue for highly controlled studies of equid-wild ungulate interactions. With the exception of bighorn sheep, considerable research experience has been amassed from tame-animal studies of various habitat features (e.g., see Currie and others 1977, McMahon 1964, Neff 1974, Reichert 1972, Smith and others 1979, Wallmo and others 1972 for studies on mule deer; Collins 1977 for elk; and Schwartz and others 1977 for pronghorn antelope). As a minimum consideration, range and forage use by native ungulates should be monitored in any study location where their presence is important. Attention should be focused both on social interactions with horses (burros) and on possible interactions mediated through the food or water resource.

6. Utilization patterns and rates should be carefully measured as a basis from which plant-community change can be inferred. Utilization rates and levels should be closely tied to amount of grazing usage (in AUDs or AUMs; see Table 3.1 for definitions) by the animal species concerned. This approach necessitates a careful quantification of growth (and regrowth) curves for ungrazed representatives of plant species studied.

7. Findings on seasonal levels and rates of species utilization should be related both to appropriate published data and to inferences drawn regarding the likely directions and rates of community change under various levels of grazing pressure and kind of animal use. Examples of literature pertinent to such information might include West (1968), Willard and McKell (1973), Pechanec and Stewart (1949), West and others (1972), Hyder and others (1975), Smith (1967), Cook (1971), Ellison (1960), and Laycock (1967). The recent bibliographic source by Vallentine (1978) should also be consulted in this pursuit.

8. The approach advocated here will yield rapid, although relatively imprecise, answers to questions about grazing impacts. An essential part of such a study is early establishment of permanent range-trend transects in both grazed and ungrazed pasture. If the experimental grazing treatments could be carried on past the 2-year limits imposed upon this study, such transects would provide the long-term data necessary for ultimately determining the effects of wild, free-roaming horses and burros on plant-community change. Such long-term research could be maintained beyond the initial 2 years by applying only low levels of labor and money. The potential payoff is high.

Project 9. Hydrologic Impacts

Rationale

Virtually no information exists on the impacts of wild equids on range hydrology. Likewise, few data have been recorded on the influences grazing livestock have on range hydrology for the western rangeland now supporting wild equids. To plan effective management programs, the rangeland manager needs to know the impact of wild equids, livestock, and/or wildlife on hydrologic parameters.

Hydrologic responses are often much slower and sometimes less obvious than vegetation changes. In order to evaluate hydrologic change adequately, such studies should endure for more than 5 years). Emphasis is given here to the impact of wild equids and wild equid-cattle interactions. This does not mean that other animals should not be considered if they are locally important.

Objectives

1. For important habitat segments, determine the influence of wild equids and wild equid-livestock interactions on selected hydrologic parameters. Use the data collected in objective 1 to:

2. Construct new models or develop variables for existing hydrologic models such as the Hawkins and Gifford (1979) model or the universal soil-loss equation.

Methodology

The following research should be carried out in conjunction with Projects 2 and 8.

1. Because of the relatively low and highly variable precipitation on the wild equid range, and the relatively short time frame of this study, data obtained with simulated rainfall should be the most reliable. This recommendation does not preclude the use of supplemental natural runoff plots or small watershed data if local conditions are favorable and funds are available for such studies.

Ideally, this study should be both intensive and extensive in design.

a. Intensive Study. This study should be conducted using small runoff plots (1.83 x 22.13 m or 6 x 72.6 ft) located on 9 percent slopes. This plot size should be large enough to include the variability present in an area, particularly that associated with vegetation patterns (i.e., brush-canopy areas and interspace areas). Data obtained from a plot of this size could be used to refine the universal soil-loss equation for use on western rangelands. The runoff plots should be instrumented with a 15.2-cm (6-in.) H-flume and a 20.5-cm (1-ft) Coshocton wheel sampler or similar water measuring and sampling devices. These runoff plots would measure and sample natural and simulated rainfall events.

A rainfall simulator (something similar to Meyer's but placed in line) should be used at selected time intervals during the year to apply rainfall to the runoff plots. The rainfall application rate should exceed infiltration rates, and raindrop size and terminal velocities should approximate a natural storm of the intensity simulated.

A minimum of three runoff plots should be used per grazing treatment and vegetation-soil unit sampled. From these runoff plots the following information should be collected at predetermined intervals throughout the year:

- Infiltration rate
- Sediment production
- Additional water-quality parameters
- Vegetational cover by species
- Bare ground cover
- Shrub-canopy area and interspace area
- Microtopography.

From shrub-canopy and interspace areas adjacent to the runoff plots, the following information should be collected at the same predetermined intervals:

- Soil bulk density
- Soil organic matter
- Soil aggregate stability
- Grass standing crop.

b. Extensive Study. This study should use a small portable rainfall simulator (scaled-down model of the one described above) and variable runoff plots that will allow for separation of shrub-canopy areas and interspace areas. Runoff plots should be 0.5 to 1 m^2 in size. Simulated rainfall rates should exceed infiltration rates, and raindrop size and terminal velocities should be similar to that of a natural storm. These plots should be relocated at selected intervals on a similar site before the next simulated rainfall is applied. A minimum of six runoff plots should be used per grazing treatment and vegetation-soil unit sampled. The following data should be collected from each runoff plot:

- Infiltration rate
- Sediment production
- Vegetational cover by species
- Bare ground cover
- Microtopography
- Soil bulk density
- Soil organic matter
- Soil aggregate stability
- Grass standing crop.

2. The data collected in the study described above should be used in the construction of new models or in developing variables for existing models, such as the Hawkins and Gifford (1979) model or the universal soil-loss equation.

Project 10. Riparian-Zone Impacts

Rationale

The riparian zone is extremely important, not only in terms of total watershed behavior, but also in terms of its individual components--fish, wildlife, insects, vegetation, birds, and soil. This study would concentrate on defining the impacts of wild equids and cattle on hydrologic behavior and water quality, both of which affect all other components of the riparian zone.

Objectives

1. Determine the amount of suspended sediment, coliform, total dissolved solids, and dissolved oxygen; measure the water temperature

and general channel stability of selected portions of the riparian habitat grazed by wild equids.

2. Relate measured water-quality and channel-stability characteristics to the characteristics of the adjacent riparian habitat. Important characteristics would include percentage of vegetative cover, grazing intensity, and rest periods. Other important considerations include general behavioral characteristics of the study animals with respect to use of the riparian habitat.

Methodology

The design of this study will depend to some extent on whether the grazing animals are using springs, established water holes, or live streams as a source of water. It would be desirable, if possible, to include riparian zones with the headwater originating in the pastures and in relatively good biological condition. The stream characteristics should be as similar in all treatments as possible. If these criteria cannot be met and a reach of a river or stream has to be used, water-quality sampling will have to be carried out on a "flow-through" basis. Samples will have to be taken as water enters a specific reach representing a given grazing treatment, and again as water leaves the reach. This scheme dictates that intensity of use must increase in a downstream direction rather than in a random pattern.

When assessing the impact of animals on ponds, seeps, or springs, similar water sources will have to be replicated in each pasture.

Data should be collected at predetermined intervals throughout the year.

CHAPTER 4

SOCIOECONOMIC AND POLITICAL ISSUES

INFORMATION NEEDS

Socioeconomic and political factors must be considered in any decisions about the management of public lands and resources. Three categories of information needs have been identified in this broad subject area.

First, economic information is needed about the demand for wild and free-roaming horses and burros and on the cost of various management alternatives. Both the direct costs of the horse and burro management program and the indirect costs on other range management programs should be assessed. Such information is needed to supplement what is known about the use and management of public rangelands; i.e., livestock and range economics focused on economic characteristics of individual firms; economic industry studies depicting the structure of livestock-dependent communities and regions, and the impact of possible changes in these structures; and economic valuation of extra-market wildlife values, with possible extensions of methodologies to horse and burro populations.

Second, decision makers in federal land-management agencies need data to help them determine proper management strategies for wild horse and burro populations on federal lands within the context of the agencies' overall responsibilities for land management. The decision-making processes of these institutions must be understood if the scientific information they provide about horses and burros is to be effectively applied. It is also important for scientists to understand the legal and political constraints confronting federal land managers, so that management decisions acceptable to all those concerned can be made.

Third, information is needed regarding public attitudes, values, and management preferences so that appropriate management policies and strategies can be determined. This information should quantify the relative worth of wild horses and burros to the various sectors of the public concerned about them. The value of wild horses and burros relative to that of livestock and other wildlife should focus on the recreational, aesthetic, utilitarian, ecological, scientific, and historical benefits and costs associated with all these animals. In addition, information is needed regarding the public's preference for alternative management and control strategies. Studies of predator control and endangered species protection have revealed that several variables seriously affect public attitudes towards management and control. The views of both the general public and special interest groups should be considered.

STATE OF KNOWLEDGE

Information Sources

Numerous sources were searched in order to assess the current state of knowledge regarding legal, political, economic, and sociological issues. Many journals, articles, Congressional hearings and other government documents, technical publications, books, and manuscripts chronicle the long history and intensity of the issue. Several basic bibliographies, periodical indexes, and computerized data-access systems were used to assess the full parameters of the debate. The following computer systems were searched for relevant citations:

AGRICOLA (Agricultural Data Base)
BIOSIS
CIS (Congressional Index Service)
CRECORD (Congressional Record)
ENVIROLINE
EPB (Environmental Periodical Bibliography)
GPO Monthly Catalogue
LEXIS
NTIS
Social Science Search
USDA/CRIS.

The library collections of the University of California at Davis and Berkeley and of Yale University were also searched. The following sources were searched manually:

Bibliographies of references uncovered by the searches
Bibliography of Wildlife Theses
Biological and Agricultural Index
Conservation and Wildlife Bibliography
Dissertation Abstracts International (Social Sciences and Biological Sciences)
Environment: A Bibliography of Social Science and Related Literature (U.S. Environmental Protection Agency)
Forest History Society Bibliographies
General Science Index
Index to Legal Periodicals
Keyword Index of Wildlife Research
Natural Science Research Reports: 1973 - May 1978, Southwest Region, NPS
Public Affairs Information Service

Reader's Guide to Periodic Literature
Wild, Free-Roaming Horses - An Annotated Bibliography
Wildlife Review.

To supplement the literature searches, several active range and natural resource economists at New Mexico State University, University of Wyoming, and Utah State University were consulted. Interested public and private organizations and individuals and various state and federal agencies were contacted personally, by telephone, or by mail.

Contacts were made with 34 agencies and organizations. Federal agencies included BLM, National Park Service (NPS), the U.S. Fish and Wildlife Service, and the USFS. Letters requesting information at the state and district level were sent to all BLM state offices and to all state fish and game departments that deal with wild horses and burros. Some 19 private organizations and interest groups were contacted by letter or telephone. After careful initial investigation, five organizations--BLM, NPS, the Humane Society of the United States, the Fund for Animals, and the American Horse Protection Association--were visited in Washington, D.C.; files were inspected and relevant personnel interviewed.

Nine individuals--academics and others with special expertise--were consulted. In addition, a great deal of anecdotal information, as well as transcripts from various public meetings, were collected and are available upon request. Correspondence and clipping files were identified as potential sources of raw data.

Economic Considerations

The economics literature that focuses specifically on issues concerning wild and free-roaming horses and burros (abbreviated WFRHB in this chapter) is rather sparse (only Hyde 1978; Godfrey 1979a, b). However, range and ranch economics has a long-established history at many land-grant institutions in the West. From the mid-1950s through 1969, the Western Agricultural Economics Research Council (WAERC) sponsored the Committee on the Economics of Range Use and Development. During those years, that committee issued a series of reports and proceedings on a wide variety of range resource and management topics; their last report (WAERC 1969) is a range and ranch economics bibliography. In our review we found many references to reasonably current studies. Nielsen and Workman (1971) and Ching (1978) list rather extensive bibliographies relating to ranching and public land use in the western states.

Thus, we conclude that enough information and background analysis exist to permit a basic understanding of the economics of livestock firms and of the economic structure of livestock-dependent communities or regions. There are many studies, cited in Appendix C, that pertain specifically to particular ranching areas in the West or that clearly define the methodological approaches that can be used in studies in other areas.

Part of the impetus for PL 95-514 was the concern that the public rangelands were producing at less than their potential. Several reports published earlier in the decade gave evidence of this situation; e.g., see portions of the Public Land Law Review Commission report, One Third of the Nation's Land (U.S. Department of Commerce 1970); study reports by the Stanford Environmental Law Society (1971) and the University of Wyoming College of Law (1970); a U.S. General Accounting Office study (1977); Box and others (1977); and papers contained in the 1977 Forum on the Economics of Public Land Use in the West (Ching 1978). The recent economics literature includes some citations on range improvement; e.g., Godfrey (1972), Stevens and Godfrey (1972), Cordingly and Kearl (1975), Heady and Bartolome (1977), and Olson and others (1977). These studies provide information about and methodologies for addressing public rangeland improvement problems, which may be useful in those cases where rangeland improvements and WFRHB populations occur together and where the economic effect of improvement must be considered in the allocative management decision.

Although little economic literature specific to WFRHB issues is available, theoretical methodologies applicable to the problem probably exist. Market and nonmarket valuation techniques are developed, although the latter are less refined and are still undergoing additional theoretical development. Nonmarket valuation and analysis for environmental and aesthetic nonconsumable goods--including wildlife--are discussed in Krutilla (1972), Brown and others (1973), NAS (1975), Brookshire and others (1979), and Section 704.129 (Recreation) of the recent U.S. Water Resources Council report (1979).

Two economists have written papers on WFRHB issues. Hyde (1978), in a variation of a paper previously presented at the 1977 National Wild Horse Forum (Artz 1977), developed an approach for a qualitative evaluation of management alternatives by comparing "consumer" benefits with management costs. The elements in Hyde's approach included (a) the value of recreational viewing of horses (and burros); (b) "vicarious" values, gained through the enjoyment of others or through the mere knowledge that wild horses (and burros) will be there whether one ever sees them or not; (c) the values of adopted animals to foster owners; (d) the opportunity cost of domestic livestock and wildlife foregone because of competing WFRHB populations on the public ranges; (e) the separable cost of managing WFRHB populations, including roundup, disposal, legal, and enforcement costs; (f) and the cost of negative externalities created by WFRHB management on private individuals and economic units--e.g., unwanted grazing on private land. Hyde recognized the difficulty in quantifying the above-mentioned elements for management, but urged that it be attempted in demonstrative case studies.

The second, and more recent, survey of the impact of the Wild and Free-Roaming Horse and Burro Act was performed by Godfrey (1979a, b). (The first citation is a project report and the second a short publication summarizing the former.) Godfrey (1979b:50) noted that "there are reasons why the capture and use of WFRHB need to be controlled but it is not obvious that the present laws result in efficient or equitable solutions," and that "most of the research that has been advocated by others is ecological, and must precede any economic evaluation of the WFRHB problem."

Major socioeconomic areas of inquiry identified by Godfrey as needing attention included: (a) the value of and demand for WFRHB, (b) evaluation of adoption procedure and success, (c) evaluation of control and management techniques, (d) analysis of optimal WFRHB numbers and management alternatives for maintaining populations, and (e) evaluation of the costs of existing legal regulations and restrictions. The study, which was based on response to a mail survey of BLM and USFS districts in the 10 western states, attempted an evaluation of the economic costs of WFRHB management through the 1978 fiscal year and described reported impacts on other uses.

Legal and Political Issues

The legal-political literature on matters directly and indirectly germane to this inquiry is extensive. In the specific area of WFRHB policy and law, numerous journals, articles, Congressional hearings and other government documents, technical publications, books, and manuscripts chronicle the long history and intensity of the issue. We conclude that when the printed material on this policy issue is added to the public hearing and other interview material generated by the efforts of this Committee, no primary research will be required.

Equally important is the extensive literature concerned with federal land-use planning, multiple-use decision making, wildlife management, and the history of public lands. The extensive literature that exists on many of the issues of concern to this Committee will provide vital input to its final report, even though no research needs to be done in these areas. The Committee's final report to Congress should discuss the historical background of the federal land-management agencies and the resources they manage. This information is already available in a number of publications. However, it must be studied so that the final Committee report can place the wild horse and burro management program in the context of the agencies' management authorities, their institutional structures, and their historic personnel and budget resources.

The legislative history of the Wild and Free-Roaming Horses and Burros Act should also be analyzed, along with the pre-1971 management of these animals under state estray laws. The material for this analysis exists already. The final report should also discuss the agencies' single-purpose mandates as they constrain multiple-use management. The constraints include the Endangered Species Act of 1973, the cultural resources program, and the mining laws. Again, the literature on these issues exists and no primary research is required.

Table 4.1 contains a list of civil cases filed under the Wild and Free-Roaming Horse and Burro Act along with brief descriptions of the legal issues presented in each case. Most of the lawsuits fall into two categories: (1) those challenging the need for roundups and the

TABLE 4.1 Cases Filed Under the Wild and Free-Roaming Horse and Burro Act

Reported Cases

1. Kleppe v. New Mexico, 426 U.S. 529 (1979) Constitutionality of the Act, particularly federal authority to manage wildlife on public lands.

2. American Horse Protection Ass'n v. U.S. Dept. of the Interior, 551 F. 2d 432 (D.C. Cir. 1977) Howe Massacre litigation. Issue: whether ownership under state laws is to be determined by state or federal officials. Final decision is federal under S5 of the Act upholding federal authority.

3. Roaring Springs Associates v. Andrus, 471 F. Supp. 522 (D. Or. 1978) Obligation of federal government to remove wild horses from unfenced private lands.

4. Sheridan v. Andrus, 465 F. Supp. 662 (D. Colo. 1979) (Craig, Colo.) Alleged improper taking by government of horses owned by plaintiffs.

5. American Horse Protection Ass'n v. Andrus, 460 F. Supp. 880 (D. Nev. 1978) (Palomino Corral and Nevada roundups). Compliance with NEPA; legality of roundups; humane conditions. (Appeal pending before Ninth Circuit).

6. American Horse Protection Ass'n v. Kleppe, 6 ELR 20802 (D. D.C. Sept. 9, 1976) Legality of Challis roundup under the Act and NEPA.

7. American Horse Protection Ass'n v. Frizzell, 403 F. Supp. 1206 (D. Nev. 1975) (Stone Cabin roundup). Legality of roundup under the Act and NEPA and legality of state cooperative agreement.

Unreported or Pending Cases

1. Mountain States Legal Foundation v. Andrus, Civ. No. C79-275 (D. Wyo. filed 9/20/79) Private parties seek to order Dept. of the Interior to reduce horse numbers so as to prevent alleged damage to public lands, to remove all horses from checkerboard private lands and to pay monetary damages for past harm to plaintiffs.

2. State of Nevada v. U.S., Civ. No. R-79-185-BRT (D. Nev. filed 8/20/79). State seeks court-ordered gathering of horses back to 1971 census levels and a declaratory judgment that the state can manage the wild horse population itself without federal interference.

3. State of Nevada v. U.S., Civ. No. R-78-0076 (D. Nev. 3/25/78) Jurisdiction of state versus federal government in ownership determinations. (Dismissed 3/28/79) (Same issue as American Horse Protection Ass'n v. U.S. Dept. of the Interior).

4. National Animal Welfare League v. U.S. Dept. of the Interior, (Civ. No. F-77-93 E.D. Cal) (burros in Saline Valley, Calif.) Legality of wild burro roundup program (bighorn conflict).

5. Humane Society of the U.S. v. Udall, Civ. No. 2158-68 (D. D.C. 1968). Challenge to Pryor Mt. roundup. Case dismissed when BLM stated it had no plans for a roundup.

adequacy of the environmental impact statements relied upon by the government, and (2) those challenging federal, as opposed to state, government authority over the animals. The lawsuits reflect serious concern about the implementation of the Act by those interested in protecting wild horses and burros, those interested in preserving state control over them, and those concerned about the impact of the animals on rangelands. The lawsuits also illustrate serious disagreement among experts about fundamental information like herd size, population levels and trends, reproductive rates, and the impact of the animals on other resources such as wildlife and the range itself. The Committee will further analyze the use of such information in these lawsuits and the reaction of the courts to this information by reviewing the transcripts of all judicial proceedings. The final report will provide more detail. However, primary research is unnecessary.

Sociological Aspects

An empirical data base is lacking regarding the sociological aspects of the wild horse and burro issue. Many interesting and provocative accounts were found, but nearly all stemmed from hearsay. The only limited attempt to ascertain public attitudes on the issue empirically--as well as to determine relative values associated with wild horses--was undertaken by Rey (1975). The major thrust of Rey's contribution was to "define exactly which resource values associated with wild horses should be maintained." To determine public sentiment on the issue, he surveyed recreationists and other key resource groups in the Pryor Mountain area for preferences regarding various wildlife species (including wild horses) and for presumptions about the benefits associated with wild horses. While the methodology could have been scientifically more sophisticated, the information provided at least some insight on the topic and represents--except for a fairly limited study by the NPS on burros--just about the only empirical material on the subject. On the other hand, some useful sociopolitical analyses have been written, and these are summarized in the annotated bibliography in Appendix C.

NEEDED RESEARCH

Levels of Inquiry

All or part of the recommended projects should be carried out at several levels of intensity. Whatever level is chosen, selection of representative research sites should be based on socioeconomic as well as biological considerations. We have identified three such levels of analytic effort that are based on the management relevance of the information generated and the availability of research resources.

A minimum-level research program in the socioeconomic area would include Project 11A--"Taxonomy of Values and Benefits of WFRHB," Project 13--"Management Costs of WFRHB Alternatives," and a time-lagged study--Project 14--"Economic Considerations for Management Alternatives Drawn from Proposed Research Programs." This research can be conducted largely, but not exclusively, by systematic analysis of existing materials.

Increased research resources would permit a higher but still restricted level of inquiry. It would involve generation of original data, but issues would have to be specific, and populations and sites would be, of necessity, limited. Projects that would be included in an intermediate research program (in addition to those noted above) are Project 11B--"Public Preferences for Alternative Management and Control Strategies," Project 12--"Analysis and Evaluation of Demands for Excess WFRHB," and Project 15--"Nonmarket Values for WFRHB."

Socioeconomic data necessary to a systems-level understanding of WFRHB management issues could be generated at a third, more inclusive, level of research effort. This level would require that all projects 11-15 be executed with the final attention to research agendas of Project 11C--"Public Attitudes, Behaviors, and Knowledge Regarding WFRHB" and Project 16--"Conceptual Development of Public Rangeland Management Models." Note that each higher level of effort is to include the projects in the level below it.

Project 11. Public Attitudes

11A. Taxonomy of Values and Benefits of WFRHB

11B. Public Preferences for Alternative Management and Control Strategies

11C. Public Attitudes, Behaviors, and Knowledge Regarding WFRHB

Rationale

The joint report submitted by the BLM and USFS to Congress in 1976 stated that "greater public understanding of the wild horse and burro situation, plus public involvement in decisions concerning these animals, is vital to stated management goals." In this section we propose a series of research efforts that could enhance agency understanding of public awareness, needs, attitudes, and preferences.

Objectives

Three interrelated projects are identified as 11A, 11B, and 11C. They involve different objectives and levels of data collection efforts. The third project, 11C, incorporates 11A and 11B within the context of a larger, much more costly primary-data collection effort.

11A: Values and Benefits of Wild Horses and Burros. On the basis of existing, secondary-source information (e.g., public testimony, hearings, Congressional records, etc.), develop a taxonomy of commodity and noncommodity values and benefits associated with wild horses and burros relative to other public land resources.

11B: Public Preferences for Alternative Management and Control Strategies. Collect original but limited site- and population-specific public attitude information regarding preferences for alternative WFRHB management and control strategies.

11C: Public Attitudes, Behaviors, and Knowledge Regarding WFRHB. Conduct national and special-interest group study of public attitudes, knowledge, and behaviors associated with WFRHB. The objectives of this project include those identified in 11A and 11B. Furthermore, collect information on public awareness, knowledge, and understanding of the WFRHB issue (including related issues of multiple-use management, legislative mandates, and potential socioeconomic impacts of alternative WFRHB management practices on rangeland-dependent commercial activities).

Methodology

11A: Values and Benefits of Wild Horses and Burros. Conduct content analysis of secondary-source information (e.g., public hearings, Congressional testimony, etc.) to develop a taxonomy of values and benefits associated with WFRHB. An empirical assessment of the relative importance and strength of these values among special-interest groups and the general public would require some form of public survey research, described below under 11C.

11B: Public Preferences for Alternative Management and Control Strategies. Conduct a small-scale survey of special-interest groups representing livestock producers, horse and burro advocates, and wildlife and range scientists regarding alternative control strategies. As much as possible, the sample site for this data collection should correspond with the location of the biological and ecological research efforts. The methodological steps associated with the survey work in project 11B are described under 11C. These same procedures are applicable in 11B but on a more restricted scale.

11C: Public Attitudes, Behaviors, and Knowledge Regarding WFRHB.
1. Sample selection and data collection. Two samples should be drawn, the first consisting of the following special-interest groups: livestock producers (particularly cattlemen), horse and burro protection advocates, and wildlife professionals. The second sample should be a cross section of the American population differentiated according to level of familiarity with or knowledge about the horse and burro issue.

The selection of both groups should be random. In the case of the special-interest groups, stratified random-sample selection may be required. For example, a random sample of livestock producers could be obtained through BLM districts, weighting each district for numbers of stockmen. In addition, the cooperation of national organizations (e.g., the National Cattlemen's Association) could be enlisted. Similarly, horse and burro advocates and wildlife professionals could be selected from organization lists properly weighted for the size and representativeness of the groups involved.

The national sample should be drawn according to probability random selection standards: i.e., each individual in the population should have a roughly equivalent chance of being selected. Given cost constraints, a telephone interview is most appropriate. In creating the sample, some type of random-digit dialing method should be employed. An acceptable method should be used to randomly designate a desired respondent within households of various sizes. Once the size of the household has been determined, the caller is to ask for the designated respondent. If that individual is not at home, a minimum of two callbacks should be attempted before the designated respondent is dropped. These callbacks should be made in the evenings and on weekends, if possible. The general public sample should not be selected or interviewed in the summer months to avoid bias stemming from different likelihoods of interviewees being at home.

The telephone interviews should not require more than 20 to 30 minutes to complete. If more time is needed, especially in the case of the special-interest group samples, mailed questionnaires should be substituted. If such instruments are used, a response rate of at least 60 percent is required, and some type of validation of nonrespondents should be carried out.

If the data collection is subcontracted, the subcontract should be made only with private or public firms with the capacity to perform national sampling. Competitive bids should be required from at least 10 potential subcontractors. These bids should include a study proposal, cost estimates with major categorical breakdowns, and a list of at least six previous clients who can comment on the subcontractor's work (if possible, such clients should be in the natural resource area or have conducted a national sample). At least 15 percent of the interviews should be verified. It is assumed that the subcontractor will code and keypunch all the data collected. The principal investigator is expected to work with the subcontractor on developing the coding system.

When special-interest groups are sampled, subgroups should be of at least the following sizes: livestock producers, 400; horse and burro advocates, 200; wildlife professionals, 200. The general public should be divided into informed (knowledgeable about the horse and burro issue) and uninformed groups. The size of the former should be at least 800; that of the latter, 400. At least 150 respondents should reside in the major livestock-producing states and, thus, a special oversampling may be required in this area. If this oversampling occurs, proper weights should be used in any analysis that refers to the overall American public.

2. Interview schedule. The basic interview schedule should consist of five sections:

a. Attitudes and values associated with wild horses and burros. This subject area should be explored separately for both horses and burros, and also in relation to livestock and wildlife.

b. Attitudes concerning the socioeconomic problems and benefits of wild horse and burro management, range management for livestock, and related wildlife-management issues. Public preferences and concerns for alternative wild horse and burro management and control strategies should be included.

c. Knowledge, awareness, and understanding of wild horses and burros, range management, and relevant wildlife needs and populations should be covered.

d. Behavioral interactions with wild horses and burros, wildlife, livestock, and outdoor recreational activities that might correlate with perceptions of the wild horse and burro issue.

e. Sociodemographic characteristics of respondents, particularly age, sex, income, education, occupation, size of town, region, and parents' occupation.

Three variations of this interview schedule should be administered, depending on whether the respondent is a member of a special-interest group, the informed general public, or the uninformed general public. The special-interest group interview schedule should consist of all the areas mentioned above, plus a number of questions of particular relevance to these groups. For example, livestock producers should be queried as to the way in which they perceive socioeconomic impacts of varying levels of wild horse and burro management; horse and burro advocates should be asked extra questions regarding alternative control options; wildlife professionals should address extra questions on the competitive interactions and population dynamics of horses and burros in relation to indigenous wildlife.

The first section of the general public interview schedule should focus on knowledge, awareness, and understanding of the issue. If the respondent indicates lack of awareness of or familiarity with the issue, only a shortened version of the remaining interview schedule should be administered. This shortened version should only include some general attitudinal questions regarding horse and burro values, alternative control options, and sociodemographic characteristics. Those members of the general public who indicate either a relatively moderate or great knowledge and awareness of the issue should be administered the complete interview schedule.

At least three complete pretests of the interview schedule should be developed and administered to samples of at least 100 respondents. The pretest samples need not be randomly selected, but should include to the extent possible a representative cross section of the population.

As much as is possible, attitude questions--particularly those regarding horse and burro management--should attempt to include socioeconomic impacts and tradeoffs in their design. In addition, all attitude questions should include some measure of intensity (e.g., Likert scale question).

3. Timetable.

Project 11A: 6-month study
Project 11B: 12-month study (breakdown similar to 11C)
Project 11C: 18-month study: first 6 months--study design, pretesting, subcontracting; 6th to 10th month--data collection; 10th to 14th month--data analysis; 14th to 18th month--presentation of results and final report. Progress reports should be submitted once every 2 months. A thorough progress report should be submitted at the conclusion of month 12. A preliminary final report should be submitted at the end of month 16.

Project 12. Analysis and Evaluation of Demands for Excess WFRHB

Rationale

Much of the research activity recommended in Chapters 2 and 3 is designed to describe or predict the future supply of WFRHB on western rangelands. If WFRHB populations need to be managed, public decision makers will have to be informed about the demand for the animals so that the "excess" may be removed and/or placed in the most cost-effective manner.

As of October 7, 1979, 14,685 "excess" WFRHB were placed via BLM's adoption program and 12,620 applications for adoption were pending ("Wild Horse and Burro Program Monthly Report, September-October 1979"). These problems and applications relate to a rather large population of adopters that can be examined to determine consumer preferences and characteristics of both successful and unsuccessful adoptions. An integrated survey of individuals and organizations active in the Adopt-A-Horse Program that seeks information on past adoptions, pending applications, characteristics of adopted animals, and potential pools of future "excess animals" will help clarify the prospects for alternative management programs. These past experiences with the adoption program can provide useful information.

Objectives

1. Carefully examine adoptions, applications, and characteristics of WFRHB populations. Give explicit attention to the following:

a. What are the characteristics of successful and unsuccessful WFRHB adoptions?
b. What are the consumer preferences for WFRHB?
c. What types of animals are adoptable?
d. Are there any demands for currently unadoptable animals?

e. Are there alternatives to destruction of unadoptable animals, or should they be immediately destroyed at roundup to save nonrecoverable costs?

f. What changes, if any, in adoptees and adopters have occurred as a result of the new provision for private ownership of no more than four animals? Has the new program caused any other changes, and if so, what kinds?

g. What are the private costs and benefits of adopting WFRHB? What happens after adoption?

h. What are the characteristics of "problem" adoptions?

i. What happens if an individual doesn't get the kind of animals he or she wants?

j. Where in the United States are there likely to be markets for future placements, and how can these potential demands be fulfilled most efficiently?

All of the questions listed above will ultimately improve methods for disposing of excess animals.

2. Evaluate the existing data base and record system for the purpose of answering questions like the ones mentioned above. The contractor shall make specific recommendations for establishing comparable record systems--including those at collection and distribution centers--to facilitate data collection and analysis.

Methodology

The successful completion of this project will require the evaluation of adoption applications, actual placements, and animal records. Both past and prospective adopters need to be surveyed. The survey(s) will probably require stratification with respect to area or region of placement, policy at placement, number of animals per adopter, etc. Valid sample subpopulations to be reflected in the stratification are to be determined by the contractor. Animal records at collection and distribution centers will also provide useful information. Statistical analysis and modeling may be required to develop predictive tools for linking possible future demands with possible WFRHB supplies.

Project 13. Management Costs of WFRHB Alternatives

Rationale

So that WFRHB populations may be managed efficiently, there is a need to estimate the economic costs of such management activities as census and inventory, roundup and disposal, enforcement, planning, and administration under current programs. It is important that all costs be accurately and uniformly identified and developed, so that managers and decision makers can be assured that comparisons between districts, herds, collection centers, distribution centers, etc. are valid.

Objectives

1. Identify separable and joint costs for management units associated with WFRHB management activities.
2. Examine current agency cost categories and estimates for coverage and adequacy.
3. Develop and monitor a cost-reporting system to reflect WFRHB management costs for at least 1 year of management activity.
4. Analyze factors influencing activity costs and make recommendations for future collection of administrative and management costs associated with the WFRHB program.
5. Suggest cost-effective management alternatives and optimally sized administrative and management units that will take into account the nature of economic costs and carry out required WFRHB management activities most efficiently.

Methodology

District and area data, and perhaps herd-specific data, can be used to develop estimates for all activities associated with WFRHB management. Factors can be identified that influence activity costs, and costs should be estimated in a uniform manner over all study areas. For example, roundup costs could be examined at three possible levels--costs per roundup, per animal, and per adopted animal--and could vary as a function of such factors as the number and age distribution of animals processed, herd density, season, topography, type of habitat and watershed, roundup technique (e.g., helicopter, water trap, etc.), and others that are found to influence costs. The data collected for different districts, areas, and herds ought to yield sufficient variability in the factors influencing costs to provide management with programmatic cost estimates over a range of management alternatives. Results will be useful for improving the efficiency of management, and can provide insights as to what kinds of herds should be fostered and how they should be managed.

Project 14. Economic Considerations for Management Alternatives Drawn from Proposed Research Programs

Rationale

This research project may be the most difficult to specify and to manage. It will require the development of a research agenda after the research programs suggested in Chapters 2 and 3 have been specified and accepted. Project 14 thus depends directly upon those research programs. It can cover a wide range of topics; it is intended to be the mechanism for translating the output of those programs into relevant economic measures.

For example, the nature of interspecific competition between WFRHB, wildlife, and livestock determines the economic tradeoffs among those species on a given type of range. The costs of repairing, replacing, or improving structures, watersheds, watering facilities, etc. are a measure of the cost of possible environmental degradation, once the nature and extent of that damage is quantified. If selected contraception techniques prove feasible as management tools, the costs associated with each method with respect to effectiveness, duration, etc., are important to management efficiency. If WFRHB have a preference for improved ranges over natural areas, what are the losses (costs) to BLM rangeland improvement programs previously expressed as livestock benefits? If there are seasonal overlaps in forage preferences, can the carrying capacity of the range be further improved, and if so at what cost? Other important economic dimensions will become evident as the research program is specified and implemented. Close coordination among the several projects will be required.

Objectives and Methodology

The objectives of this project need to be developed after the Committee's other research programs are specified and initiated. The objectives should be identified at the end of the first year's research programs, after the nature and design of those programs have been clarified and they have been implemented for the first season. Project development could be an item on the agenda of the Committee or its Subcommittee 3 at the time the Committee reviews the first year's research. One approach to implementation might be to supply funds for a project investigator(s) and for the augmentation of projects that are determined to have aspects of interest to Project 14.

Project 15. Nonmarket Values for WFRHB

Rationale

This project requires an investigation into the nonmarket aspects of WFRHB. Such an inquiry might follow the lines of recent advances in wildlife valuation. The nature and extent of nonmarket WFRHB values need to be ascertained so that managers can make decisions that are supported by a wide spectrum of the public. Quantification of nonmarket and recreational values for WFRHB would be an aid to future management efforts.

Objectives

1. Quantify the nonmarket values of WFRHB populations in the West. Examine a variety of questions, including, for example:
    a. Are there areas (herds) where WFRHB are being demanded on an aesthetic or recreational basis or are values more characteristically "option" values or "existence" values?

b. What is the nature of these values and is there currently any commercial effect on local communities or regions?

c. Would recreational benefits be enhanced by establishing viewing refuges as opposed to more dispersed spatial distributions?

d. Are there "negative" recreational impacts and how might those negative benefits (costs) be mitigated?

2. Direct equal attention toward determining whether district, area, or herd differences affect nonmarket values for WFRHB populations.

Methodology

This project will require surveys of potential "user" populations that investigate aesthetic, option, and existence values. It may be desirable to coordinate this investigation with the regional and national survey to be conducted for Project 11, which seeks to identify public attitudes, values, and preferences associated with WFRHB. Additional field activity will be required to identify characteristics associated with "valued" herds and areas, a designation determined by the level of current visitation and viewing.

Project 16. Conceptual Development of Public Rangeland Management Models

Rationale

This proposed project is meant to be a conceptual mechanism for drawing together the outputs from the various research projects to be funded under this program. Project 16 would examine the comprehensiveness of the proposed research program and suggest how the various bits and pieces of preexisting information might be integrated with the proposed research results into usable management models for several selected study areas. This project serves a twofold purpose: first, to help ensure that research outputs are potentially usable in alternative models and to suggest possible additional information needs that would facilitate such use; and second, to provide a springboard for a possible empirical study to be conducted after results are available from the study program recommended by this Committee. A large amount of information will be generated by the various research projects recommended in this report. Most of that information will become available just prior to the completion of the Committee's contractual obligation. The empirical study would be a continuation of this proposed "conceptual development of public rangeland management models" project, and would involve the quantification of those conceptual models.

Objectives

The objective is to enhance the management of public rangelands in the West, by creating policy-relevant models that will facilitate the examination of alternative objectives or goals. Once the factual information base about horses and burros is strengthened, the models should be able to evaluate the outcomes of alterative solutions against changes in the population dynamics of WFRHB. Such models could quantify the tradeoffs among WFRHB, wildlife, and livestock. Such models should also help assess the impacts of alternative management policies on ecosystems and economic activities.

Methodology

This project provides the opportunity to thoroughly review what is known about WFRHB and their interactive effects by applying that knowledge to the development of conceptual models for public rangeland management. Such models must reflect institutional as well as scientific and socioeconomic realism, and must include alternative management scenarios for multiple use of public grazing lands in the West.

CHAPTER 5

RESEARCH AND MANAGEMENT METHODOLOGY FOR WILD EQUIDS

INFORMATION NEEDS

Chapters 2, 3, and 4 of this report have explored what is known about the biology of horses and burros, their interrelationships with other ecosystem components, and the social and economic values involved in their management. These sections have also outlined research needed to expand knowledge in these three areas. But little has been said so far about actual management methods, or about some of the technical problems that will be encountered in the prescribed research.

This chapter addresses some of these methodological problems. A reliable census method is obviously indispensable to a sound management program, and the existing censuses have been criticized by a number of observers. Hence, considerable space is devoted to this tool. Similar scrutiny is given to the commonly used range-survey methodology, inasmuch as a knowledge of range condition is essential to understanding both equid welfare and that of the other ecosystem components.

PL 95-514 also raises the possibility of "sterilization" in addition to natural control and removal for maintaining equids at desirable population levels. Hence, some consideration is given to the matter of hormonal contraception in the mare. Since horses and burros must be restrained in the course of both management and research efforts, the techniques of chemical immobilization and capture are reviewed.

A variety of research techniques is also considered. Alternate techniques of diet analysis as well as some of the unique problems of studying equid nutrition are discussed in this chapter and in Appendix A. Sampling considerations in behavioral studies, and the assay of blood chemistry to provide indices of nutritional state, both for research and management purposes, are explored at some length.

STATE OF KNOWLEDGE

Information Sources

In addition to reviewing the published and unpublished sources described in previous chapters, Committee member Eberhardt visited four BLM districts (Burns, Vale, Lakeview, and Challis) for the purpose of gaining preliminary familiarity with census procedures. He spent 2 hours in the air in one of these districts and considerable time interviewing people on the ground in all four. As a result of these efforts, he has acquired 300 to 400 photographs, and a considerable mass of BLM census data from numerous districts. This document file (currently at New Mexico State University) remains to be cataloged and reduced.

Committee chairman Wagner conducted preliminary analyses on the wild-horse census data from 72 BLM districts and national forests covering periods of 1 to 11 years (see Table 2.11). He detected several biases and calculated preliminary estimates of their magnitude. It was from these data that the preliminary calculations on herd increase rates discussed under "Equid Demography" (Chapter 2) were made. The state of knowledge concerning census is reviewed in the following section. But the data need further analysis, which should be carried out as part of the census research program.

Census

Potential Methods

Animal population measurements fall into one of three basic categories: (1) indices, (2) complete counts, and (3) estimates based on sampling approaches of various kinds. With the exception of a few small-scale research studies, most current and recent efforts to census wild horses and burros have involved some form of aerial counting, and complete counts have usually been attempted. Doubtless this choice has evolved from considerations of cost-effectiveness, topography, and manpower limitations. There are almost no published data on the accuracy of aerial counts of wild horses and burros, and very little data on the variability to be expected in repeated surveys of the same areas. It is essential to obtain such information before making a final decision on a particular method, and in order to do so, aerial surveys for wild horses and burros must be researched. In this review we have assumed that the principal method to be considered is aerial counting, and other potential methods will be touched upon only briefly.

1. Indices. Many wildlife problems have been approached by measuring relative abundance, i.e., using an index of abundance. Indices generally do not provide estimates or counts of the actual numbers of animals in an area, but rather give relative measures of numbers. All indices depend on one universal assumption: that the index values are some constant function of, or bear some constant relationship to, actual population size. Where this assumption holds, they are valuable for estimating rates of population change over time, and often can be used in estimating mortality and reproductive rates. They are also frequently useful in comparing relative densities between areas.

It is problematical whether such index methods as roadside counts, track counts, and fecal counts have utility for wild horses and burros. Roadside counts might simply be tallies kept in the course of travel on other business or made on selected routes at prescribed times. In suitable areas, counts at watering sites could conceivably be effective. Track counts might be combined with visual counts, but would probably be most effective if made on fresh snow or after a heavy rain. Fecal counts have not been used much for equids. They have been extensively employed for cervids, particularly for white-tailed deer and elk. Correction factors are available to convert the counts to estimates of absolute abundance. Similar factors might be obtainable for equids. Development of an effective index method would require that a designed study be combined with censuses conducted by proven methods.

Since any management program involving forage allocation to a specified number of equids would require an estimate of absolute numbers of horses and burros, an index would not in itself be suitable. It would have to be "calibrated" somehow so as to provide an estimate of absolute numbers. Actually, it may be appropriate to consider many of the present aerial-survey estimates as indices, as will be discussed below. It is for this reason that the subject of indices has been mentioned briefly here, and because of the tentative inferences on horse-population trends drawn earlier in this report from the aerial censuses.

2. Complete Counts. The present BLM surveys are almost exclusively attempts at complete aerial counts of all animals on a given area. In fairly open areas with low vegetation, a skillful observer working with a cooperative pilot may well be able to tally nearly all of the animals present. Scientific proof of such an assertion depends on some sort of independent check, presumably best obtained by a marking program. In areas of dissected topography and heavy cover, it is quite likely that some proportion of the animals present are missed. Caughley (1974) has assembled data from various surveys of different species indicating that appreciable fractions of the animals present are not seen from the air. A great deal of experience with African "game" has led workers there to use rather narrow strips for aerial counts, and to depend on sampling rather than attempting complete counts (cf. Sinclair 1972, Goddard 1967). Since much of that experience comes from environments quite similar in topography and vegetative cover to many horse and burro ranges, it is appropriate to give careful consideration to the techniques thus developed.

There is also evidence that such factors as airspeed, altitude, width of strip searched, type of aircraft, and observer experience have important effects on aerial counts. These factors are described by Erickson and Siniff (1963), Pennycuick and Western (1972), LeResche and Rausch (1974), Norton-Griffiths (1975, 1976), Caughley and others (1976), and Frei and others (1979).

The major problem with attempting complete counts is to devise tests of their accuracy and correction factors for deviations from absolute accuracy. One such test is the "bounded-counts" method. It requires a number of successive counts, made under such conditions that there is some positive probability of counting all animals present in an area in at least one of the counts. The two highest counts are then used to estimate the actual population. The method is based on theory developed by Robson and Whitlock (1964), and was suggested by Regier and Robson (1967). Overton and Davis (1969) provide some further discussion.

The bounded-counts method depends on the ability to conduct repeated independent counts of the same population without tallying any animal twice on a given count. The critical assumption in the method is that conditions will permit a definite (although possibly very small) probability that all animals in a population are counted. No technique for checking it seems to have been suggested as yet. As an illustration of the kind of situation in which the method may fail, we have used data on 18 successive aerial counts of black rhinoceros presented by Goddard (1967), and computed population estimates from the bounded-counts method on 6 successive sets of 3 surveys. The results were 24, 26, 40, 47, 28, and 34 rhinos estimated to be in the population. However, Goddard had independent data to show that there were in fact 69 animals present. Some of the animals were under heavy cover or otherwise concealed so that they could not be seen from the air.

Another alternative exists for areas where known numbers of animals are removed. If counts are made before and after the removals, and these counts are consistent--i.e., the degree of undercounting is the same on each count--then some simple algebra employing the counts and the known number removed yields an estimate of the degree of undercounting, and thus an estimate of the true total.

One prospect for checking coverage has been described as "ground truthing," or having ground observers maintain intensive coverage of some sample areas in such a fashion that they can determine whether given bands are missed from the air. This scheme has not been attempted with wild horses or burros, but it has been applied elsewhere. An account of the essential aspects of one application may be found in Eberhardt and others (1979). Some trials would be necessary to determine if the method could be usefully applied to wild horses or burros. A likely approach would be that of positioning ground observers in places where they could keep one or more bands of horses under continuous observation, and thus determine whether those bands would be spotted by the aerial observers. An obvious difficulty is that of determining just which bands were sighted by the aerial observers. That may be dealt with by careful mapping of locations from both air and ground. In censusing wild horses, band size and coloration of particular individuals could be used to aid in checking the identity of given bands.

Possibly radio telemetry could be used in place of ground observers to establish the positions of particular bands. These data can then be checked against the aerial observer's record. An application of this idea has been given by Floyd and others (1979), who conducted quadrat searches for white-tailed deer. They used telemetered deer, and arranged flight plans (without the observer's knowledge) so that the aircraft passed over the area in which the deer were located. The marked deer were identified by the presence of "collars" and the fraction of marked deer actually seen was used to correct the total counts on the survey quadrats. As the authors noted, these checks should be done on quadrats that are part of the actual survey area, and should be conducted within the framework of the actual survey. Also, if complete counts are attempted, there should be no need to conduct a special auxiliary survey of this type. All that is needed is to be sure that the observers do tally any marked animals.

Another means for checking the accuracy of absolute counts is by marking specified numbers of animals in areas to be censused, and then determining the proportion of these seen during the census. It is then assumed that the same proportion of unmarked animals is seen. It is an implicit assumption that the probability of seeing a marked animal is the same as that of seeing an unmarked animal, and it must then be true that the mark is not so conspicuous as to make the animal more readily seen. It must also be true that the act of marking does not make the marked animals shy and more prone to flee at sound of an approaching aircraft.

Marking has been done either with paint-filled frangible bullets fired from a carbon-dioxide-powered gun, or with specially made darts propelled from an explosive-powered gun. The latter device is said to have much better accuracy and range. The use of natural marks undoubtedly has potential; some investigators have used them, particularly people doing behavioral studies in situations where the results might be influenced by the handling or harassment involved in applying an artificial mark or tag. The main technical question has to do with the problems of misidentification or failure to identify a "known" individual in subsequent samples. Because of the potential for such confusion, it might be advisable to use natural marks only in situations where a few thoroughly experienced observers are working together in a circumscribed area and where photographs can be used to record (and recheck) markings. The technique thus does not seem useful for large-scale surveys.

One variant of the use of natural markings may be worth further consideration for use on wild horses. This is an adaptation of the technique developed by Hewitt (1967), who censused male red-winged blackbirds by the Petersen (Lincoln index) method. Birds were "marked" by locations and landmarks described into a tape recorder (distances were measured by a car odometer) during the first trip through a census area. On a second trip, the observer listened to the tape and checked distances to determine which of the birds seen were also observed on the first trip. For wild horses, a combination of distinctive coloration, band size, and location could be used to identify previously sighted bands. Such a census might be practicable only on rather open and accessible ranges. Otherwise, the tendency for bands of animals to occupy particular areas might well bias the results by making "marked" bands more likely to be reobserved on the second trip than unmarked bands. Counts would need to be made on successive days to reduce the effects of movements from area to area, and thus several observers might be required to cover a given management unit.

3. Estimates Based on Sampling. While most of the current work on equid census attempts complete counts, there may be situations in which accurate, complete counts are not practical or feasible, and in which some sampling approach might be appropriate. Far more wildlife census work depends on sampling procedures than on complete counts. Several of the currently used principles of sampling estimation may be useful for equid census under given conditions.

a. Mark and resight methods. This method, a modification of the more traditional capture-recapture method for aerial use, might well have potential. Animals in the first sample from an area are marked after being captured--or from the air as described above--and then released into the population at large. Visual sightings are then used to determine the fraction marked and thus to estimate the population size. The attempts to date to use this method on equids have apparently been restricted to the application of the Petersen method to a single resighting survey (unpublished BLM studies in Arizona).

A more effective approach would be to use repeated resighting surveys to improve the precision of the result (narrow the confidence limits). This has been done for deer by Rice and Harder (1977). When repeated resighting surveys are used, it is important to determine the relative efforts that should be devoted to marking as compared to resighting. Relative cost or effort data should be obtained and used, along with variance estimates from the appropriate population estimation model, to determine an optimum allocation of effort. Robson and Regier (1964) have done this for the Petersen method with a single marking and single recapture. If their analysis can be extended to multiple recaptures, it would correspond with the mark and resight situation.

Once again, an underlying assumption for this method is that the probability of resighting is the same for marked animals as it is for unmarked animals. However, it may be that the trauma experienced by animals shot with tranquilizer darts from a helicopter will make them take flight when they again hear a helicopter. Thus the probability of their being resighted changes. Very likely this is a situation where natural marks might be used in a behavioral study designed to compare the response of animals that have been marked with those that have not been handled. A companion study might also be done in which telemetered animals are observed during the approach of aircraft at various distances and altitudes. The probability of capture also depends on sighting, so that large bands and bands frequenting open areas are more likely to be marked and to be resighted.

b. Plot sampling. Where areas are too large for, or the terrain and cover not suited to, total and thorough search for complete counts, populations can sometimes be estimated from complete counts on sample areas, and the total number of animals extrapolated from the densities on these areas. Sample areas can be units of convenient size for searching, over which the aircraft is flown on some sort of search pattern, or they can be sample strips of prescribed width on each side--or on one side--of the aircraft. The latter are usually known as strip transects.

The more compactly shaped areas, or quadrats, are commonly searched by repeated circling. This technique has the advantage of giving the observers a thorough look at an area from several perspectives. It may also serve to startle resting or concealed animals, making them easier to see. Quadrat searches are thus of special value in rough country, or in areas with substantial vegetative cover. A possible disadvantage is that horses are highly mobile, so that repeated searches of a particular sample unit may drive the animals present out of the unit. It is necessary to take this possibility into account in designing a sampling survey. An alternative is to use photography of the quadrat, as has been done by Norton-Griffiths (1973, 1974) and Mathisen and Lopp (1963). Some of the extensive experience in using quadrats is presented in papers by Siniff and Skoog (1964), Evans and others (1966), Goddard (1969), and Bergerud and Manuel (1969).

The same major problem experienced in total counting arises in the use of sampling; namely, that of checking the degree of coverage attained (i.e., the fraction of animals present that are actually enumerated) and, if possible, seeking to "calibrate" or adjust such counts for the fraction missed. The same approaches discussed above under "Complete Counts" apply to the plot-sampling methods.

Sampling strips have the advantage that they can be spaced far enough apart so that there is little prospect of given bands moving from one strip to another in successive passes by the aircraft. Disadvantages are the prospect of missing some animals on the strip and the limited area coverage sometimes achieved, which may result in substantial variability of the estimates. As with the other methods, it is necessary to do field studies to determine the importance of these potential difficulties.

As previously noted, the strip-census method has been widely applied in Africa, where a great deal of practical experience concerning its use has been accumulated. A review and description of the techniques used there can be found in Norton-Griffiths (1975). There has also been an appreciable amount of experience with strip transects in Australia (cf. Frith 1964, Caughley 1974, and Caughley and others 1976), in arid and semi-arid areas. This experience indicates that only a rather narrow strip can be searched effectively, and that low altitudes and airspeeds are required. Even so, an unknown fraction of the animals present is missed (Caughley and others 1976). Here again, independent checks on the degree of bias are needed. A particularly impressive demonstration of the effect of strip width has been presented by

Caughley (1974) and Caughley and Goddard (1975). These investigators report a dramatic change in the numbers of elephants counted from the air with changes in strip width from 100 m to 600 m.

c. Line transects. In this method, estimates of the distances from the observer to the animals sighted are used to correct for the fact that visibility drops off with distance from the transect line. An important assumption is that all of the animals immediately on the transect line are detected. Some experience with other species (Eberhardt and others 1979) suggests that this assumption is likely to be attainable only with specially equipped aircraft: namely, those with a "nose bubble" or similar arrangement. Since the BLM work must be done in many locales and usually with locally chartered aircraft, this requirement may present difficulties. On the other hand, many of the available helicopters do have good forward visibility. At present, it appears that the first step is to assess present experience with aerial census methods that have actually been applied to wild horses and burros or similar species. If such an analysis suggests a limitation due to small numbers of animals observed, then it may be desirable to investigate line-transect methodology. A detailed review of the methods is available in Eberhardt (1978) and Eberhardt and others (1979). The line-transect method is not restricted to aerial surveys, and much work has been done with it in ground-based surveys.

Sources and Corrections of Bias and Variability

1. Group Size. One source of bias not yet investigated in wild horse and burro censusing is the likely effect of group size on visibility. This problem actually subdivides into two kinds of bias. The first is simply that group size will have a marked effect on the probability that a given group of animals will be seen. One model for estimating group size is that of Cook and Martin (1974), while a more general approach has been explored by Patil and Rao (1978). Jolly and Watson (1978) have suggested some quite simple corrections for missed groups that can be derived from ratio data collected to adjust for members of groups that are observed, but incompletely.

It should also be noted that group sizes are likely to vary seasonally, a factor that should be taken into account in survey design. In general, larger groups are much easier to locate from the air, so there is an advantage to working in the seasons when large groups are most prevalent. However, other factors may also affect the choice of season. One disadvantage to surveying large groups is that counting may call for repeated circling over the animals, and this may cause a large group to break up into its component bands, thus changing the group size in subsequent surveys.

The second source of group-size bias is the increasing difficulty of accurately counting the numbers of animals in a group as its size increases (Sinclair 1973, Bell and others 1973). This problem has been studied by African workers, who recommend photographing groups larger than 10 animals, and checking the visual count against the photographs (procedures are given by Norton-Griffiths 1975).

2. Sampling Methodology. A number of sampling issues must be considered as research is continued on censusing horses and burros. Random sampling is generally recommended, but should be properly conducted; otherwise searching one sampling area might affect the animals on, or adjacent to, the next such unit. This problem will not arise if the sampling is truly random, that is, if the units are searched in the order in which they are drawn. However, such a procedure is demanding in terms of travel between units, so many investigators will draw the entire sample and then traverse the units systematically across the study area. An alternative is to use restricted randomization, i.e., to place one sampling unit at random in each of a number of blocks that are large enough to avoid much movement of animals between blocks. The process can then be repeated on successive days of searching. Perhaps a more practical scheme is to use systematic sampling with a new random start on each day of searching.

Stratification should be considered, but may have a similar drawback in that movements from one stratum to another are possible. An additional problem with stratification is that strata may be chosen by cover type, which will likely result in differences in visibility between strata. There is then the need to make separate corrections for each stratum. Unless the study units are very large, or animal densities vary markedly, it may be best not to stratify.

If sample areas other than strips are to be searched, it may be most practicable to use units of differing sizes. This approach brings in the problem of combining data obtained from units of disparate size. Jolly (1969) has suggested the use of sampling with probability proportional to size (PPS sampling) or of a ratio method for this situation. PPS sampling requires that a sampling unit be included each time it is drawn. Many workers using this method do not search the unit each time, but simply apply the result of the first search to each subsequent drawing of the sampling unit. However, this practice may not be suitable for use with wild horses, since--as already noted--the disturbance of an aircraft working over the area will most likely rearrange the population repeatedly. Hence, in PPS sampling, the units should be searched each time they are drawn. In most cases, the areas to be searched for wild horses and burros will be well defined, with adequate landmarks for laying out and conducting census flights. If such is not the case, then it will be worthwhile considering an approach that requires only demarcation of a baseline. This method is described by Bell and others (1973) and Norton-Griffiths (1973).

3. Variability. The appraisal of variability is obviously a critical issue in the overall problem of censusing wild horses and burros. If an unbiased method turns out to give extremely variable results, then it may be preferable to use a somewhat more biased

procedure. Unfortunately, most decisions about variability require actual data collected under field conditions, and these have not been available for wild horses and burros except in a fragmentary and limited way. Hence, the issue of variability must be included as an important part of the needed field research program.

4. Double Sampling. One possible means of testing the completeness of counts--either total counts on an entire area, or counts on sample plots--is that of "double sampling." This approach involves using an accurate, unbiased method on a series of test areas--when and if one is devised--in combination with some other admittedly biased, but perhaps less expensive and more readily applied, method (Cochran 1977) on the same area. Ratio or regression methods are then used to extend the results from this "calibration set" to a larger set of areas on which only the less expensive method is used. The practical difficulty is that present recommendations (Cochran 1977) call for samples of approximately 30 pairs for the calibration. Very possibly this requirement can be reduced somewhat, but we suspect that the sample ought to be at least 20 pairs. Such an approach does not seem feasible for the circumstances discussed here. A possible exception concerns estimation of the entire population of horses (or burros), in which case it may be feasible to use the most recent BLM district estimates as the "auxiliary variable" in double sampling, and survey a subsample with the accurate method to obtain an improved estimate of the total.

The double-sampling approach has other potential uses. For example, Jolly and Watson (1978) advocated that a subsample of the groups of animals sighted in a survey should be circled and observed until the observer is satisfied that all animals in the group have been sighted. These more accurate estimates are then used in a ratio correction to adjust the overall group size observed on the transect line (i.e., observed without circling). A problem with this approach is that some of the smaller groups will not be seen at all. Jolly and Watson suggest an approximate method for correcting for this problem, based on the ratio data. Their approach would probably work best on strip transects, since it is likely that nearby groups will be disturbed while one band is being circled for accurate counting.

Preliminary Analysis of BLM and USFS Census Data

The accuracy and precision of existing horse and burro census procedures need to be investigated in connection with the proposed research on this subject (Project 17). It is only with that research that any firm assessment of the procedures can eventually be obtained. The various and extensive data on horse and burro censuses in BLM and USFS files should be analyzed thoroughly as part of the census research effort.

As discussed under "Equid Demography" (Chapter 2), we obtained census data from the files of 10 BLM districts and one national forest on 67 horse herds, 3 burro herds, and two areas that contained both (see Table 2.11). The data were analyzed to gain some preliminary estimates of the accuracy of the censuses, and to see what biases and variables could be detected. Upon first examination, several characteristics became evident:

1. The time interval over which each herd was censused varied between 1 and 11 years, and the number of counts varied between 1 and 18. Most of the herds had been counted over 4 to 7 years.

2. The time of year during which a herd was counted often varied between years. Thus a herd might be censused in March of one year and August of another. The numbers in all seasonally breeding animal populations vary during the year, rising to a maximum at the end of the birth season, and then declining until the next as a result of mortality. Since wild horse foals are dropped seasonally, counts in March and August of even the same year could vary by 15 or 20 percent. It is a basic principle in censusing animal populations that inferences about year-to-year trends and comparisons between areas must be based on censuses taken at the same season each year, or at the same stage in the annual life cycle. While burro populations produce colts throughout the year, the number of births intensifies in late spring and early summer. Hence, this same principle should be applied to burro census.

3. While most of the counts were made from the air, the mode of census varied; sometimes censuses were conducted on the ground, sometimes from fixed-wing aircraft, and sometimes from helicopters. In many cases the method was not specified. Casual inspection of the data showed one seemingly obvious difference between census modes. It appeared that in most cases where fixed-wing aircraft were used in one year and helicopters in the next, the censuses increased abruptly in the second year. An effort was made to explore this variation further. Out of the 72 herds, there were 19 horse herds in which a change from fixed-wing to helicopter counts was made between years and recorded, and in which the census season was held reasonably constant. The unweighted mean difference between the 19 pairs of counts showed the helicopter counts to be 88 percent higher than the fixed-wing counts of the previous year. Even after discounting this percentage by 14 percent for population increase, the helicopter counts appear to be some three-fourths more efficient in finding animals than the fixed-wing counts. Since fixed-wing counts were used more commonly in the earlier years, and helicopters more generally in recent years, it is quite likely that earlier counts underestimated the actual numbers to a considerable degree.

The helicopter counts also appear to be less variable than the fixed-wing counts. The coefficient of variation about the mean count for the fixed-wing censuses was 170 percent, and that about the mean count for helicopters was 131 percent. Changes in herd size and length of individual record sets will of course influence this comparison.

As mentioned earlier, it seems possible that very nearly all of the horses in open terrain can be seen and counted by a skilled observer working under favorable weather conditions. If the censuses err in any direction, they are probably conservative because some animals are missed.

It seems likely that the degree of error is much lower in horses, which are more likely to run when approached by an aircraft, than in burros, which are more likely to remain motionless. In addition, the burros' grey to brown coloring blends in with the desert terrain they inhabit and further reduces visibility. One insight into the magnitude of error in aerial burro census is provided by Ohmart and others (1978).

These authors flew a 15,360-ha area in the Black Mountains, Mohave County, Arizona, making 7 hours of low-level helicopter flights similar to those used for census counts. They marked every burro they saw with a CO_2-charged pistol that expelled oil-base paint pellets. After 5 to 9 days, they flew the area again, recorded every animal they saw, and determined whether or not it was marked with paint. About one-third of the animals they observed were marked, and the inference drawn was that typical aerial census operations for burros could be expected to count only about one-third of the animals present. The authors also suggested that a mark-resight method would be more appropriate for burro census than attempts at total counts.

Review of Range-Survey Methodology

Although the Public Rangelands Improvement Act of 1978 authorizes the Secretary of the Interior to take necessary action to remove excess animals on rangelands where several species utilize the same forage resource, the question of which herbivores are in excess is difficult to resolve. Principal among the biological factors to be considered in making such a determination are forage and habitat preferences and specific grazing impacts on soil and vegetation resources (see Chapters 2 and 3). Other factors, including season of use and characteristics of the land that influence distribution and grazing patterns, must also be weighed in range analysis. Much of BLM decision making in these regards is based on the range inventory or survey.

The first standardized range-survey method was developed in 1937 and is sometimes referred to as the Ocular Reconnaissance Method (Interagency Range Survey Committee 1937). It is still discussed in BLM manuals and is still being used by that agency in some areas. Other agencies have slowly developed other methods ("weight estimate," range sites and soil surveys, SCS; Range Environmental Analysis, USFS). Around 1978 to 1979, BLM began using the "Soil-Vegetation Inventory Method." It is based primarily on the SCS methods (U.S. Dept. of Interior 1979).

Range inventories made by BLM or any other agency are usually used for more than one purpose. BLM is probably the only agency in the United States that is still very concerned about establishing an initial grazing capacity. Other purposes of inventory are (a) to establish a baseline for monitoring range "trend" and (b) to provide basic information about resources and conditions to be used for planning and management. Hence, in talking about "inventory" there is more at issue than just the establishment of stocking rates. However, those inventory factors and processes that are most controversial are the ones applied primarily to obtaining stocking rates.

Historically, initial determinations of grazing capacity on public lands were based on range inventories or surveys that attempted to estimate average, usable forage production. The available forage was then allocated to domestic livestock producers through an adjudication process that considered their relative privileges under existing laws and regulations. A percentage of the available forage was usually set aside for wildlife, or the survey methodology was presumed to reserve wildlife forage before grazing capacities for livestock were established. However, few--if any--forage reservations were ever made for wild horses and burros. These processes were completed on most public lands many years before wild horses and burros became by law the responsibility of the federal government.

Recently, the BLM has begun to make determinations of grazing capacity (initial stocking rates) as part of its land-use planning procedures and environmental impact studies of livestock grazing problems. These are being made primarily because many people believe that earlier studies did not adequately consider the suitability of the land for livestock grazing, nor did they properly allocate range resources among all uses and users; e.g., wild horses and burros, habitat as well as forage for wildlife, protection of threatened and endangered species, cover for watershed protection, enhancement of recreational experiences, and others, as required by recent legislation.

Initial grazing capacities (or "stocking rates"), whether determined through the historical survey and adjudication procedures, or the newer land-use planning processes, were made to be adjusted periodically on the basis of continued monitoring studies in the grazing units. At the least, monitoring studies should employ actual use records, permanent range-condition and trend-monitoring sites, and utilization measurements. They may also include such studies as water-quality monitoring, surveys of nongame species, analyses of grazing impact on cultural resources, and soil-loss evaluations.

Forage for wild horses and burros was not generally provided for in either public land adjudications or land-use plans prior to passage of the Wild and Free-Roaming Horse and Burro Act in 1971. However, many domestic horses were legally licensed to use public lands. Since 1971, BLM and USFS range managers have had a legal mandate to manage wild horses and burros to achieve and maintain "a thriving natural ecological balance on the public lands" (U.S. Congress 1978).

An attempt has been made by this Committee to review some recent BLM and USFS documents that consider wild horse numbers in terms of current land-use planning and management. The purpose was to evaluate how adequate range-survey methodology has been in addressing questions of proper equid numbers based on range biological factors. No detailed review of the literature on range-survey methodology has been published, although that literature is extensive. Vallentine (1978) lists 138 references to herbage-removal studies alone. We obtained and examined 10 wild horse capture plans with accompanying environmental analysis reports (EARs) (see literature cited under BLM for titles). Of these, 8 were BLM plans and 2 were joint BLM/USFS plans; 9 were from Nevada, and 1 from Oregon. Two capture plans (East Range and Paradise/Denio) were proposed primarily because of the high proportion of nonfederal land within the horse-use area. Thus range condition and forage competition with other herbivores were not direct considerations. The remaining eight wild horse reductions were proposed primarily for the purpose of either correcting depleted or unsatisfactory range condition and overutilization of forage, or adjusting existing horse populations "to numbers established in the land-use plan."

Few of the plans and EARs provided much information to support the contention that range conditions were unsatisfactory or explained how those conditions were determined. Rarely was any attempt made to show which herbivores (horses, cattle, or wildlife) were responsible for the range condition presented in the report. In one case (Lucky C), there was obvious disagreement between state and district office personnel as to actual conditions. The BLM district claimed there had been no livestock grazing the range in question for at least 2 years, and yet the BLM state specialist concluded that wild horses were only a minor contributor to admittedly deteriorating range conditions. The most recent EAR (Pine Nut Mountains), however, had detailed supporting material to document the impact of horse populations. This information included actual use records by allotments, as well as data from 38 vegetative trend plots and 4 years of range utilization studies.

We conclude that although adequate range studies may not always have been used to evaluate and support proposed numerical adjustments of wild equids, the technology to do so exists and appears to be adequate. Therefore, we believe that additional research on range-survey methodology is not justified at this time in the present context, except where it can or must be included as a part of other studies.

Limitations of Techniques for Diet Analysis

Most studies assessing dietary composition for both horses and burros have relied on fecal analysis for determination of the relative contribution of each forage species to the diet (e.g., Hansen and Martin 1973, Hubbard and Hansen 1976, Hansen and others 1977, Salter 1978, Vavra and Sneva 1978, Salter and Hudson 1979). Other techniques can be used for quantifying diet composition. Moehlman (1974) observed actively foraging animals daily in her study of Death Valley burros. Browning (1960) analyzed stomach contents. However, such approaches are often expensive, time consuming, or impractical for use on free-ranging animals. Consequently, fecal analysis has been widely used. The BLM currently prescribes the use of this procedure in contract studies that are conducted to provide a basis for forage allocation. However, the accuracy and precision of the technique, at least for research purposes, is presently subject to question.

Smith and Shandruck (1979) found that fewer plant species could be identified in the feces of antelope than in their rumen contents. In addition, the amount of browse and forbs found in the feces of mule deer correlated poorly with the known composition of their diets. Extreme disparities can occur between known diet composition and that indicated by fecal analysis: Slater and Jones (1971) found the epidermal tissues of white clover to be completely absent from the feces of sheep, even when the animals were fed diets containing 37 percent clover.

These studies were conducted with ruminants, and the digestive system of equids could conceivably minimize these problems. Casebeer and Koss (1970) determined that fecal and stomach-content analyses of zebra diets agreed best when the diet was composed mostly of grasses. However, grasses in the early stages of growth and forbs were poorly represented or absent in fecal samples. Owaga (1977) also compared stomach and fecal contents of zebra, although her methodology differed somewhat from that of the other studies cited in that she identified intact plant parts in samples rather than cuticular or epidermal fragments. She determined that of some 60 grass and sedge species that constituted the diets of her zebra, the 10 most important ones in stomach samples were also the most important species in fecal samples, although the order of importance sometimes varied. Thus fecal analysis apparently sacrifices some degree of accuracy even when applied to equid species under the relatively unrigorous conditions of a grass-dominated diet.

The more general weakness of any technique relying on microscopic identification of cuticular or epidermal fragments was highlighted by Owen (1975). Plant species are highly variable with regard to the proportion of epidermal fragments having one or both identifiable surfaces. Large errors in diet quantification occurred in his study unless correction factors were established for each species.

However, Sparks and Malechek (1968) found that the dry weights of four grass and four forb species in known mixtures were directly proportional to the number of epidermal fragments identified and counted in subsamples of the mixtures. The analytic technique outlined by Sparks and Malecheck (1968) has been the basis for most of the laboratory analysis of horse feces carried out in the western United States since their paper appeared.

Inferences about dietary composition based on fecal analysis should be drawn cautiously until the technique is further validated with a proven procedure such as microscopic analysis of fistula extrusa (Theurer and others 1976). Data from fecal analysis will apparently suffice for such purposes as ranking the dietary importance of various plant species (Vavra and others 1978). For situations where a high degree of accuracy is not necessary, such as in certain management applications, fecal-analytic data are apparently useful. However, the user should recognize the limitations of such data and should not make inferences implying high accuracy.

A potentially serious limitation to fecal analysis that has not been evaluated is the lack of assurance that fecal samples represent forage consumed in the vicinity where the samples were collected. The transit time of food through the gastrointestinal tract of horses has been estimated at 37 hours for long hay (Wolter and others 1974). Thus, in situations where animals range over a variety of sites or vegetation types in their daily feeding circuit, it is improbable that the botanical composition of the diet can be related to the kinds and amounts of forage available in the vicinity where feces are collected except in a very general sense. In the cases of deer and elk, Collins (1979) found that roughly half of all defecations occurred during 3 to 6 percent of the day, when the animals were traveling between preferred feeding sites. More often than not, the vegetational subunits separating the preferred feeding sites were of marginal or no value to the deer or elk as food resources. Similar criticisms can be leveled against diet studies based on rumen content analysis, and particularly against fecal-analytic studies of ruminants, whose food transit time is considerably longer than that of equines.

Another important consideration regarding any technique based on microhistological analysis of dietary materials or residues is the adequacy of reference materials. Typically, this aspect of the technique involves collecting all forage species in the areas where fecal material or diets are sampled. Most researchers who have dealt with diet analysis, by one technique or another, will readily admit that selectively feeding herbivores often ingest considerable quantities of plant species that the researcher finds difficult or nearly impossible to locate, even by intensive systematic sampling of the plant community. Consequently, reference collections often lack representation of a few plant species that may, on occasion, contribute significantly to diets. This is especially true when the reference species are collected by someone other than the person doing the dietary or fecal analysis. Extreme caution should be exercised in interpreting studies that do not report at least some small (say, <10 percent) proportion of a diet as unidentifiable material.

Sample size and frequency of sampling are also matters of great concern to those who wish to make strong inferences from dietary data. Van Dyne and Heady (1965), working with sheep and cattle that had esophageal fistulae, calculated that 1 to 298 samples were required from a single population of animals in order to estimate dietary composition within 10 percent of the mean with 90 percent confidence. The greatest variability in diets occurred in early summer, when an abundance of different forage species was available, but it still remained high in late summer. Similarly, Harniss and others (1965) showed that large numbers of samples of fistula extrusa were required to determine accurately the diets of sheep grazing a sagebrush-grass range in spring. They found that for species contributing 40 percent or more to the composition of diets, the coefficient of variation ($s/\bar{x} \times 100$) was around 30 percent. For such species, 26 samples would provide estimates within ±10 percent of the population mean 90 percent of the time. If accuracy of only ±20 percent of the population mean was required, then the number of samples necessary dropped to eight.

Unfortunately, most studies on horse and burro diets have not presented variance statistics for dietary composition. Thus a comprehensive survey of sampling variability is not possible. However, Hubbard and Hansen (1976) did present standard deviations for their mean dietary composition data. From their published figures, approximate sample sizes were calculated according to Snedecor and Cochran (1967) that would estimate within ±20 percent of the population mean of a species 90 percent of the time. The required number of samples for the three most abundant grasses in their horses' diets were 17 for Stipa comata, 33 for Agropyron spp., and 48 for Bromus spp. If less common species were to be estimated accurately, more samples would be required. Aggregate categories such as "grasses" could be estimated with far fewer samples, particularly in view of the apparently small variation in grass composition of horse diets suggested by Table 2.22.

Not only is variability high from animal to animal in diet studies, but there is often extreme short-term variation within a season as well (Van Dyne and Heady 1965; Collins 1977, 1979). Thus frequent sampling is necessary--often every 2 weeks--if one is to have a true picture of seasonal preferences. Vavra and others (1978) even suggest that important daily variations in diet occur.

Even if adequate data have been obtained, questions remain concerning their interpretation and inferential value. In this regard several problems arise. The most common approach for relating dietary-composition data to plant-community composition has been to calculate preference quotients. These quotients are produced by dividing the quantity of a forage in a diet by the quantity of that forage available to the animal (see Krueger 1972 and Petrides 1975 for detailed discussions of this concept). Forages that are relatively more abundant in the diet than in the plant community are assumed to be "preferred." However, failure of an animal to exhibit a "preference" for any environmental factor, whether it be food or something else, does not necessarily indicate that the factor is unimportant. Rather, there may simply be more of it in the surroundings than the animal needs. Smith (1954) suggested that the simple percentage occurrence of a species in the diet may accurately represent preferences for plants where availability does not limit consumption.

Determining Range-Forage Digestibility in Equids

In studies of ruminant nutrition, in-vitro techniques have proven valuable in evaluating forage digestibility. In-vitro approaches, while possibly less accurate than in-vivo techniques, are often the most practical in situations where the forages are difficult to collect in sufficient quantities for feeding trials. However, we know of no in-vitro procedures that have been specifically modeled after equid digestive physiology.

L. M. Slade (Department of Animal, Dairy and Veterinary Science, Utah State University, personal communication, 1979) stated that in-vitro methods commonly used for studying ruminant diets were likely to be applicable to equids, providing the inoculum is buffered at a pH of 7.0 to 7.2 during the fermentation stage. Koller and others (1978) used a modification (Goering and Van Soest 1970) of the Tilley and Terry (1963) technique to investigate cell-wall and dry-matter digestion in ponies. The in-vitro technique was not as responsive to change in the ponies' nutritional status as was an in-vivo (nylon bag) method. The authors acknowledged that the effect of the predigestion by gastric secretions of the foregut and small intestine on fiber entering the cecal and colonic environments is not known. Hemicellulose digestion may be enhanced by exposure to the intestinal environment prior to cecal fermentation (Keys and others 1969, 1970).

It would be worthwhile to investigate how in-vitro techniques suitable for ruminant nutritional research could be adapted to studies of range equids. How well and how accurately these procedures can be transferred is uncertain. Further study comparing the results of appropriate in-vitro procedures with in-vivo digestion is needed. Possibly a procedure that more closely duplicates the sequence of equid digestion should be developed (i.e., acid-pepsin digestion should precede anaerobic fermentation).

As an alternative to in-vivo digestion trials where fecal output is collected and measured, indicator methods (Kotb and Luckey 1972) might prove suitable. Pulse and others (1973) demonstrated no significant differences among estimates of fecal output determined by three techniques: total collection, Cr_2O_3 indicator, and a polyethylene powder marker. Similarly, Knapka and others (1967) reported that polyethylene and Cr_2O_3 methods are reliable indicators of fecal output to be used in determining digestibility in burros.

The possibility should also be investigated that the free-ranging horse's ability to digest forage can be adequately estimated from chemical data by a regression procedure or summation equation such as that proposed by Van Soest (1967) for ruminants. Given the horse's apparent propensity to eat grass almost exclusively, this approach could prove highly successful. Problems might be anticipated where shrubs and other unconventional forage items form a large proportion of the diet. Certain published data (e.g., Fonnesbeck 1968, 1969; Vander Noot and Trout 1971) would provide a valuable departure point for research on such an approach.

Blood Assays as Possible Indices of Nutritional State in Horses and Burros

Assays of easily taken blood samples may have potential both for evaluating the nutritional condition of individual animals and for using an animal's condition to indicate nutritional adequacy of the range (Seal 1977). The evaluation of individual animals may include nutritional condition in terms of very recent food intake (protein and energy), and of the quality of that intake during recent months. One may also evaluate specific nutritional deficiencies, as well as the physiological effects of various capture and handling techniques for horses.

The literature relating nutritional status to breeding capability of mares is extraordinarily sparse (Sutton and others 1977, Ellis and Lawrence 1978). A study in South Africa (van Niekerk and van Heerden 1972) compared two groups of mares (one kept on pasture and the other kept on pasture with supplemental grain) in terms of the occurrence of estrus, ovulation, and successful conception. The pasture grass contained approximately 3.2 percent protein and the supplements contained 12 to 15 percent protein. Six of eight animals maintained on grass alone exhibited estrus, but only two of these ovulated and both conceived. In contrast, the seven mares maintained on grass plus supplement exhibited estrus and ovulation, and the six served conceived. The supplemented animals gained a total of 53 kg over the 53 days of the study, whereas the unsupplemented animals did not gain weight. The starting weight averaged 370 kg. These data, like those for other species, suggest that variations in nutritional intake can affect ovulation. Horses are also vulnerable to abortion and stillbirth, to lactational failure, and to loss of foals too weak to nurse properly; however, quantitative studies addressing these points and their relation to nutrition do not appear to be available (Ginther 1979).

Nitrogen intake and absorption in horses can be assessed by measuring plasma urea nitrogen concentration (Fonnesbeck and Symons 1969, Reitneur and Treece 1976, Owen and others 1978). Fonnesbeck and Symons studied diets ranging in protein content from 8.3 to 16 percent. This span neglects the very low protein content of range forage that may be encountered during some seasons of the year. The correlation of plasma urea nitrogen with apparent nitrogen absorbed was $r = 0.78$. There were indications of variations in plasma protein, sugar, and cholesterol concentrations with the several diets. However, there was no direct correlation, except that those diets with the highest soluble carbohydrate content resulted in the lowest serum cholesterol concentrations. To encompass the range of conditions likely to be encountered in natural habitats, a study including diets of 3 to 4 percent protein and 6 percent protein would be required. Serum protein and hemoglobin levels will decrease at a lower protein and energy intake, as was found with animals maintained on pastures without supplementation (Owen and others 1978). However, there are no controlled experiments available concerning these possibilities in horses.

The effects of fasting for periods up to 9 days have been described in ponies (Baetz and Pearson 1972, Wensing and others 1975, Gronwall 1975, Baetz 1976). These authors described increases in bilirubin, cholesterol, phospholipid, free fatty acids, triglycerides, other serum lipids, pyruvate, lactate, and alpha-one-globulins. Serum urea, phosphorus, and magnesium decreased. It appears generally possible to use several of these assays to distinguish fasting or total food withdrawal from reduced food intake, and thus it is not necessary to confuse these conditions. There are differences, however, between ponies and larger breeds of horses, including Morgans and thoroughbreds (Robie and others 1975). Apparently ponies maintain higher triglyceride levels in cold weather and are also more vulnerable to fasting hyperlipemia than the large animals. These results imply the desirability of analyzing data from captured wild animals in terms of season and lipid metabolism. There is no evidence that season affects serum urea nitrogen unless the animals are on pasture without supplementation (Owen and others 1978).

Literature on hematology and blood chemistry of burros (Brown and Cross 1969, Yousef and others 1971) and domestic horses is available. In addition, there have been several careful studies of water metabolism in the burro under desert heat conditions (Yousef and others 1970, 1971). Data for newborn and young foals are available as well (Kitchen and Rossdale 1975, Medeiros and others 1971).

Studies on zebras (Seal and others 1977) provide evidence that equids are similar to other mammals in their blood responses to trauma and disease. Blood proteins that increase during any disease process or tissue injury are called acute-phase reactants. The response pattern of each protein is characteristic, and careful studies in humans have demonstrated a semiquantitative relationship to such traumas as myocardial infarction, surgery, and various infectious diseases. Measurement of such proteins as fibrinogen, haptoglobin (Allen and Archer 1971, Spooner and Miller 1971) and perhaps C-reactive protein provide simple yet powerful tools for assessing the general clinical condition of an animal without undertaking a full spectrum of clinical diagnostic procedures. Prior exposure to various infectious diseases in currently well animals can be detected by seriological assays, which are readily available for certain widespread agents of major domestic importance.

Detection of the effects of handling, exercise (Hensley 1978; Keenan 1979; Lucke and Hall 1978; Krzywanek and others 1976; Rose and others 1979; Snow and MacKenzie 1977a, b), and sustained chasing and capture is a matter of continuing concern and interest for those involved in the capture and transport of both wild and domestic animals (Harthoorn 1976). Increased hormone secretion by the adrenal cortex and medulla (Anderson and Aitken 1977) is considered to be a physiological response to such disturbances. A study of horses (Kirkpatrick and others 1979a) comparing different techniques for handling found no differences in serum cortisol concentrations and concluded that the several techniques were minimally stressful in terms of their impact on serum corticoid levels. Additional sensitive techniques for detecting the effects of different levels of exercise and muscular exertion in horses appear to be measurement of creatine phosphokinase (CPK) activity (Anderson 1976), uric acid (Keenan 1979), and bilirubin (Hensley 1978). The enzyme CPK is a sensitive indicator of exercise and significant muscle trauma. Animals in initially poor condition tend to respond with much greater increases in serum CPK after graded levels of exercise.

If captured animals die--particularly after chases and during their first 5 days in captivity--then the possibility of metabolic acidosis and myopathy resulting from the exertion need to be considered. This condition has been well documented in zebra by

Harthoorn in a long series of studies in Africa. He described an effective treatment that consists of giving a liter of electrolyte solution with 1,000 mEq sodium bicarbonate added, which counteracted the decreased blood pH and resulted in survival. There are available pH meters suitable for field use that would allow diagnosis of the problem.

Other techniques for evaluating animal condition include hair bulb diameters, autopsy, direct measurement of rump fat thickness; gross and microscopic evaluation of tissues; estimation of fat thickness by ultrasonic measurement (Westervelt and others 1976); and measurement of body weight in relation to age and bone growth. Extensive growth data on domestic horses exists from about 140 days of gestation up to maturity at 24 to 36 months. Most domestic horse strains appear to attain about 45 percent of their mature weight at 6 months, 65 percent at 12 months, and about 80 percent at 18 months. At the same time intervals, thoroughbreds achieve 83, 90, and 95 percent, respectively, of their mature height at withers; apparently quarterhorses and Arabians do also (Hintz and others 1979, Platt 1978).

Behavioral Sampling: Methods for Comparison Between Treatments and Experiments

Since different experiments within the research projects have been organized to analyze particular aspects of equid biology, but at the same time to allow comparability across experiments, it is necessary to measure behavioral responses within experiments and relate these responses to other treatments within and between experiments. For example, the data in feeding trials will relate nutritional plane to reproductive success. In order to relate the findings on nutritional condition in trial animals to animals in enclosures or on the open range, it will be essential to be able to compare the level of activity between groups. Since activity determines part of the nutritional requirement, the ability to measure and compare activity is critical to the ability to generalize the results of the feeding/nutrition experiment. Likewise, an understanding of the social effect of contraception on the horse will require good experimental measures that are comparable with measures used on the behavior of wild populations. An overall lack of comparability severely limits the ability of researchers to generalize their experimental findings to wild populations.

A primary goal of the behavioral sampling scheme is to establish a set of data that are comparable across experiments. However, each experiment has unique questions that require information unnecessary for other experiments. Therefore, the discussion on behavioral sampling is presented in two separate sections. The present one deals with data to be collected that will be used for comparisons across experiments. The next section will concern data used within a single experiment or a subset of experiments.

Comparative Methods in Behavioral Sampling

Two initial decisions are required for a behavioral sampling scheme. First, it must be decided how animals from a population are to be chosen for sampling. Second, it must be determined how the behavior of the chosen animals is to be recorded.

There are two widely used techniques for choosing the individual(s) for sampling. The scan sample is a method in which all animals in a group or some subset of the group are sampled simultaneously. The method provides a good sample of a population's response. Furthermore, since the sample is created instantaneously, this method removes temporal and spatial variability to a greater extent than methods where behaviors of individuals of a population are lumped but recorded on different days and locations (e.g., focal-animal sampling, discussed below). However, since several individuals are monitored at once, data are usually recorded in a way that makes it impossible to reconstruct which individual performed which behavior--as a raw percentage score. Thus, individual profiles of animals cannot be constructed. This weakness not only eliminates the capability of considering individual performances and requirements, but also makes it impossible to compare variability between individuals, between treatments, and between experiments.

The second method for choosing subjects is the focal-animal sample, in which the researcher focuses attention solely on one animal for the sampling period. The advantages of this technique are that a great deal of detailed data can be recorded. From these data individual profiles and variability can be determined, a capability that allows more extensive statistical testing. One disadvantage of the technique is that a generalization to population response is more difficult, since data are recorded on only one individual at a time. "Population responses" inferred with this technique are really collections of individual records taken on different days, and so variability is increased because of changes in time, season, and location between samples. Another disadvantage is that a great number of individual records must be amassed to provide a sample size as large as that possible with scan samples. Furthermore, the work time necessary to characterize population responses by means of focal-animal sampling is great.

The series of experiments in the recommended research projects will require both the ability to characterize behavioral differences across treatments (i.e., mean treatment responses) and the ability to measure intra-treatment variability (i.e., differences in responses to a treatment). Because of the size and observability of equid groups and the ability to distinguish individuals within groups, a subject-sampling method is proposed that combines the focal- and scan-sampling techniques. If data are taken by scanning the group being watched and attributing behavioral scores to the individual who performed the behavior, then the strengths of both sampling techniques will be combined. This method will allow data on a number of animals to be gathered simultaneously, thereby increasing sample size and reducing temporal and spatial variability. At the same time, individual variability and profiles can be calculated. Because of the rate at which equids perform behaviors, and their size, it is possible to combine these two techniques.

The second decision in behavioral sampling is that of how to record the behavior. Again, two techniques are commonly used. The instantaneous or point sample records the behavior of an individual at a given point in time. Usually this sample is taken at regular intervals throughout the sample period. Point samples are often combined with scan samples and the behavior of several or all animals in a group is recorded at an instant in time. Point samples allow the amount of time spent in activities to be estimated. However, they underestimate the duration of rare events and behaviors that are instanteous or short lived. They cannot be used to estimate the duration of activity nor to investigate accurately the sequential dependency of behaviors. Point samples would allow the comparison of behavioral rates and activity rates between treatments and experiments, but would not provide an estimate of individual variability.

The second method of recording behavior is to note the state of the animal continuously. In this method--called continuous sampling--the onset, termination, and sequence of behaviors are recorded (usually against a real-timed record). These data are more detailed and therefore more difficult to record than are point samples. They are usually restricted to one sample animal and usually employed with focal-animal sampling. Continuous data have the advantage of preserving a much greater amount of information about the individual's activity and behavior. They can be analyzed for frequency, duration, and sequence as well as for rate means and other common statistics. Continuous data also can be recorded along with, e.g., point-sample information to generate statistics that can be compared to other data sets. Continuous data have the disadvantages of being difficult to collect, time consuming and costly to transform to an analyzable format, and of requiring large numbers of samples to characterize populations. Since they are commonly used with focal-animal samples, they share the disadvantages inherent in those samples as well.

The data collected for comparative purposes should be gathered by means of a technique that yields large sample sizes easily, is statistically viable, and can be recorded and transformed for analysis with ease. For these reasons, we favor the point sample over the continuous sample for comparative purposes. Continuous data are suitable for--and are used for--several of the individual experiments.

For the purpose of the general comparative behavioral samples, the FSP method, which combines the focal-scan sample with point samples, can provide a data base from which the following might be analyzed:

1. The mean and variance of behavioral rates within treatments and thus the capability of testing for differences in responses between treatments.
2. Differences in behavioral rates between experiments.

3. Definition of rates of activity within experiments and extrapolation to rates measured in other experiments (e.g., the activity-level example discussed earlier).

4. Tests for correlations in response within treatments. For example, weight gains for a given nutritional level may show individual variability. Behavioral data gathered by FSP methods would permit differences in weight gain to be tested for correlation or regression with differences shown by the individuals in their activity levels.

5. Construction of individual profiles of animals. Animals may show serial dependency or compensation between behaviors. For example, individuals who are active in the morning may be inactive in the afternoon or vice versa. Population measures would not detect this effect if horses showed no preference for morning or afternoon activity. Consideration of individual energy budgets requires measurements that can be identified at the individual level.

FSP Sampling Scheme

1. Behaviors to be Recorded. The following recommendations are for minimum data recording. Recorded data are to reflect (a) activity states that provide information for calculating energy budgets and (b) social behaviors that characterize the rates and directions of social interactions (i.e., who does what to whom). The following categories are to be scored: standing, standing eyes closed, lying down, walking, trotting, running, feeding, urinating, defecating, grooming, and social interactions. Social interactions constitute a large body of often species-specific behaviors that will require precise and common definitions across experiments. Researchers involved in these studies should be required to standarize these definitions after initial work has begun.

2. Sample Animals. Where experimental design permits, FSP horse samples should include the dominant male and at least one subordinate male, two females, and a foal. For burros, whose groups are not as spatially coherent, samples cannot be simultaneous on different classes of animals. FSP burro samples should include territorial and nonterritorial males, females in groups, and females with offspring. In experiments where mixed groups will not be used--such as the reproduction/nutrition trials--the sufficiency of animals within a treatment will be determined by the variability of response with the treatment.

3. Sampling Schedule. To eliminate diurnal variability, the following schedule should be followed. FSP samples should be taken for 30 minutes each hour from 0600 to 1800 once every 2 weeks. Points are to be recorded every 2 minutes within the 30-minute sample. Ideally, the full range of samples should be done on the same day so that they will provide daily profiles and allow the determination of interdependence of behaviors within the day. Two minutes has been

chosen as being a sufficiently long period for a trained observer to record behaviors and identify individuals for an FSP that includes up to 5 or 6 focal animals, while providing a reasonable number of sample points (15 per 30-minute period).

Behavioral Sampling for Specific Experiments

Contraceptive Experiments on Penned Animals

1. FSP

a. Focal animals. The groups for this experiment should be composed of stallions and mares. Stallions of different social rank (if multi-male groups are used) should be chosen as focal animals. Mares should be picked to include animals of different ranks in both the control and treated (contraceptive) groups.

b. Sampling schedule. The sampling schedule should be intensified during the breeding season so that good activity profiles are available for different phases of the breeding cycle.

2. Specific Behavior Sampling

a. Rationale. Behavior of animals is important to the determination and functioning of their social groups. Since contraception changes the hormonal activity of the female, and hormones are often linked closely with behavior, it will be essential to measure the differences in behavior exhibited by normal and contraceptive mares. The effect of individual behavioral changes on the group's social dynamics will be monitored and the ecological and management implications of these effects may be suggested.

b. Sampling scheme. Refer to paragraph (4) under the "Methodology" section of Project 6 (Chapter 2) for a description of this sampling scheme.

Nutrition/Reproduction Experiments

1. Purposes of the Data Collection

a. To determine activity levels so that nutritional levels can be accurately generalized to free-roaming populations, in which activity levels are likely to be different.

b. To correlate differences in reproductive performance and condition to activity measures.

c. To compare nutritional treatment effects on activity.

2. Specific Behavior Sampling. When females in the experiment are mated, behavioral samples identical to those used in the contraceptive experiment should be recorded. (Sampling scheme has been detailed in the "Methodology" section of Project 6.) These data will show how the nutritional plane affects the sequence of sexual behaviors between the stallion and mare.

Field Feeding Trials (Small Enclosure)

1. FSP. The purposes of the data collections are to compare activity levels between treatments and to be able to compare activity levels between experiments.

2. Specific Behavioral Sampling

a. Rationale. Assessment of the feeding response of cattle and horses to inter- and intraspecific competition will require detailed observation of the feeding animals. The purpose of these samples will be to record diet and dietary proportions to assess treatment affects, to generalize feeding behavior within the habitat type of the small enclosure, and to record feeding behavior in sufficient detail to determine which characteristics of the food are important factors determining diet in horses and cattle.

b. Sampling scheme. The sampling scheme for monitoring detailed feeding behavior should be a continuous focal-animal sample. Data are to be recorded in a continuous timed sequence on an individual animal. The schedule for sampling should be identical to the FSP schedule described in the previous section. Data are to be recorded on one individual for 30-minute periods of each hour from 0600 to 1800. In these samples the onset, termination, and sequence of all behaviors (see subsections on the FSP sampling scheme and the contraceptive experiments for behavioral categories) should be recorded against a real-timed record. The identity and size of all plants and plant parts eaten are to be recorded.

One must have this detailed record in order to understand the basis of dietary selection in the horse and to measure changes in feeding response when inter- and intraspecfic competition occurs. The detailed data on food intake are also necessary to estimate energy and nutrient balances in animals whose fecal output is collected. For both of these calculations it is necessary to know not only what is eaten, but also the specific rates at which particular species are eaten, the quantities ingested as a function of time, the sequence of ingestion through the day, and the diurnal patterns of gross intake rates. The results of these balance trials will serve as an intermediary condition for translating results of the highly controlled nutrition/reproduction feeding trials to the free-ranging feeding observations.

Spacing data should be recorded at the beginning and end of each 30-minute sample. These data, coupled with displacement data collected as part of the continuous record, will allow dominance interactions to be related to feeding behavior.

Habitat-Choice Experiments

1. FSP. These data will allow the activity and social interaction rates to be compared between treatments within the

experiment and between experiments to determine if differences are due to interaction with cattle (as opposed to horses) or to the habitat choice of the horse.

2. Specific Behavioral Sampling

a. Rationale. The purpose of these data is to measure the use of the space and habitat type within these enclosures by horses and cattle to determine the effect of intra- and interspecific competition on the use of space.

b. Sampling scheme. At the beginning and end of each 30-minute FSP sample period, the location of the group being sampled is recorded on a topographical map of the enclosed area. The type of habitat occupied is also recorded. Because these locations are likely to be variable depending on the season and weather, sampling frequencies for this experiment are to be increased from 2 to 5 days per month.

c. Other behavioral measures. Data on the feeding and social behavior of animals in this group would be of benefit, but the feasibility of recording data requiring closer observer contact with the animals is doubtful. Since the primary goal of the experiment is to determine use of space, any space-related reaction by the horse to observers will damage the accuracy of the results. The ability of the horse to become habituated to the observers will determine the degree to which other behavioral data can be recorded.

Wild Populations with and without Contraception

1. FSP. These data will be used for comparative measures with other experiments and comparisons of general activity between normal and contraceptive mares.

2. Specific Behavioral Sampling

a. Rationale. Continuous focal-animal samples of activity, feeding, and social behavior are necessary to make specific comparisons. Activity is to be compared to levels in the feeding trials to determine how range conditions comparable to feeding levels would affect animals active under free-ranging conditions. Feeding behavior is to be compared with that measured in the small enclosures to determine if the feeding responses are similar in the enclosed and free-roaming condition. For example, does the increased amount of locomotion required of free-ranging animals change their dietary choices by shortening the amount of time spent feeding at each plant? Finally, social behavior--and in particular sexual behavior--is to be compared with measures in the penned contraceptive experiment to determine how the free-roaming populations respond to contraceptive implantation. Effects of the treatment on social behavior and organization may differ between the confined and free-roaming conditions.

b. Sample scheme. Since observational conditions and habituation of the animals to human observers will differ widely in free-roaming populations, a strict sample scheme cannot be projected at this time. The researcher should employ the same sampling methods and schedule for continuous focal studies as are used in the experiments to which comparisons will be made (i.e., sexual behavior should be recorded as per the instructions outlined in contraceptive experiments, feeding behavior as described under the small-enclosure feeding trials, etc.).

c. Sampling schedule. Continuous focal-animal samples should be 30 minutes in length and conducted each hour between 0600 and 1800, light permitting. These samples should follow one animal for the entire day. Each focal animal is to be sampled in this manner once a month. Focal horses should include at least one dominant male, two females (one contraceptive, one normal), one subordinate male, and one foal. Focal burros should include one territorial male, one nonterritorial male, two females (one normal, one contraceptive), and one foal.

Spacing, location, and habitat data should be recorded at the beginning and end of each 30-minute sample.

Behavioral Sampling Summary

1. Contraceptive Experiments on Penned Animals
   a. FSP: 30-minute samples, 12/day, 2 months
   b. Continuous focal samples (CFS) on sexual behavior (schedule determined by researcher)
   c. Spatial data: beginning/end each 30-minute FSP sample
2. Nutrition/Reproduction Experiments
   a. FSP (schedule same as above)
   b. CFS during mating
3. Field Feeding Trials (Small Enclosure)
   a. FSP
   b. CFS on activity, feeding, social behavior: 30-minute samples, 12/day, 2 months
   c. Spatial data: beginning/end each FSP sample
4. Habitat-Choice Experiments
   a. FSP: 5/month
   b. Location/habitat data: beginning/end each FSP sample
   c. Other behaviors measured as possible without disturbance of animals
5. Wild Populations
   a. FSP: 2 months
   b. CFS on activity, feeding, social, and reproductive behavior
   c. Spatial data: beginning/end each FSP and CFS sample
   d. Location/habitat data: beginning/end each FSP and CFS sample

Contraception in the Horse

Contraception is not being advocated in this section as a population-control measure in horse management. That is a matter of policy decision. It is the purpose of the following discussion to point out some of the technology that is available if contraception is chosen as a management tool to be used in a particular situation. The efficacy of the techniques can be evaluated in a relatively small sample of domestic horses but determining their usefulness in free-roaming populations will require field trials.

Fertility control or sterilization of the harem stallion has been suggested as a means of limiting the growth rates of wild horse populations. This approach is based on the premises that the females of a harem or band are bred only by this male and that this social structure is in some measure constant. It assumes that the behavior will be constant while the females undergo repeated estrus cycles during the breeding season, and that the females will continue to have a limited breeding season. The approach is currently being tested in field trials using hormone injections effective for a single season. Evidence reported by investigators in Wyoming and Montana suggests that these assumptions may not apply to all wild-horse populations. Several males have been observed breeding females in estrus; males may change band affiliation; a given stallion may maintain dominance only about 4 years; and some mares spend long periods of time outside of a band. A study of burro bands, whose dominant males were vasectomized, found that the females were then bred by young males previously considered nonbreeders (McCort 1979). These considerations, plus the fact that the reversible contraceptive techniques for males currently being tested are effective for only 6 months, indicate that this approach will require annual reapplication and will not be effective in horse populations with more fluid social structures. Computer simulation of population effects of female contraception indicate that the treatment may need to be effective for 5 to 7 years to prevent population growth or to achieve a decline in population numbers.

Artificial manipulation of the estrous cycle in horses (Ginther 1979) and other domestic animals has been oriented toward relatively short-term applications. These have included: (a) synchronization of estrus and breeding for scheduled pregnancies, especially for artificial insemination; (b) treatment of infertility; (c) early induction of estrus and ovulation; and (d) suppression of estrus in feedlot cattle to reduce activity and interactions. Long-term control of fertility has been intensively studied only in human beings, and more recently there has been work with hormones and mechanical devices in dogs and with hormones in a few exotic wild species (Seal and others 1976) and in white-tailed deer (Matschke 1977a, b; Harder and Peterle 1974).

Approaches to fertility control that might have application for female horses include: (a) hormones, hormone analogs, and hormone antagonists; (b) mechanical devices such as intrauterine devices (IUDs) and pessaries; and (c) surgical intervention.
Surgery--including a laparoscopy approach for females--would be

impractical under field conditions because of the infection risk and the time required for each animal. Surgery is also permanent. The IUD has been an appealing possibility because its effectiveness lasts indefinitely, it is potentially reversible, and it would not interfere with normal hormonal and behavioral patterns except for pregnancy. However, it is unsuitable (a) because variations in uterine size require individual fitting; (b) considerable care and skill is necessary in placing the device so as to avoid damage and infection; and (c) retention has been variable in some species.

Detailed, extensive information is available on the reproductive cycle of the domestic mare and stallion (Ginther 1979, Rowlands and others 1975). The feral mare appears to be more strongly seasonal than the domestic mare (Kirkpatrick and others 1979b). However, published data on the long-term effectiveness of contraceptive agents in horses are nonexistent. The literature on artificial control of the mare's estrous cycle is oriented towards synchronization of estrus, treatment of infertility, and early induction of estrus and ovulation (Ginther 1979). Zimbleman and others (1970), in studying melengestrol acetate, found that intravenous administration of this agent had no effect on the occurrence of estrus. However, the study by Ganjam and others (1975) offered a rationale for the failure of this approach. They demonstrated that there is little or no specific plasma-protein binding of progesterone in the horse, and so the half-life of progesterone (2.5 minutes for compartmental mixing and 20 minutes for disappearance) and presumably other progestagens is very short. This observation would also explain the fact that very large daily doses of progesterone have been required to inhibit estrus (100 mg/day) and ovulation (200 mg/day) in the mare (Loy and Swan 1966). Such information suggests that a different approach needs to be taken.

Other compounds tested in domestic horses include chlormadinone acetate (Arbeiter and Jochle 1975) and an orally administered synthetic progestin, 17-α-allyl-estratiene-4-9-11, 17-B-ol-3-one (Webel 1975). The latter compound (allyl trenbolone) has potential for use in implants. It has been administered to pregnant horses with no apparent adverse effects.

A range of contraceptive agents is available, and effective implants are either available or can be produced that release small amounts of active agents on a continuous basis for periods up to 5 years, depending upon the compound and the nature of the implant (Dziuk and Cook 1966, Kinel and Rudel 1971). They have been tested in humans in extended field trials, and several agents have been used in more than 400 animals now covering a range of species (Seal and others 1976). Given the logic for contraception in the mare (Nelson 1979, Miller 1979), these agents would appear to be a choice for testing in females.

Implants can be installed in minutes under field conditions, but they require handling of the animal. Preparations that could be delivered from a dart gun are available, but they are only effective for about one year in their present form. The animals must be identified in some permanent fashion and appropriate records maintained so that the effectiveness can be monitored. A full 5 years of study of domestic animals would not be required to determine the likely span of effectiveness, since it is possible to measure release rates of the compounds from the implants as well as their levels in the blood, and thus to predict their effective lifespan. It is only necessary to establish that this mode of administration and the particular compounds chosen would provide effective contraception.

Studies of domestic mares to determine the effectiveness of this approach might employ the following design: use animals with proven reproductive histories, install the implants, observe the animals for signs of estrus, collect blood samples for hormone assay, use rectal palpation or serum progesterone to determine if ovulation has occurred, test with a stallion to detect behavioral responses characteristic of estrus, and test for pregnancy if breeding occurs. It is possible that estrous behavior might occur but that ovulation might not. It is also possible that ovulation and breeding could occur in some circumstances, and yet the condition of the fallopian tubes or uterus could prevent implantation.

In summary, the use of reversible endocrine contraception in mares or stallions is feasible from an endocrine point of view. Single treatments could provide periods of effectiveness ranging from 1 to 5 years depending upon the hormones used and the mode of delivery selected. The choice of a particular strategy would depend upon the characteristics of the specific horse population and the management constraints.

Chemical Immobilization and Capture of Wild Equids

The capture of wild equids and their restraint and handling in zoos and nature preserves has provided an impetus for development and testing of chemical immobilization agents (Harthoorn 1976, Haigh 1978, Fowler 1978). Use of these drug techniques requires considerable skill and is best accomplished by people with adequate knowledge of physiology and anesthesiology if losses are to be kept to a minimum. Many of the problems that have arisen with immobilization drugs have been the result of their administration by inexperienced and untrained personnel (Harthoorn 1976, Haigh 1978). Veterinary practitioners also commonly have to deal with horses at pasture and fractious animals that cannot be handled by standard techniques. The experiences have resulted in the development of techniques for using tranquilizing and immobilizing agents.

Chemical immobilization of individuals is not an efficient procedure for the primary capture of large numbers of animals within a reasonable period of time. It is frequently more effective to employ appropriate trapping, corralling, or herding techniques. If necessary after capture, animals can be immobilized by drugs for further handling, but it is possible to use other handling techniques. Chemical immobilization can be effective and useful when applied selectively by trained personnel and when it is appreciated that it is a time-intensive technique (Harthoorn 1976).

It is possible to come within shooting range of horses or burros with dart guns by pursuing them in helicopters, waiting at water holes, or stalking. The range of the currently available rifles for projecting darts varies from 30 to about 100 yards. Capture of free-ranging wild animals using dart-gun techniques has been facilitated by the recent development and successful use of a small radio transmitter suitable for use with darts. This device has a range of up to a quarter of a mile, depending upon terrain, and allows animals to be located and followed in rough country after they have been shot.

Discussion of the drugs used for immobilizing equids can be found in Harthoorn (1974, 1976), who did much of the work on developing techniques for zebra capture in Africa. It appears that either of two drugs can be used for capture if circumstances are appropriate. One is succinylcholine, a muscle relaxant, which is neither a tranquilizer nor an anesthetic agent. It can be administered intramuscularly by way of a dart gun, and when used successfully can immobilize an animal within 5 to 10 minutes. The dosage of succinylcholine needed for capture can vary with season of the year, sex, and age, so a suitable dose range for a particular population would need to be established from experience. Borchard and others (1979) have recorded experience with this agent, and in skilled hands the death rate would probably run no more than 2 to 10 percent. Respiratory arrest in successfully immobilized animals may occur in 20 percent or more of animals. Therefore, rapid access to the animal is necessary and the ability to support respiration is essential. The use of succinylcholine has been greatly restricted by court orders based upon humanitarian concerns. Animals do not lose consciousness or sense of pain with this drug.

The other drug is etorphine, a morphine-type compound that is effective at low doses. It acts as an immobilizing agent, an analgesic, and an anesthetic (Harthoorn 1976, Bogan and others 1978, Hillidge and Lies 1978). There is an antagonist available for use with this drug--diprenorphine--that reverses the immobilizing drug's effects. An animal can recover spontaneously over a period of time ranging from 30 minutes to 2 hours without administration of the antidote. Etorphine appears to be a suitable drug for capturing wild equids in the field: it also can be used with the wild ass (Woodward 1979). Etorphine is customarily used in combination with acepromazine or xylazine. Effective doses of etorphine range for equids from 5 to 10 mg per animal. Equids have a wide tolerance for this compound, and as much as 10 times the effective dose has been administered without fatal results.

Xylazine has been used alone and in combination with etorphine for capture of wild equids. It should be used with great care in combination with etorphine, since both are respiratory depressants and the combined effect can lead to respiratory failure, which, if not treated promptly, results in death. Xylazine, in combination with hetamine, has been used for anesthesia of domestic horses. The combination is also being used for immobilization of many wild species and may be useful for wild equids. Xylazine can effect dramatic alterations in metabolic pathways (elevations in glucose and urea) that would make blood samples useless for evaluating the nutritional status of the animal (Short and others 1972, Eichner and others 1979).

If succinylcholine cannot be used for horse immobilization, it will be necessary to test other drugs and combinations, such as etorphine with a tranquilizer, or xylazine and hetamine (Alford and others 1974, Hoffman 1974, Holmes and Clark 1977, Kaha and others 1979, MacKenzie and Snow 1977, Muir and others 1978).

NEEDED RESEARCH

Project 17. Census Methods for Wild Horses and Burros

Rationale

Section 14(b)(1) of PL 95-514 states that the Secretary of the Department of the Interior shall "maintain a current inventory of wild free-roaming horses and burros." Effective management, both in terms of resource use and communication with the interested public, requires that such inventory data be accurate and reliable. Little is known about the accuracy of the existing estimates. There is thus an urgent need for research to evaluate the existing methods, and to develop satisfactory alternate methods where needed.

A research project is outlined below that would investigate three approaches to horse and burro census: "complete" counts (the approach currently used by the management agencies), mark-resight estimates, and strip-transect estimates. The three approaches would be used together in each study area to serve as checks against one another, and to determine which provides the greatest accuracy and precision: (a) under a given set of environmental conditions (terrain, vegetation, etc.) and (b) for horses or burros. For the present, quadrat and line-transect estimates are not suggested for inclusion in the initial study. When an initial set of data has been collected and analyzed, it may be found desirable to test these and other methods.

This project might benefit from being directed by two people: one with expertise in statistical methodology--especially with interest and experience in animal-population measurement--and the other a wildlife biologist with experience in aerial census. This suggestion does not preclude direction by one person with adequate training and experience in both areas.

The first project will direct attention only to wild horses, and will be considered a pilot effort. Subsequent efforts will investigate burro census and alternate census methodology, if adequate progress in the work with horses and sufficient funding are assured.

Objectives

1. Test the accuracy and precision of three approaches to wild horse census:
   a. Complete counts, including bounded counts
   b. Mark-resight estimates
   c. Strip-transect estimates

2. Develop a set of criteria by which to choose the appropriate approach for a given area with particular habitat characteristics.

3. Investigate the role of such variables as weather, vegetation, terrain, herd size, and horse distribution on probability of observation.

4. Prepare a report that would outline procedural details for carrying out the three approaches. It should especially document any further work needed to establish methodology (including a reference manual) for future BLM censuses.

Methodology

1. Select, with the help of BLM officials, three or four areas in the western United States in which to evaluate the three approaches. It is desirable that these areas contain geographically discrete populations--physiographically isolated or fenced if possible--to minimize or prevent ingress and egress. Modifications of the methodology suggested here may be required for individual sites.

2. Conduct a typical complete-count census of each area with helicopters in late summer or early fall.

3. As soon as possible after censusing, mark approximately half (if possible) of the horses on each area from helicopters with paint capsules. Costs may impose a limitation on the proportion marked, and a cost function should be applied to obtain an optimal balance between effort expended in marking and resighting.

4. After marking, conduct a series of overflights at 3- to 7-day intervals, counting the number of marked and unmarked animals seen and tallying group sizes. Two overflight patterns are possible. One consists of parallel, straight-line flights across the entire area, spaced at 1- or 2-mile intervals and covering the entire area. Each such set could be oriented toward a different compass direction, and should be selected _a priori_ without relation to the area's terrain and vegetational characteristics or to the locations of marked horses. The second alternative is to use random starting intervals rather than the equidistant ones oriented to random compass directions. Terrain or visibility factors may dictate this option.

5. Use additional overflights for strip-transect sampling of horses in the line of flight. First priority should go to the mark-and-resight effort as a check on the complete counts. However, strip transects may be deemed especially suitable for some sites.

6. As soon as possible after the overflights, conduct two or three more complete counts from helicopters to provide an array of values for the bounded-count method of checking the accuracy of the complete counts. This is regarded as having lowest priority.

7. With regard to objective 3, conduct intensive interviews with personnel experienced in large-animal census to gain information on the effects of vegetative, climatic, and equid behavioral variables on observability. This step should be an initial one, and may lead to necessary modification of the proposed methodology. Group size should be investigated as a factor affecting observability.

8. Take opportunities to conduct surveys over ground-truthed research projects wherever possible and convenient.

9. Encourage potential contractors to offer improvements to the above procedures. Tests of complete-count methods are, however, regarded as essential.

Project 18. Contraception Studies

Rationale

Those who manage wild equids will have to deal with multiple populations of differing size, composition, and accessibility. If population control is desired, but removal techniques cannot be applied, contraception might be a useful technique. The studies proposed here will provide data on short-term effectiveness in mares. The long-term limits of effectiveness can be projected by determining blood levels of the compounds and by calculating measured rates of release. Tests in stallions in wild bands and in captivity are in progress. They are designed to be effective over the span of a single breeding season (Kirkpatrick and others 1979a). Compounds effective in mares for several seasons could be adjusted to last for only a single season.

Objective

Establish a method for reproductive inhibition in female horses and burros that (a) is at least 95 percent effective (i.e., of 100 animals treated, no more than 5 become pregnant during the specified test period); (b) requires only a single treatment or administration under field conditions; (c) could be adjusted to last up to 7 years; (d) is potentially reversible; and (e) will not adversely affect the health or behavior of the animal.

Methodology

1. Establish five experimental treatments each of five captive mares, as follows:
   a. Control: no treatment (placebo/vehicle)
   b. Compound A: estimated dose for 5 years
   c. Compound A: five times base dose
   d. Compound B: estimated dose for 5 years
   e. Compound B: five times base dose.

Use nonpregnant breeding-age females (4 years of age or older), preferably ones whose reproductive status has been established (i.e., those known either to have cycled or to have been pregnant the past year).

2. Place implants intramuscularly early in the breeding season, if possible. Consideration should be given to implants of solid

silastic polymer in the form of rods. Use known amounts of drug in each implant.

3. Measure the following:
   a. Reproduction
      - Estrus: does it occur or is it completely suppressed? (Observe behavior and appearance of genitalia.)
      - Ovulation, determined by rectal palpation and serum progesterone
      - Breeding: will the female accept the stallion?
      - Pregnancy, established by rectal palpation and hormones
      - Foaling
      - Foal heat.

In this sequence, if an agreed-upon percentage of the animals becomes pregnant, the trial is a failure and should be terminated.

   b. Condition
      - Hematology (CBC)
      - Blood chemistry

High priority	Lower priority
Serum urea nitrogen	Free fatty acids (NEFA)
Glucose	Ketones
Triglycerides	Haptoglobin
Serum protein and albumin	Transferrin
Uric acid	
CPK	
Bilirubin	

      - Behavior
        -- Detailed guidance for measuring behavior can be found earlier in this chapter ("Behavioral Sampling for Specific Experiments: Contraceptive Experiments on Penned Animals," and in Chapter 2 ("Project 6: "Methodology," paragraph 4).
      - Hormone levels: the following should be measured regularly:
        - Blood levels of contraceptive hormone
        - Serum progesterone
        - Rates of release of contraceptive from device

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APPENDICES

Appendix A

The Digestive Physiology of the Horse and Its Interrelationship with Feeding Ecology of the Equidae

A report for the National Research Council
Committee on Wild and Free-Roaming Horses and Burros

by

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Introduction

The overall purpose of this review is to provide an interpretive perspective of the digestive and nutritional characteristics of the horse. This perspective is aimed primarily at understanding the way digestion and nutrition in this species affect its overall ecology, encompassing both its interactions with its food supply via diet and other herbivores, primarily cattle. Although this paper reviews the literature, it does so selectively. The emphasis has been to include key papers that enable digestion to be related to equid ecology. Extensive and recent reviews of horse nutrition and digestion are already available in the literature (Olsson and Ruudvere 1955, Mehren and Phillips 1972, Frape and Boxall 1974, Robinson and Slade 1974, Frape 1975, Hintz 1975, Hintz and Schryver 1978).

The horse is a herbivorous animal which extracts substantial energy from the structural carbohydrates of plant material. To accomplish the digestion of these carbohydrates, vertebrates must rely on a symbiotic relationship with bacteria and protozoans (Moir 1968). This digestion occurs by a process of fermentation in the gut. Although the products of fermentation are widespread in the G.I. tract (Elsden et al. 1946), they are usually concentrated in a site within a particular section of the tract. This fermentation site provides not only a protected environment of the proper pH for the microbes, but also the ability to slow down the passage of fibrous particles for more complete fermentation.

One of the primary functional dichotomies in the classification of herbivores is based on the location of the fermentation site (Janies 1976). The equids ferment forages in the hindgut. The ruminant species are primarily foregut fermentors. Ruminants are so named because they regurgitate forage already ingested and remasticate (i.e. ruminate) the bolus to break down the forage particles for more complete digestion. However a number of foregut fermentors (e.g. colibid monkeys, macrapods, hippopotamus) do not reuminate. The rumination process is ecologically quite important and should be distinguished as a separate characteristic beyond foregut fermentation. In a confusing bit of well-established terminology, hindgut fermentors are called nonruminants (this nomenclature could easily apply to foregut fermentors as well). I will continue this misnomer for the sake of convention.

Plant Material, Chemical Classification and Fermentation

Plant material is not homogeneous in its response to the digestive systems of animals. Plants are composed of components which differ in the rates they can be digested by animal and microbial enzymes. Therefore, ideally, plant material should be characterized by the component fractions within which the action of digestive enzymes is uniform. To establish relative digestibility would be a case of determining the proportions of the component fractions in the foods. The problem facing nutritional assays is complicated because chemical analyses do not necessarily act on forages to separate nutritionally uniform elements.

This problem is particularly acute with the widely used crude-fiber determinations which attempt to separate the digestible and indigestible components of forages. Crude friber recovers mainly cellulose in the indigestible fraction (although it is nutritionally available to herbivores) while losing part of the lignin (truly unavailable) to the digestible fraction. In the first growth of temperate grasses where lignin is positively correlated with cellulose, crude fiber is an adequate predictor of digestibility (Dijkstra 1969); but in tropical grasses, where no such relationship exists, crude fiber is a poor index of forage quality (Olubajo et al 1974).

The detergent system has been developed to correct, in part, this problem (Van Soest 1967). Because the principal chemical components of plants differ in their solubility at different pHs, successive extractions with solutions of different pH will sequentially remove these components. This method separates plant material into cell constituents and cell-wall fraction, further dividing cell wall into cellulose, hemicellulose and lignin (Table 21). Although these chemical entities are good predictors of digestibility (Mertens 1973), the detergent system does not characterize the digestibility of particular constituents of the forage. Digestibility within these fractions can vary with taxon, growing conditions and extent of lignification. However, cell contents can generally be characterized as rapidly digestible while the components of the cell wall, hemicellulose and cellulose, ferment slowly.

The major functional division of plant material is between the cell constituents and the cell wall (Table 21). The contents of the cell are the fraction active in plant metabolism and are composed primarily of sugars, proteins, and storage carbohydrates. This fraction can be digested directly by vertebrate enzymes or fermented rapidly by microbes. The cell wall provides the structural matter for the plant. This fraction cannot be degraded by vertebrate digestion but can be hydrolized by bacterial and fungal enzymes (Gibson 1968). Therefore the utilization of the cell wall as a nutrient source is dependent on microbial symbiosis (Hungate 1966). The cell wall while providing the plant with structural support also functions to defend the plant against herbivores. By increasing the proportion of the plant which is slowly digestible or totally resistent to breakdown, the plant decreases its digestibility and palatability.

Cellulose and hemicellulose, the principal structural carbohydrates of the cell wall, vary in the extent of their availability for fermentation dependent upon the lignin content of the cell wall (van Soest 1967). The mechanism by which the effect of lignin is exerted is unclear but may be involved with the cross linkages which occur between the lignin and the structural carbohydrates of the cell wall (Van Soest 1977). Kawamura et al. (1974) have shown through histological studies of digesting plant matter that the structual characteristics of the tissue in conjunction with chemical linkages affect the rate of digestion. For this reason characteristic taxonomic ratios of lignin to cellulose and hemicellulose are important nutritive characteristics of forages (Van Soest 1973).

Table 22 is a compilation of chemical analyses of plant materials grouped on the basis of their function. Several interesting patterns are apparent. In general there is a positive association between the permanency of a structure and its cell wall and lignin contents. Cell wall and lignin function as both structural support and herbivore defense. Since plants are most likely to put the most energy into the defense of more permanent parts (McKey 1974) and these structure are most likely to be supportive, both function are likely to produce a positive relationship between permanence of the plant part and its cell-wall and lignin content. Herbivores are likely to be sensitive to differences between the functional categories of plant material when making feeding decisions.

Different life forms show somewhat different fiber values within functional categories. Grasses have lower fiber content in their stems than trees and shrubs but higher cell-wall and lignin fractions in their leaves. Therefore grasses provide a larger fraction of slowly fermentable material because they have a larger

TABLE 21. THE CHEMICAL FRACTIONS OF PLANT MATERIAL (AFTER VAN SOEST 1967).

PLANT MATERIAL				
CHEMICAL FRACTION	FUNCTION	CHEMICAL CONSTITUENTS	DIGESTIBLE BY ENZYMES	DIGESTION RATE
CELL CONTENTS	METABOLISM	SOLUBLE PROTEINS, CARBOHYDATES & NUTRIENTS	VERTEBRATE, MICROBIAL	RAPID
CELL WALL				
CELLULOSE	STRUCTURAL	POLYSACCHARIDE	MICROBIAL	SLOW
HEMICELLULOSE	STRUCTURAL	POLYSACCHARIDE	MICROBIAL	SLOW
LIGNIN	STRUCTURAL (ANTIPREDATOR?)	PHENOL POLYMER	INDIGESTIBLE	

Table 22. CHEMICAL COMPOSITION OF PLANT MATERIAL.

FUNCTIONAL GROUPS	C.W.[1]%	H.G.%	CEL.%	LIG.%	N	SOURCE
Structural Tissue						
Wood (trees)	88.1	22.5	45.4	20.2	6	Browning (1975)
Bark (trees)	76.1	10.9	44.0	20.2	3	Van Soest & Robertson (1976)
Stems, spring (trees & shrubs)	35.8	7.7	18.9	9.2	20	Short et al. (1975)
winter	61.9	13.1	29.1	19.8	20	Short et al. (1975)
Stems (tropical grass)	74.3	29.6	35.3	10.1	9	Van Soest (1973)
(temperate grass)	60.7	28.4	29.5	2.8	2	Laredo & Minson (1975)
Stems (legume)	54.0	9.8	34.6	10.4	22	Luckett et al. (1967)
Photosynthetic Surfaces						
Leaves (trees & shrubs)	57.1	16.5	23.5	14.6	18	Robbins & Moen (1975)
Leaves (tropical grass)	66.3	32.7	27.4	5.8	9	Van Soest (1973)
(temperate grass)	55.4	29.0	23.6	2.8	2	Laredo & Minson (1975)
Leaves & Stems (tem. annual grass)	59.0	23.0	29.8	6.2	15	Van Soest (1975)
Storage Organs						
Underground storage (domestic)	10.0	3.5	5.1	.8	5	Van Soest & Robertson (1976)
Reproductive Organs						
Seed hulls	76.0	15.3	47.9	13.5	6	Van Soest & Robertson (1976)
Seeds with hulls	52.5	13.7	19.5	19.4	20	Short & Epps (1977)
Seeds without hulls	17.8	7.1	5.4	9.9	5	Short & Epps (1977)
Seeds (legume)	40.4	20.0	16.3	4.2	9	Short & Epps (1977)
Fruits (fleshy, inc. seeds)	40.9	10.9	15.2	14.8	47	Short & Epps (1977)
Fruits (domestic, no covering)	14.4	3.6	8.8	2.0	4	Van Soest & Robertson (1976)

[1] CW = cell wall; HC = hemicellulose, CEL = cellulose, LIG = lignin

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cell-wall component and a smaller indigestible fraction. For animals specializing in extracting energy by means of microbial fermentation, the grasses hold the greatest potential.

Temperate grasses show lower cell-wall and lignin fractions than tropical grasses. Deinum and Dirven (1975) demonstrate that the extent of cell-wall formation of both temperate and tropical grasses was a response to temperature, independent of age after maturity. They also found that the digestibility of the cell wall decreased with age at a greater rate at higher temperatures. This decrease occurred because of the lignification of vascular bundles and sclerenchyma (Deinum 1976). Stems, which have higher proportions of vascular bundles and sclerenchyma relative to parenchyma, which is not lignified, will show higher lignin values than leaves and hence a greater potential for depresssion of digestibility with age and temperature. The generally lower digestibility of tropical forages reported by Minson and McLoed (1970) and reviewed by Moore and Mott (1973) is most likely due to the differences in termperature at which they were grown and their greater stem-to-leaf ration. Furthermore tropical grasses show a greater difference between cell-wall and lignin values in the stem and leaves than temperate grasses, while the amount of soluble carbohydrates within the stem is greater in tropical grasses (Deinum and Dirven 1975). Therefore selective grazing would be expected to be more important in tropical than temperate grass-lands.

Digestive Process

Digestive rates. -- The actual digestibility of a forage is a function of the digestion rate (enzymatic action) acting on a particle for the duration of its retention in the digestion site. Waldo et al. (1969, 1972) proposed a digestion model involving the fiber kenetics of the rumen. They considered the rumen to be filled with two fractions (pools), one digestible and the other indigestible, whose disappearance from the rumen was a function of the rates of digestion and passage. Plots of the log arithm of residual cell wall as a function of time for *in vitro* digestion trials yield linear results when the indigestible portion is subtracted from the calculations (Smith et al. 1972). These results (i.e. a constant proportion of the cell wall removed per unit time) indicate first-order kenetics and validate this assumption in the Waldo model.

Mertens (1973) found retention time to be the most important factor predicting intake and digestibility in sheep. Intake and retention time are linked. Increased intakes decrease retention time and depress digestibility (Raymond et al. 1959, Pearce and Moir 1964, Moe 1965, Alwash and Thomas 1971 and 1974, Tyrrell and Moe 1975). The type of diet, related to its physical form, often affects retention times in both ruminants (Alwash and Thomas 1974) an nonruminants (Uden 1978). Direct correlation between particle size, retention time, and digestibility have been determined in sheep (Pearce and Moir 1964).

The concept that digestion can be characterized by two parameters, digestion rate and retention time, is potentially useful for comparisons of ruminants and nonruminants. Differences in digestibility of forage between the two groups can be examined in light of evidence for differences in these two parameters.

Fermentation site. -- The more important processes occurring in the fermentation site (either ruminant or nonruminant) are diagrammed in Fig. 9 . The fermentation site, regardless of location, is an ecological system within which there is active competition between individuals for energy and nutrients (Hungate 1966). Upon entry to the site all digestible fractions of the forage are subjected to microbial digestion. The soluble nutrients (i.e. cell contents) are rapidly fermented and the rate of the digestion of other components is related to their solubility (Hungate 1966). Microbes produce respiratory products, volatile fatty acids (VFA), which are the primary energy source from fermentation for the host. Heat and methane, also products of fermentation, are unavailable and their energy value is lost to the herbivore. Values for these losses vary depending upon diet but generally range from 10-30% of digestible energy (DE) (Baldwin et al. 1977).

Microbial populations within the fermentation site form an ecosystem of populations (McBee 1971). The populations grow at rates proportional to their nutrient supplies (Orskov 1978). They assimilate energy and utilize dietary protein or ammonia as nitrogen sources for growth and reproduction (Hungate 1966). The ability to upgrade ammonium ions to protein nitrogens has the potential to provide urea recycling and microbial protein synthesis to the herbivore. Since microbial bodies are being continually washed from the fermentation site the protein (and other synthesized components such as vitamins) have the potential to be digested and absorbed in their synthesized form.

The positioning of the fermentation site along the gut is important to the function of fermentation for the herbivore (Parra 1978). Since the soluble fraction (cell contents) of the forage is directly digestible by gastric enzymes of vertebrates, if this fraction is fermented in the foregut, a sizeable fraction of the energy is lost to heat and methane production. Since little of the soluble nutrients escape fermentation (Bryant 1963, Bryant and Robinson 1963, Nolau et al. 1972), a critical difference between ruminants and nonruminants exists in the importance of the soluble fraction as a dietary component. This point will be discussed in detail below.

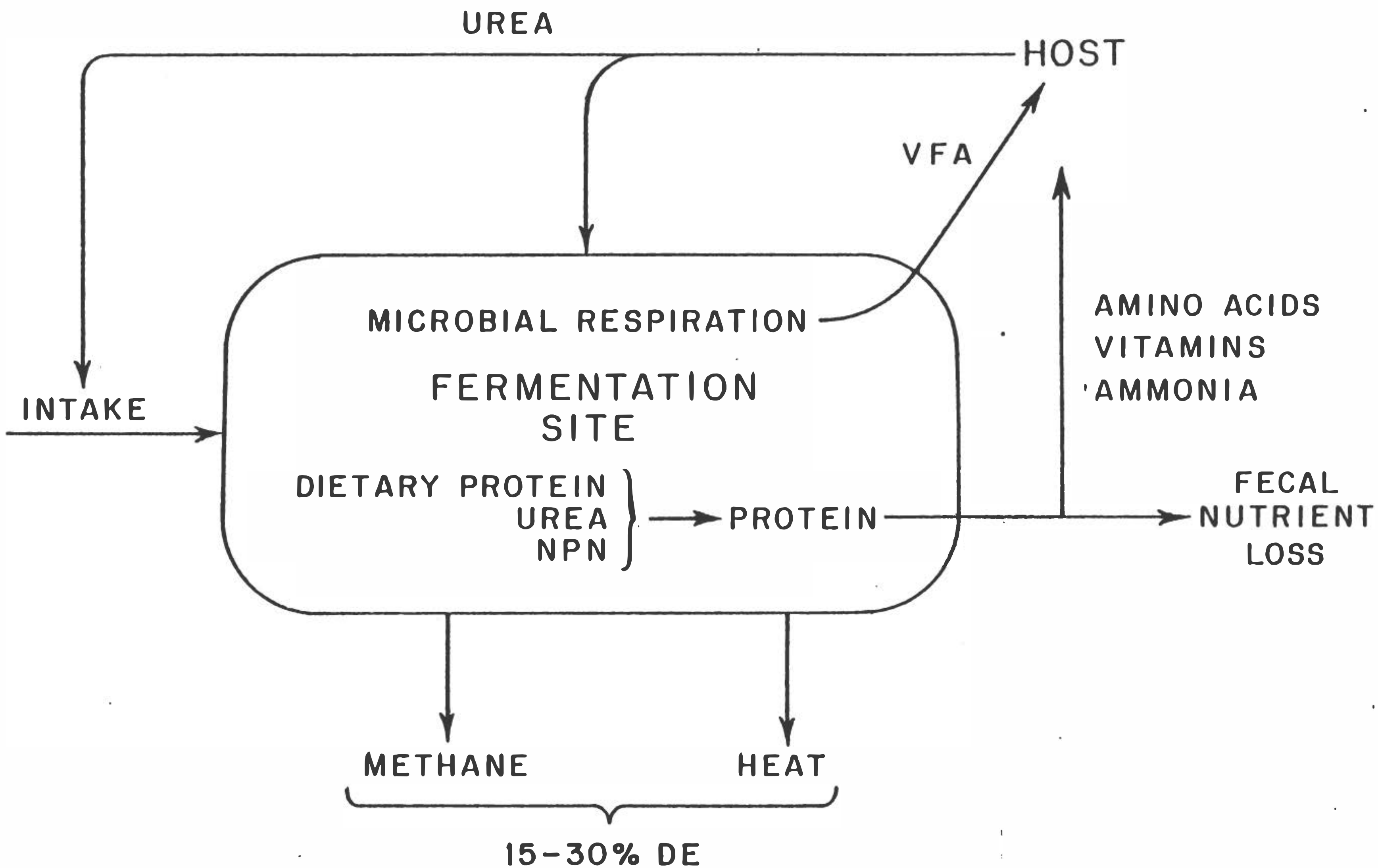

Figure 9 . Dominant process of the fermentation site relevant to the ecology of ruminants and nonruminants. This figure is a generalized picture applicable to varying degrees to fore- and hindgut fermentors.

Fermentation-site positioning may also determine the relative capacity of ruminants and nonruminants to utilize the synthesized nutrients in the bodies of the microbes. In the foregut fermentors, microbes are subjected to gastric digestion in the abomasum and the resulting components are absorbed in the small intestine. However, for the nonruminants no established mechanism has been identified for the digestion of microbes in the colon and somewhat contradictory evidence exists for the absorption of any digestion products. The utilization of urea and microbial protein is a clear example of the differences in these systems and because of its importance as a limiting nutrient in grassland ecosystems (Sinclair 1977) will be discussed in detail below.

The ability of ruminants to utilize low-protein diets has been widely established (see reviews by McDonald 1968, Tillman and Sidher 1969). They show the ability to survive on diets composed entirely of NPN (Loosli et al. 1949, Virtanen 1966). Since there is no evidence that their amino-acid requirements are different from other mammals (Moir 1968), this ability reflects the microbial synthesis of amino acids from NPN source (NAS 1976).

In the foregut fermenters, dietary protein is attacked by the rumen microbes for energy (Hungate 1966). The intense competition among the microbes for energy sources is reflected in the low concentrations of free amino acids and peptides in the rumen (Bryant 1963, Hungate 1966). Ammonia, produced partially from hydrolysis of protein, is rapdily incorporated into microbial protein (Bryant and Robinson 1963). Nolan et al. (1972) found that 80% of the N in the bacteria of the rumen was from the ammonia pool. Some of the protein of low solubility does however pass through the rumen without digestion (Chaluysa 1972) and some free ammonia is absorbed through the rumen wall and transported to the liver for amino-acid synthesis or urea formation. The microbes, carrying the preponderance of the dietary protein, are washed from the rumen and their proteins digested and amino acids absorbed in the small intestine (Armstrong and Hutton 1975). Ammonia produced in this process is absorbed into the portal system and returned via the blood as urea to diffuse into the rumen (Houpt 1959), and to the salivary glands to reenter the rumen via the esophagus (McDonald 1948, Nolan et al. 1972). Microbes can hydrolyze the recycled urea and utilize the ammonia as a nitrogen source (Bryant and Robinson 1963). The recycling system, capable of upgrading endogenous urea to essential amino acids, also has the ability to utilize dietary NPN sources for all amino-acid synthesis. Therefore dietary selection for amino acids is not essential, but selection for nitrogen in any digestible form is critical. Also because rumen microorganisms rapidly assimilate most of the glucose in the rumen, foregut fermenters must rely heavily on deamination of protein in the liver for their blood-sugar supply. Because urea is a product of deamination, without the ability to recycle urea, large nitrogen losses would occur in the urine of ruminants (Moir 1968).

Because in the nonruminant dietary proteins are hydrolyzed in the stomach and small intestine by the herbivore's proteolytic enzymes and absorbed directly into the body in the small intestine, the energy losses involved in the microbial breakdown and resynthesis of protein in the rumen are avoided. However because the major fermentation site is posterior to the site of digestion and absorption, the digestion of protein and absorption of amino acids must occur in the colon. The mechanism for the digestion and absorption of amino acids in this organ is not well documented. Furthermore because the fermentation site is located in the hindgut the time for the digestion of the microbes and absorption of their nutrient components is much reduced relative to the ruminant system. Therefore nonruminants would be likely to show higher fecal nitrogen losses than ruminants of the same size.

The existence of nitrogen cycling in nonruminants has been demonstrated in man (Walser and Bondenlos 1959), rats (Rose and Dekker 1956), horses (Houpt and Houpt 1971, Prior et al. 1974) and rabbits (Rogeczi et al. 1965, Houpt 1963). A number of studies have demonstrated the presence of urea nitrogen in the body amino acids (Richards et al. 1967, Snyderman 1967, Grimson 1971, Rogeczi et al. 1965, Davies and Koonberg 1950). Since recycling of nitrogen does occur in nonruminants, the ecological consideration is whether there are quantitative and qualitative differences between the two digestive strategies.

Quantitative differences between ruminants and nonruminants would be expected on the basis of the positioning of the fermentation site. The magnitude of the difference should be size specific, decreasing with larger body size as retention times increase. Prior et al. (1974) show similarity in urea retention between horses, cattle, deer and sheep. The horse's large body size compensates for the hindgut fermentation site to produce efficiencies similar to the deer and sheep. Man and rabbits showed much lower efficiencies. The rabbit's inefficiency may be a function of its size where in man, an omnivore, the absence of a highly developed fermentation site would likely impair the efficient hydrolysis of urea by microbes.

Qualitative differences arise if the site of amino acid synthesis is the liver or the microbes of the gut. The range of amino acids that can be synthesized in the liver is limited. Those amino acids required by the animal but not synthesized by the liver must be present in the diet and are referred to 'essential' amino acids. However microbial synthesis can supply the full complement of amino acids.

Ample evidence of all the cirtical steps of nitrogen recycling exist for the nonruminants, but except for the horse (where the evidence is by no means unequivocal, see discussion in Robinson and Slade 1974), there was no demonstration of the ability to absorb amino acids from the colon. Work on germ-free animals indicates that urease (the enzyme for hydrolysis of ureau in gut is solely of bacterial origin (Delluna et al. 1968). Therefore the contact of ingesta with a concentrated bacterial population is important for efficient nitrogen recycling (i.e. humans, who lack developed fermentation sites, would not be expected to show high nitrogen recycling capabilities). The administration of antibiotics to the nonruminant reduces or eliminates its ability to retain nitrogen (Wrong et al. 1970, Houpt and Houpt 1971). Once ammonia enters the liver and is dextoxified to urea, it is recycled in the blood to the caecum of the horse (Houpt 1963), G.I. tract in man (Waser and Bodenlos 1959, Richards 1972) and to the salivary glands (Forland et al. 1964). The urea in the gut is hydrolyzed and the free ammonia can either diffuse through the colon wall (Castell and Moore 1971) or be assimilated by the microbes in the cecum (Wootten and Angenzio 1975).

The degree to which ammonia is utilized by the microbes is dependent on the energy sources in the lower gut (Mason 1976). The ability to absorb amino acids in the colon has been demonstrated only in the horse (Slade et al. 1970). The ability of mature horses to maintain themselves regardless of the nitrogen source is further indication of the assimilation of microbial amino acids (Robinson and Slade 1974). However the actual mechanism by which the microbial cells are digested in the lower gut has not been described. Several mechanisms have been suggested: the continued activity of pancreatic enzymes in the caecum (Robinson and Slade 1974), autolysis of microbes in the colon (Baker 1942) and the activity of protrolytic bacteria, common in the squid caecum (Kern et al. 1973).

Comparative Anatomy and Digestive Function

Size of gut components. -- Since retention of particles within segments of the gut is a function of intake and the volume of the section, the relative size of segments in the G.I. tract indicates the relative capacity for digestion within the segment. On a comparative basis differences in allotment of volume to the segments indicates the digestive strategy of the species. Data on the volume, estimated by contents, is given in Table 24 . Some interesting patterns are apparent. As expected, ruminants devote the majority of the gut volume to the foregut and nonruminants allocate a substantial capacity to the hindgut. Within the non-ruminant the relative volume of the hindgut increases, indicating the growing importance of fermentation with larger body size. However donkeys have, on an absolute scale, substantially larger lower tracts than expected and show greater capacities for fiber digestion than the horse (Wolter and Velandia 1970).

The fermentation products, a crude estimate of fermentation rates, show that nonruminants achieve similar concentrations within the fermentation site as ruminants (Table 23). The horse and the cow are similar in body weight and weight of gut contents (Eldsden et al. 1946). The fermentation contents appear to be slightly greater in cows than horses (10.0-17.8% of body weight in the cow, 11.2% in the horse). Interestingly Parra (1978) found that the weight of fermentation contents had a similar exponent

Table 23.[1] Comparison of Capacities and VFA Production in Sections of the Gut of Herbivores.

	Body Wt. (kg)	N	% Wt. Total Ingesta: Stomach	Small Int.	Caecum	Colon	Rectum	VFA Concentrations (g/100g DM): Stomach	Small Int.	Caecum	Colon	Rectum
Rat (NR)[2]	.963	6	26.2	26.9	24.7	7.4	14.7	.26	.38	4.07	3.20	1.60
Rabbit (NR)	1.170	5	38.3	10.3	43.8	4.5	30.0	.32	.41	2.09	1.50	1.06
Pig (NR)	20.4	2	34.1	18.2	15.6	28.0	4.1	1.62	.47	4.22	4.53	2.45
Donkey (NR)	224.0	2	15.0	8.9	11.2	60.0	4.0	-	-	-	-	-
Horse (NR)	426.3	3	13.3	16.7	15.8	57.0	9.0	.45	1.40	6.20	4.31	1.63
Sheep (R)	82.0	3	79.5[3]	8.4	7.5	2.7	1.8	7.09[4]	.53	3.96	2.20	1.87
Deer (R)	-	1	80.4	2.0	5.4	3.4	2.7	3.55	.88	2.93	2.32	1.66
Cow (R)	273.0	2	83.3	9.6	3.1	2.1	1.9	4.82	1.07	3.38	2.74	1.51

[1] Data from Elsden et al. (1946) for all but donkey (Wolter and Velandia 1970).

[2] NR, nonruminant; R, ruminant.

[3] Ingesta of ruminants is rumen, recticulum, abomasum and omasum.

[4] VFA concentrations for rumen and reticulum only.

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Table 24. Amount of Biomass (T/ha) of particular percentage C.W. in different habitats.

	Total Biomass T/ha	Biomass (T/ha)									
		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	% C.W.
San Joaquin[1] Annual Grassland 11-25-74	.53		.04	.01		.48					
Bridger[1] Mt. Grassland 6-12-72	1.71			.02	.10	.22	.08	.71	.56		
Bridger[1] Mt. Grassland 8-22-72	3.19				.06	.52	.12	2.43	.02		
San Joaquin[1] Annual Grassland 4-25-74	4.59				.51	.12		3.96			

[1] Data courtesy of US/IBP Grasslands Biome studies, Fort Collines, Colorado.

for regression against body weight, as gut-contents weight in ruminants and nonruminants fit the same regression line.

The horse, similar in weight, metabolic requirement, and fermentation-site size, shows differences in its ability to digest the fibrous fraction of forages. Similarity in the above parameters affecting digestive capacity implicates the different retention mechanism of the rumen and caecum in producing differences between horses and cows in digestive efficiencies of the cell wall of forages.

Mechanisms of retention in the cecum and rumen. -- Uden (1978) did comparative work on the digestive capacities of ruminants and nonruminants. He found that fecal particle size was larger in nonruminants than ruminants. Although this phenomenon is often attributed to the longer retention times of ruminants (see below) there are a series of differences in the two digestive systems which produce different particle size.

A critical element of the rumen's function is the selective delay of ingesta. The selective delay occurs by lowering the probability that forage recently ingested will escape the rumen. If a volume is filled with a liquid, in which perfect mixing occurs, there is a certain probability that some intake will be simultaneously lost. Once a particle enters the volume its probability of escape does not change with time. The rumen has a mechanism to link the probability of escape with residence time of a particle. Smith (1968) has demonstrated how particle-size breakdown occurs microbially in the rumen and that particle size is related to passage rate (Fig. 10). Since forage enters the rumen as large particles and is progressively reduced to small size, the rumen efficiency is produced by linking the probability of passage to residence time via particle size.

Although somewhat elective, the caecum behaves more like a perfect volume than the rumen (Uden 1978) and particles of different sizes appear in the colon at similar rates (Argenzio et al. 1974). These results would suggest higher rates of escape for undigested particles, and coupled with differences in transit times, should produce lower digestibilities of the cell-wall fraction of forages in nonruminants.

Body size. -- A number of anatomical and physicological factors are related to body size but because they often change with weight at different rates individuals of different sizes are required to be different types of animals. Both metabolic rate and gut capacity change differentially relative to weight. The significiance of this ratio was originally suggested by Short (1963) and has been discussed by Prins and Geelen (1971), Janis (1976), and further developed by Parra (1978). To formulate this relationship more precisely a model is presented.

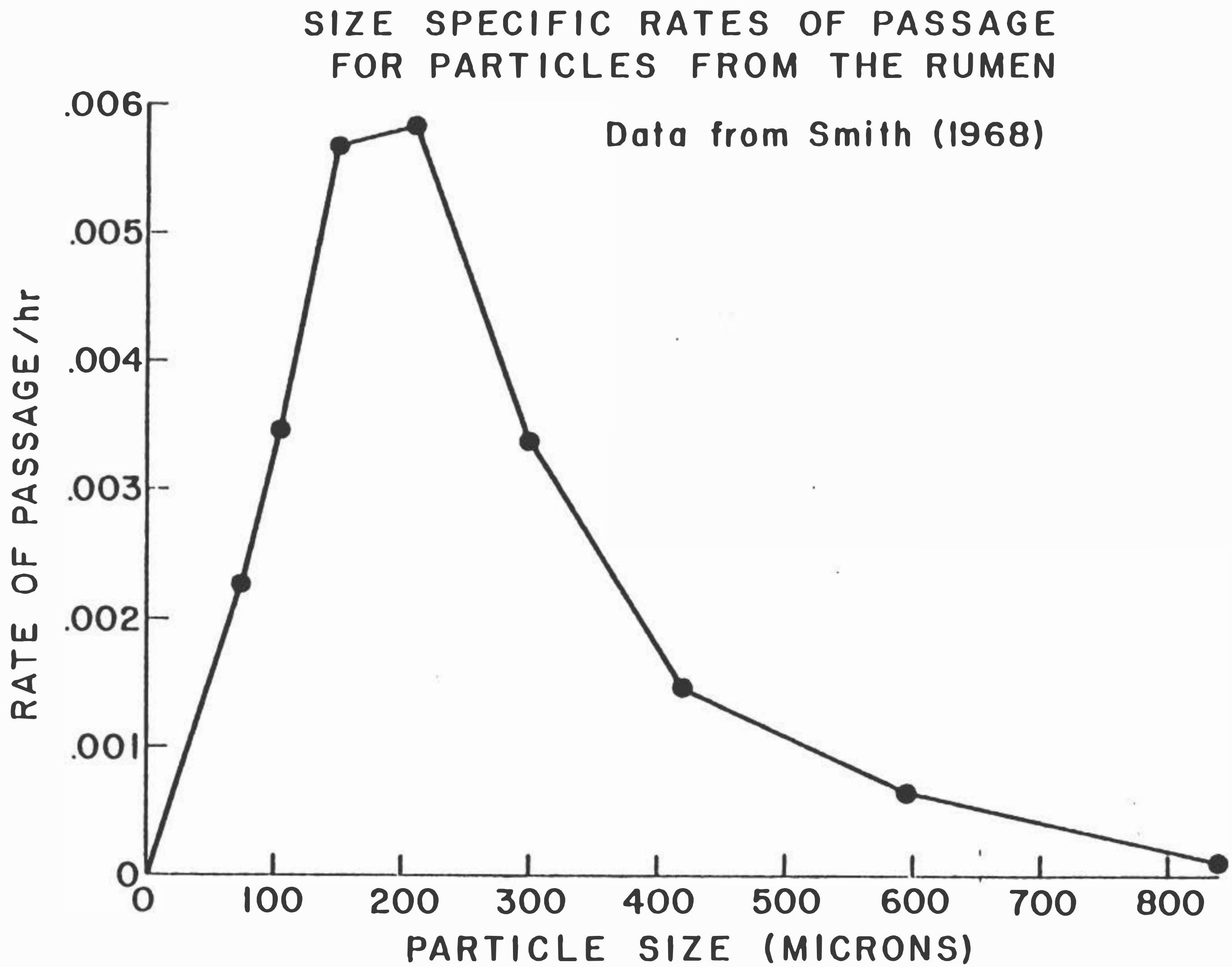

Figure 10. A plot of size-specific passage rates of particle from the rumen of sheep (data from Smith 1968). The plot shows that large particles have a low probability of passage, and with decreasing size likelihood of passage increases until very small-sized particles again have low probability.

Because basal metabolic rate (Kcal/kg/time) decreases nonlinearly with body weight, the total metabolic requirements of mammalian herbivores, M_R (Kcal/day), increases as

$$M_R = 70\ W^{.75} \qquad \text{(Kleiber 1975) (1)}$$

where W = weight in kg. The use of the exponent .75 is applicable for interspecific comparison across a wide range of body sizes. Differences in this exponent between species (Thonney et al. 1976) may slightly modify specific comparisons I may make, but will not alter the general conclusions. Because M_R increases with weight, albeit at a decreasing rate, large animals always require more total energy but small animals require more energy relative to their body weight.

The capacity of the gut determines, in part, the capacity for digestion in the herbivore. Parra (1978) plotted the wet weight of gut contents of herbivores, both ruminants and nonruminants, against weights (Fig. 11). Demment (submitted) argues that the bias of the measure of capacity by digesta weight is systematically related to body size. He suggests that the exponent should be 1.00 instead of the 1.09 of Parra's regression. Importantly ruminants and nonruminants show the same gut size relative to weight (Parra 1978).

If the rate of metabolism determines the nutritional requirement, and the gut size the capacity to process food into nutrients, then the nonlinear response of metabolism coupled with the approximately linear response of gut size produces higher ratios of metabolism to processing capacity in small animals relative to large.

If the gut is considered a volume into which mass flows, but behaves like liquid, the problem can be examined using single-pool kinetics (Shipley and Clark1972). The time a particle spends in the volume, its retention time, T, can be expressed as:

$$T = \frac{V}{I} \qquad (2)$$

where V is the capacity of the gut (mass) and I is the intake (mass/time). The dry-weight volume of the gut has been approximated as 10% of the wet-weight contents and Parra's fitted equation (Fig. 21) has been corrected accordingly:

$$V = .00936\ W^{1.0768} \qquad (3)$$

where W is the body weight in kg and V is the GIT capacity in kg dry matter. Kleiber's equation for basal metabolism can be converted to a dry-matter (kg) requirement using 4409 Kcal/kg (N.R.C. 1973). The intake of dry matter (kg/dry) required to balance basal metabolism at a constant digestability is:

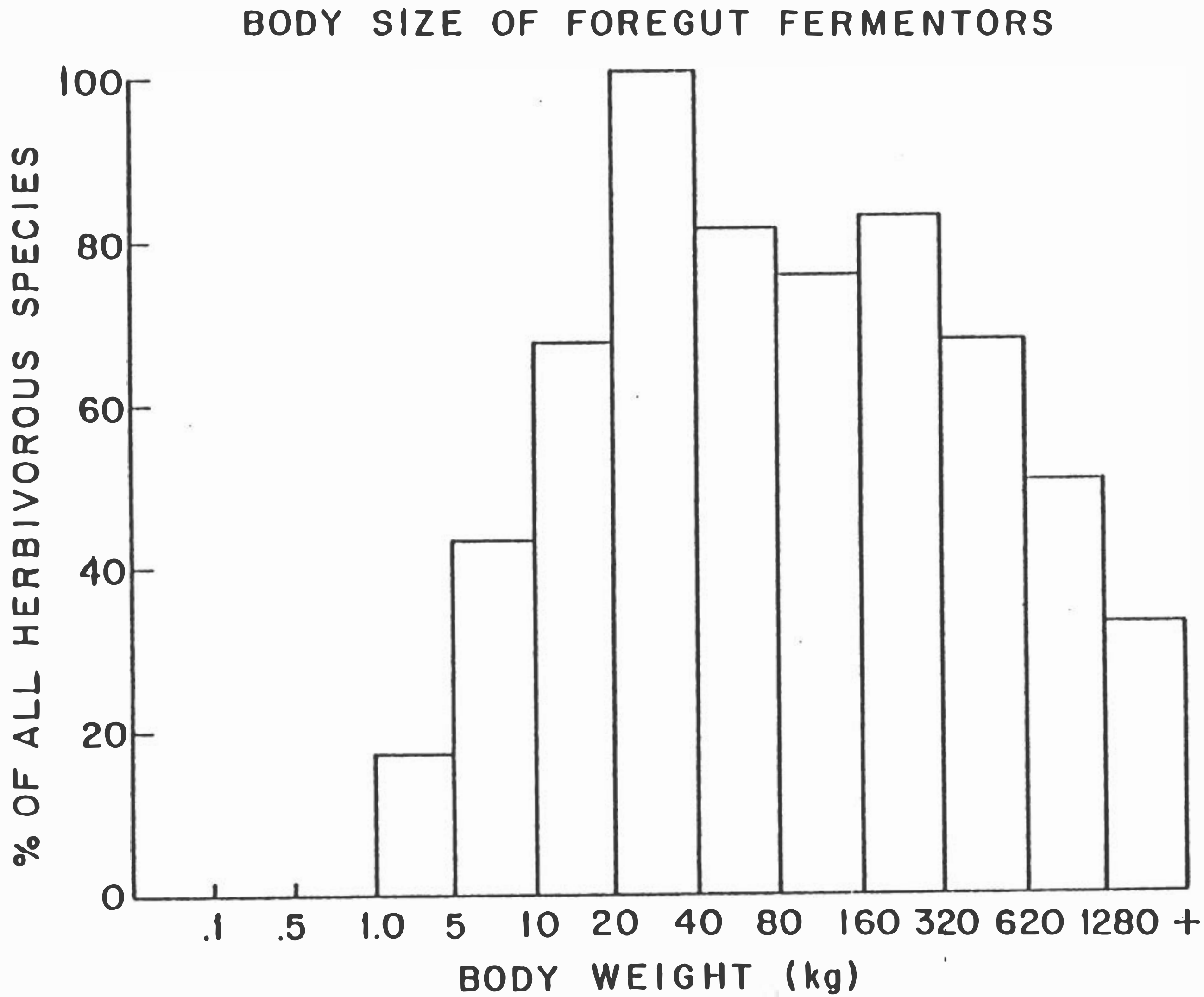

Figure 11. The percentage of all East African herbivorous species (N = 187), which are foregut fermentors is plotted against body weight. The small and very large species are hindgut fermentors. The ruminants (a subset of the foregut fermentors) dominate the middle body sizes. There are no ruminants in the 1280 + kg category. Only the hippopotamus, which is a foregut fermentor, does not ruminate.

$$I = \frac{.0159\ W^{.75}}{D} \qquad (4)$$

where D is the percentage dry matter removed from the intake and not present in the feces.

Substituting equations (3) and (4) into (2) yields:

$$T = .589\ D\ W^{.3268} \qquad (5)$$

The rate of passage, Kp (a rate constant), is the reciprocal of the retention time:

$$Kp = \frac{W^{-.327}}{.589D}$$

Equation 6 states that rates of passage in small animals must be higher than in large animals to meet basal metabolic requirements on the same quality foods.

This relationship suggests that small animals are constrained by rapid passage. To compensate they eat rapidly digesting foods (i.e. large cell-content fractions). Only in the middle body sizes (5-800 kg) is the MR/gut size ratio sufficiently low to allow selective delay of forages. In these body-size ranges, ruminants are dominant in grassland ecosystems (Fig12). Since total metabolic requirement increases with body size, larger animals require more total food than smaller animals. The general relationship of abundance and forage quality is presented in Table 24. These data suggest that high-quality forage is rare and low-quality forage abundant. Therefore as body size increases, diet quality must decrease (Demment 1978). Demment and Van Soest (in prep) argue that the upper limit on ruminant size is set by the rate at which low-quality diets can be reduced in particle size for passage. It is the very mechanism that allows increased efficiency of fiber digestion that limits the range of diets the ruminant can utilize efficiently. Therefore very large herbivores are nonruminants which eat a lower-quality diet than ruminants.

The dominance of the perissodactyls during the Eocene and the subsequent reduction in number coincidental with the rise of the ruminants in the Oligocene (Janis 1976), coupled with the present patterns of body-size distributions of the two groups, strongly argues that competition from the ruminants has been of major importance in shaping equid feeding ecology. The more efficient ruminant system for the digestion of plant cell walls may have displaced the equids as the grasslands of the world became predominant. As argued above, the nonruminant system, designed for passage and not delay, functions effectively in the small and very large body sizes. The evolutionary response of the horse has been to increase its body size through evolutionary time (Simpson 1950), quite possibly in order to

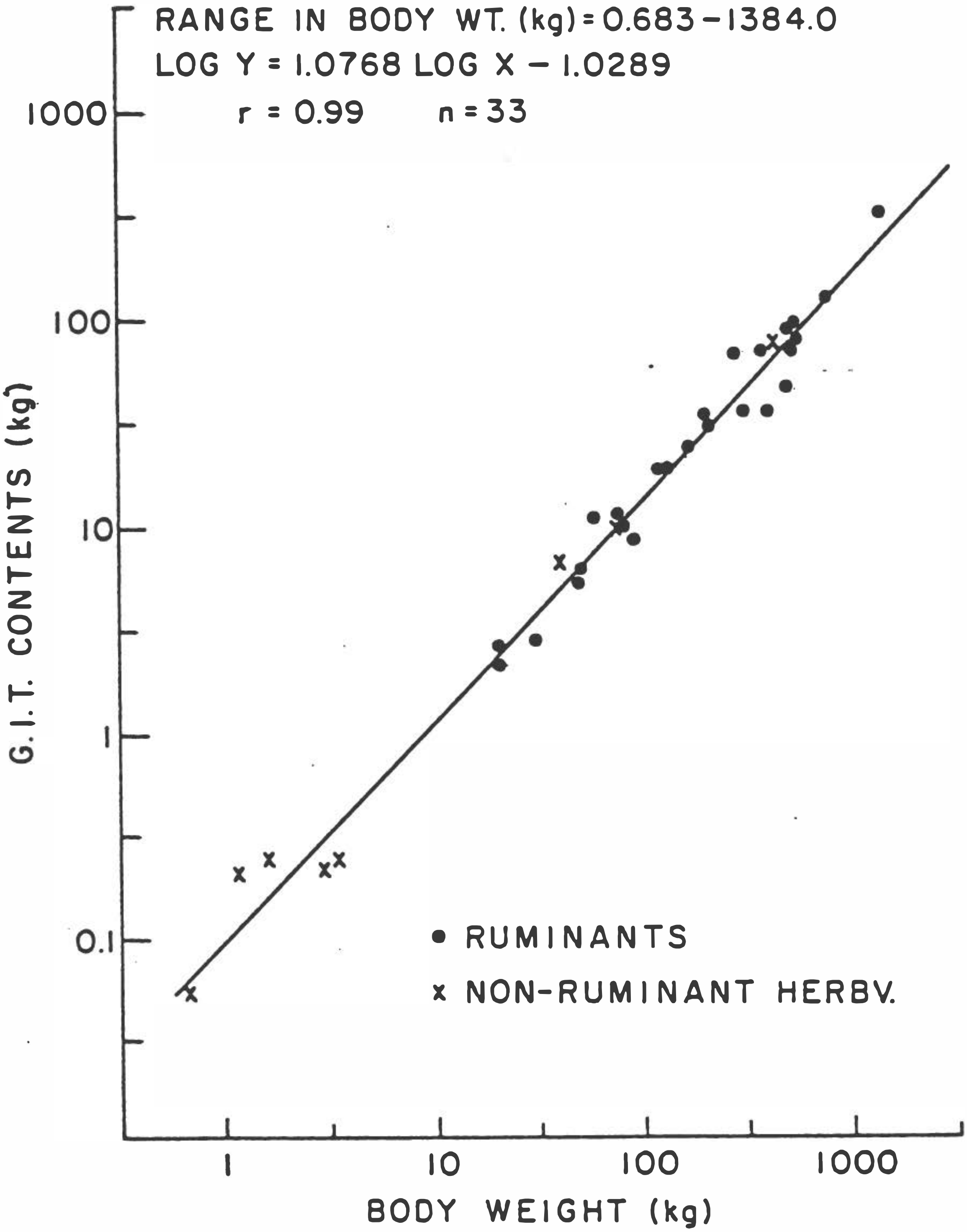

Figure 12. (From Parra 1978). Linear log-log plot of gut-contents wet weight on body-weight yield. The exponent is very close to 1.00, indicating an isometric increase in gut size with body weights. There is no significant difference between ruminants and nonruminants in this relationship.

have a body size sufficiently large to eat a diet of coarser quality than the ruminants (Bell 1969).

Digestive Capacity of Equids

Crude-fiber digestion. -- The fibrous fraction has been shown to be the most important forage parameter for predicting digestion coefficients for horses (Olsson 1949, Hintz 1969, Fonnesbeck 1969, Vander Noot and Trout 1971). High correlations with crude-fiber values have consistently been found (e.g. Olsson 1949). But Fonnesbeck (1969), evaluating several assays, found Van Soest's methods (1964) of detergent analysis to be the best predictor of digestibility in forages for horses (the inadequacy of crude fiber as a forage measure was discussed under "plant material" above).

Olsson (1949) conducted the most extensive review of the literature on digestion trials of horses. He determined the following relationship between the digestion coefficient of organic matter (y) and crude fiber as percent of dry matter (x):

$$y = 99.71 - 3.066x + .0679x^2 - .00056x^3, n = 1094.$$

A depression of digestion coefficients with the increase in the fibrous fraction of forages is hardly unexpected nor confined to equids (Baumgardt 1970). However substantial evidence exists to indicate that ruminants show declines in digestion coefficients that are not as rapid as equids with increasing cell wall. Higher digestibilities for cattle than horses have been widely recorded (Axelsson 1949, Hintz 1969, Barsaul and Talapatra 1970, Vander Noot and Gilbreath 1970, Geyer 1974). Several studies have measured the digestibility of chemical components of the forage and found that while equids can digest NFE and often protein as well as ruminants, they consistently show lower digestibilities for the fibrous fraction (Axelsson 1949, Barsaul and Talapatra 1970, Vander Noot and Gilbreath 1970). Hintz et al. (1973) found that, while ponies and sheep had similar dry-matter digestibilities, ponies were lower in the digestion of cell wall than the sheep and New World camels. Since the ponies were four times heavier than the sheep, the difference is likely due to body size. Camels and ponies were identical in weight.

In the most extensive controlled comparison of horses with cattle (also sheep and swine), Axelsson (1949) calculated regression equations of digestibility against crude fiber for each species ($N > 100$ for each species). His equations are as follows:

horses	$y = 88.2 - 1.25x$
ruminants	$y = 87.8 - .83x$
swine	$y = 93.7 - 1.60x$

where y is digestibility of organic matter and x is crude fiber as a percentage of dry matter. The regressions for horses and ruminants are plotted with Olsson's (1949) regression equation in Fig. 13 . Since the real data are not given in either paper, nor plotted as points, it is difficult to determine if the differences in the horse curves are due to regre sion techniques. Intuitively one would expect the differences between horse and ruminants to remain at least constant (Hintz's (1969) evaluation supports this notion) with increasing fiber content. However this relationship is clearly one requiring further investigation. I have added an addendum which addresses this problem.

Horses show shorter retention times than do cattle (Tables 25 and 26). If the caecal design allows the escape of incompletely digested particles, this inefficiency when compared with the rumen should require higher intake rates and faster passage rates (all other factors being the same). The data from Argenzio et al. (1974) emphasizes the retention capabilities of the equid lower tract. The absence of sufficient particulate marker in the fecal collections negates the ability to calculate particulate retention times for these data. Linerode (1966, ref. in Robinson and Slade 1974) suggests that passage through the upper digestive tract may be three times faster in horses than ruminants.

The passage rate does not appear to be affected by diet composition (Vander Noot et al. 1967) although sample size is small in this experiment. High individual variability is often the case with digestion trials and passage measurements (Uden 1978) and determination of treatment differences would necessarily require large sample sizes. The physical form of foods (pelleted, ground, chopped, or loose) showed no effect in work by Wolter et al. (1976) while the same workers (1974) found that hay (normal ground, pelleted) took 37, 26 and 31 hours respectively to transit the gut. Haenlein et al. (1966) measured more rapid passage with pelleted and wafered hay than loose hay.

Fistulation of horses appears to lengthen retention times and increase digestibility (Pulse et al. 1973). While the importance of caecal retention times are citical to the determination of fiber digestion in the horse, the effect of fistulas and cannulas, necessary for these determinations, must be carefully measured in each experiment.

Hindgut fermentation. -- The sequence of digestive enzymes to which a forage is exposed as it transits the gut is different in the cow and horse and has the potential to supply different quantities of nutrients to the herbivore. Initially forages are exposed to gastric enzymes in the horse and microbial fermentation in the cow. The digestion of the soluble carbohydrates and protein is almost complete in the horse (Fonnesbeck 1968, Roberts 1975a,b). Although some cell contents may escape to the lower tract when diets consist of large quantities of concentrates on a wide range of forage/concentrate ratios, these nutrients are directly digested

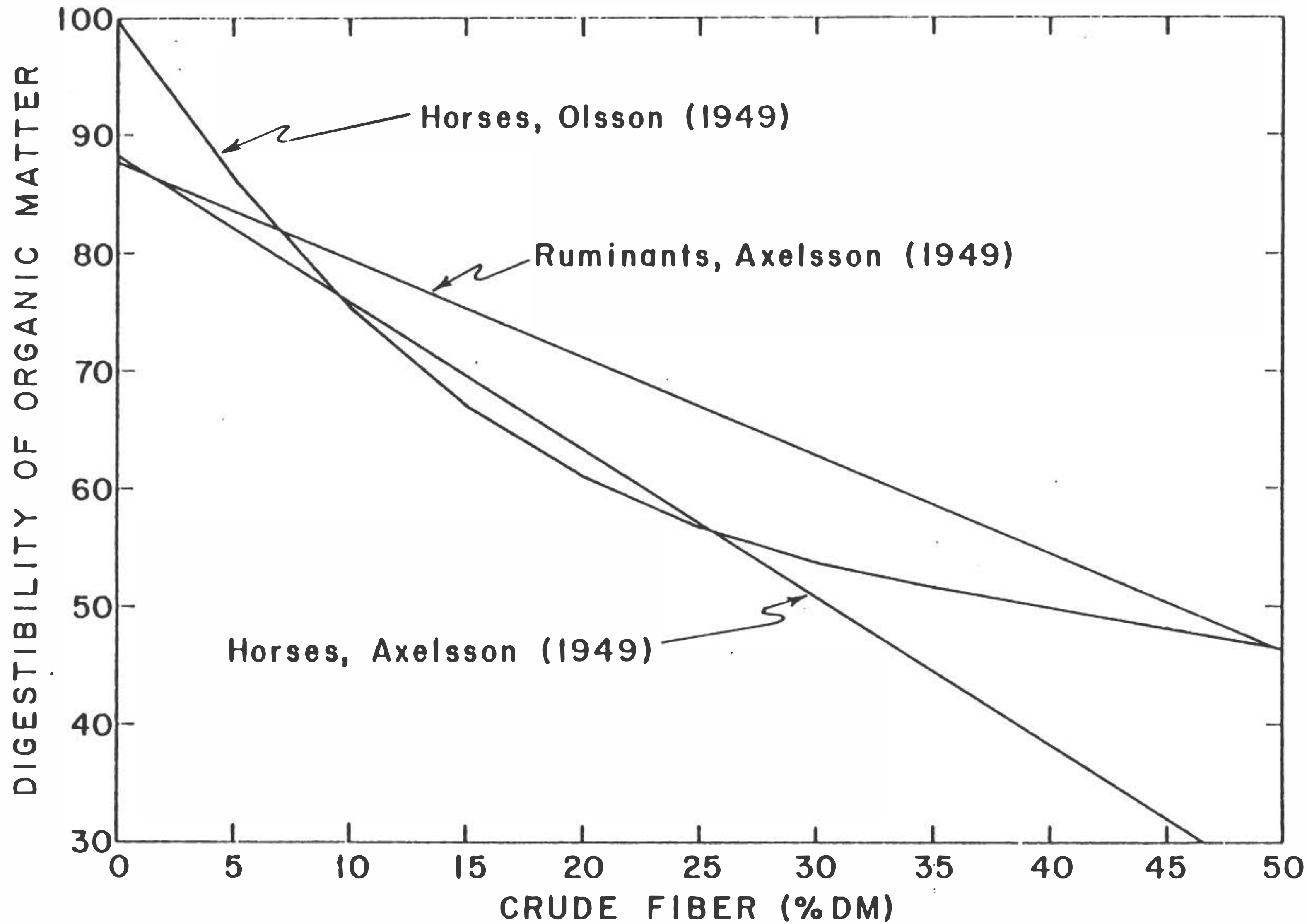

Figure 13. Digestibility of organic matter (OM) plotted against crude fiber (%DM) according to regressions from the literature (Axelsson 1949; Olsson 1949). Note the correspondence between Axelsson's regressions and those plotted from the NRC tables (Fig.). No evidence is found of the curvilinear relationship suggested by Olsson 1949.

Table 25. Equine Particle and Liquid Mean Retention Time Calulated According to Castle (1956) in Horses and Ponies (hrs.).

Author	B.W. (kg)	Diet	Intake (g/kg BW) DM	Intake (g/kg BW) CW	Mean Retention Time GIT	Mean Retention Time GIT+ TT	Mean Retention Time Caecum	Mean Retention Time Ventral Colon	Mean Retention Time Dorsal Colon	Mean Retention Time Caecum+ Colon	Markers
Vander Noot *et al.* (1967)	440	Grain + alfalfa	10	?	26	38					Cr_2O_3 (liquid)
Wolter *et al.* (1974)	170	Grasshay: Long	26	ca.16	25	37					Stained particles
		Ground	"	"	13	25					
		Pelleted	"	"	19	31					
Wolter *et al.* (1976)	200	Conc.: Ground	20	ca.10	16	28					Stained particles
		Pelleted	"	"	18	30					
		Extruded	"	"	17	29					
Argenzio *et al.* (1974)	160	Hay + grain; pelleted	7.5				4	31	38	70	CrEDTA (liquid)

Table 26. Particulate and Liquid Marker Retention Time in GIT (GIT + TT) Rumen-reticulum (R-R), Lower Tract (LT), Abomasum (ABO) and Omasum (OMA) and Their Transit Time (TT) in Cattle (Hrs.).

Author	Diet	Treatment or Physical Form	Mean Body Weight (kg)	Average Intake (gDM/kgBW)	Mean Retention Time: GIT + TT	R-R + LT	R-R	LT	ABO	OMA	TT	Marker
Schellenberger and Kesler (1961)	hay, corn		510	32	52	35					14-20	stain part
	silage and		510	25	63	46					14-20	
	concentr.											
Campling and Freer (1966)	hay	long	544	9	66	38					28	
	"	ground	"	9	50	30					22	
	"	long	"	20	53	29					24	
	"	ground	"	20	50	32					18	
	oat straw	long	"	9	83	43					40	
	"	ground	"	9	67	35					32	
	"	ground+urea	"	9	51	27					24	
	"	long	"	10	75	39					36	
	"	ground	"	13	73	45					28	
	"	ground+urea	"	20	61	39					22	
Warren _et al_. (1974)	alfalfa hay	chopped	397	26	41							^{140}Ce
	orchard gr. hay		"	23	38							
	fescue hay		"	21	40							
	all (mean)	118°C	"	24	37							
	all (mean)	132°C	"	24	43							
Waldo _et al_.	hay	long	408	13		39						stain part
	"	pelleted	"	13		57						
	hay+grain		"	11		57						
	silage	chopped	"	16		29						
Mäkelä (1956)	hay	long	495	8			66	6	2	12		lignin
	"	long	204	19			53	4	1	5		
Bauman _et al_. (1971)	hay/grain:											
	(60/40)		575	27			5					PEG
	(10/90)		"	30			11					
Topps _et al_. (1968)	concentrate		130	18			18					
	hay	cubed	130	23			7					

in the foregut (Hintz et al. 1971). In the rumen the soluble fraction is rapidly fermented and in a sense, this energy is needlessly run through another trophic level where the cost of fermentation (i.e. microbial respiration and methane production) must be subtracted. Therefore, when considering the soluble fraction, the difference between DE and ME (metabolizable energy) is much greater in the cow than in the horse. This point will be considered more quantitatively under the intake section below.

The fibrous fraction has been largely digested when it escapes the rumen; some fermentation does occur in the lower tract of ruminants. The foregut placement of the rumen greatly enhances the ability of the ruminants to digest and absorb the microbial bodies (discussed above with reference to protein). When the digesta leaves the stomach of the horse it is composed largely of cell wall which is fermented in the hundgut. The relative importance of fermentation in the colon increases as the concentrate in the diet decreases (Hintz et al. 1971). Therefore under field conditions, as the forage matures, there will be a shift decreasing the amount of energy being absorbed as glucose in the small intestine (because the soluble fraction is decreasing) and increasing the energy derived from VFA in the hindgut. Since the metabolizable energy available from glucose is greater than that from VFA production, for the reason stated above, the maturing of forage causes a decrease in ME not apparent in DE values for the horse. This shift does not occur for cattle since the proportion of a feed fermented will change little with forages.

What are the possible effects of the pretreatment of forage in the stomach on the efficiency of hindgut fermentation in the horse?

(1) The digestion of carbohydrates, protein and fat precaecally decreases products required for methane production in the lower tract of nonruminants (Maynard et al. 1979, p. 199). In a comparison of species' values from the literature, Calloway et al. (1968) found relatively lower values of methane concentrations in the hindguts of nonruminants (horses, rats, and humans) than ruminants. Hungate (1966, p. 272) states that methane production correlates inversely with proprionate production. Proprionate production usually increases with the quantity of starch in the diet (Stevens et al. manuscript). Similarly Moe and Tyrrell (1979) have shown that methane production in the rumen of cows is affected more by digestiable cellulose and hemicellulose than by soluble nutrients.

(2) Structural carbohydrates ferment more rapidly when pretreated with gastric digestion. Although suggested by a number of researchers (Van Soest pers. comm.; Uden 1978), to my knowledge no work has addressed this problem.

(3) The absence of soluble carbohydrates slows digestion of the fiber fraction. Although Kern et al. (1973) have shown that the addition of oats to forage increases the numbers of bacteria in the caecum (presumably by increasing the amount of soluble carbohydrate reaching the lower tract), it did not increase the numbers of cellulolytic bacteria nor increase cellulose digestion.

Substantial evidences exists to support the contention that fermentation processes and VFA absorption in the hindgut are similar to the rumen (Stevens et al. manuscript, Argenzio et al. 1974, 1977). However the efficiency of the microbial populations may differ. Alexander (1963) suggested that, because cotton thread digested more rapidly in the caecum of the pony than the rumen of the cow, cellulolytic organisms in the pony were more efficient than their counterparts in the cow. However Koller et al. (1978) commented that cotton thread bears little resemblance to the cell wall of forage plants. To examine the comparative digestive capabilities of cellulolytic microbes in the pony and cow, Koller et al. (1978) compared forage digestibilities using <u>in vitro</u> and nylon bag techniques. Their results show that ruminal bacterial digest the dry-matter and cell-wall fractions more efficiently than do caecal bacteria when exposure times are constant. They caution that their experimental procedure does not resemble the treatment of forages in the complete animal digestive system, citing keys et al. (1969, 1970) who found indications that hemicellulose digestion in the hindgut may be enhanced by intestinal action on fiber.

Evidence exists of differences in passage rates, forage quality reaching the fermentation site and efficiency of digestion within the site (albeit often contradictory). To develop a meaningful understanding of the capabilities of the horse as a herbivore will require a better understanding of the dynamic aspects of fermentation in the lower gut of equids.

<u>Intake</u>. -- No single topic has received as much research attention and yielded such equivocal results as intake. Intake and its determinants have been principally studies with ruminants since intake is an important factor affecting production (Reid 1961). This research has been particularly interested in the responses of intake to dietary quality. A number of herbivorous species are capable of increasing intake in response to diets of decreasing caloric density (rats, Peterson and Baumgardt 1971a, b; chickens, Hill and Dansky 1954; pigs, Owen and Ridgmen 1968, sheep, Dinius and Baumgardt 1970, Weston 1966, lambs, Owen et al. 1967; cattle, Montgomery and Baumgardt 1965). But the intake response to compensate for lower caloric densities is limited. Beyond a critical point, intake decreases in response to lower-quality diets (rats, Peterson and Baumgardt 1971a, b; pigs, Owen and Ridgman; sheep, Dinius and Baumgardt 1970, Weston 1966, cattle, Montgomery and Baumgardt 1965). The initial response to decreasing caloric density has been considered a physiological response to balance energy requirements while the depression of intake beyond the

critical point is interpretated as the limits of gastro-intestinal or rumen capacity (Baumgardt 1970, Baile and Forbes 1974). The point where intake compensation ceases appears to be sensitive, independently, to the energy requirements of the animal and its body size (Peterson and Baumgardt 1971b, Owen and Ridgmen 1968). The observation that digesta present in the gut and the rumen is a relatively constant maximal value, regardless of forage, has led to the concept of fill models in ruminant studies (Blaxter et al. 1961, Compling et al. 1961).

Rumen fill modeling has become quite sophisticated in these 20 years (c.f. Ellis 1978). However the achievement of the unified predictive model of intake is still elusive. From the simple concept that the rumen volume limits M intake (Adolph 1947), these models have developed into formulations of the dynamics of rumen fill. All the processes likely to play a role in influencing fill have been implicated as determinants of intake (digestibility, Crampton 1957; passage rate, Compling et al. 1962; particle break-down, Weston 1966; rate of disappearance of particles in the rumen, Blaxter et al. 1956; rumen volume, Compling and Balch 1961, Egan 1972; volumetric qualities of the forage, Van Soest 1966). What is quite clear from this literature is that intake is a response to a complex set of variables and that the importance of a particular parameter in determing intake varies depending on the conditions of the animal, the experiment and the forage (Baumgardt 1970).

No comparable models nor similar research has been conducted on equids, to my knowledge. The traditional argument has been that nonruminants can respond to a greater degree than ruminants by increasing intake on low-quality diets (Bell 1969, Janis 1976). The ruminant appears to be limited in the rate at which cell wall can be broken down to relieve rumen fill. Welch and Smith (1969, 1970) have found strong correlations (r = .99, .94) between cell-wall intake and rumination time. Cell-wall measures have always shown strong correlations with intake (Mertens 1973), but recent work has shown that cell-wall content and intake is only weakly correlated with bulk volume (P. Vander Aar, unpublished data). These facts suggest that the cell wall of low-quality forages may limit the intake of ruminants by restricting particle-size reduction via rumination (Demment and Van Soest, manuscript).

Nonruminants cannot compensate with intake for low-energy diets in an unrestricted response. In fact data on the rat (Peterson and Baumgardt 1971b) show a critical point in diet dilution beyond which compensation does not maintain constant energy intake. The response curve looks similar to those measured for ruminants (Baumgardt 1970). However the complication of body size and physiological state make it difficult to compare the points at which compensation response terminates with those of ruminants.

The addendum to this review shows the relationship between TDN of forages for cattle and horses and their crude-fiber values (taken from the NRC requirements for the two species). While the trends in nutrient availability are clear, they are fairly useless in determining energy levels available to an animal on the range. It is critical to any prediction of intake or possible reproductive capacity to know the degree to which a species can respond to low-quality forages by increasing its intake. In the rat, lactating females showed higher intakes on all diets than males even beyond the critical point. This result shows that physiological states can influence performance for animals of approximately similar gut sizes (Peterson and Baumgardt 1971b). This point is especially pertinent when the assumed adaptation of nonruminants is the capability of large increases in intake to compensate for decreasing nutrient density in its foods. Since, as discussed earlier, digestibility is determiend by retention time, which itself is a function of intake, calculations of intake directly from digestibility values are crude. A focus of future horse research should involve the intake-forage-quality problem.

Energy Requirements and Intake Calculations

In only one study among the recent work on the energy requirements of horses have measures been made independent of energy intake. The one exception is Wooden et al. (1971) where heat production was calculated, but discarded due to disagreement with Kleiber's (1975) formulation. Results from the NRC (1973), Stillion and Nelson (1972), and Wolfram et al. 1977 are all based on DE values which are not indicators of ME since equations for this conversion are not available in the literature. Wooden et al. (1970) used the ME values for cattle which are most likely very crude approximations. Although .75 exponent of body weight is widely cited, it is not documented for horses. Thonney et al. (1976) has shown that metabolism is often a function of exponents significantly different from 175 power of body weight within a species.

These comments aside, the NRC (1973) recommendation for maintenance is

$$DE\ (kcal/day) = 155\ W^{.75}$$

where W is weight in kg. This value is considerably higher than Knox et al. (1970) have suggested (114 kcal DE/$W_{kg}^{.75}$/day), or Hoffman et al. (1967) adovcated (112-128 kcal DE/$W_{kg}^{.75}$/day). On the other hand, Wolfram et al. (1977) measured values of 176 kcal DE/$W_{kg}^{.75}$/day, substantially greater than the NRC requirement. These differences, however discomforting, are likely to be of minor importance in the face of estimating the energy requirements of exercise from qualitative data (e.g. Hintz et al. 1971).

Maintenance metabolism for mature bulls (calculated by regression of NRC data, 1976 is DE (kcal/day) = 194.7 $W^{.75}$. In a comparison of 500 kg animals, a horse would require 16.4 (Mcal/day) and cattle 20.6 (Mcal/day) at maintenance. The 4.2 (Mcal/day) or 20.4% difference in DE is presumably fermentation losses. For cattle

ME as a percentage of DE varies linerarly from 80% at 50% digestibility, to 88% at 80% digestibility by the equation:

$$\text{ME (Mcal/kg DM)} = -.45 + 1.01\ \text{DE (Mcal/kg DM)}$$
(Moe and Tyrrell, 1976)

It is useful to combine this information with data on forages to be able to predict intake for a particular animal on a given forage quality. To do this I have plotted a linear regression of TDN (%DM) against crude fiber (%DM) from data in the NRC (1973, 1976) requirements for horses and cattle (see addendum and Fig. 14). These equations have the form:

$$T_{DN} = f - dC_f$$

where T_{DN} is TDN (%DM), f is 90.0 for cattle, 91.0 for horses, d is 1.023 for cattle, 1.27 for horses and C_f is crude fiber (%DM). Since $D_E = K\ T_{DN}$ (NRC 1979) where D_E is DE (Mcal/kg DM), K is 4.409 and ME can be expressed by equation of Moe and Tyrrell (1976) for cattle and for horses (ME = DE), and $M_t = aw^{.75}$ where M_t is total ME requirement (Mcal/day/animal), then maintenance intake for animals of different weights can be derived by substitution:

$$I = \frac{M_t}{ME}$$

where I is intake (kg DM/day/animal). By substitution,

$$I - \frac{aw^{.75}}{b + (c\ K\ (f - d\ C_f))} \qquad \text{(Cattle)}$$

where b is -.45 and c is 1.01 (i.e., constants from the Moe and Tyrrell equation), and

$$I = \frac{aw^{.75}}{K\ (f - d\ C_f)} . 100 \qquad \text{(Horses)}$$

The values of intake calculated from these equations are presented in Fig.15 for horses and cattle of different weights. Intake for horses is consistently lower than for cattle on diets of low crude fiber. As this fiber fraction increases, horses approach cattle intake levels and then exceed them above ~40% crude fiber. This pattern reflects the loss of DE to fermentation in the cow dominating the lower overall DE values for horses. As the fiber fraction increases the depression in digestibility in the horse eventaully exceeds the fermentation losses in cattle.

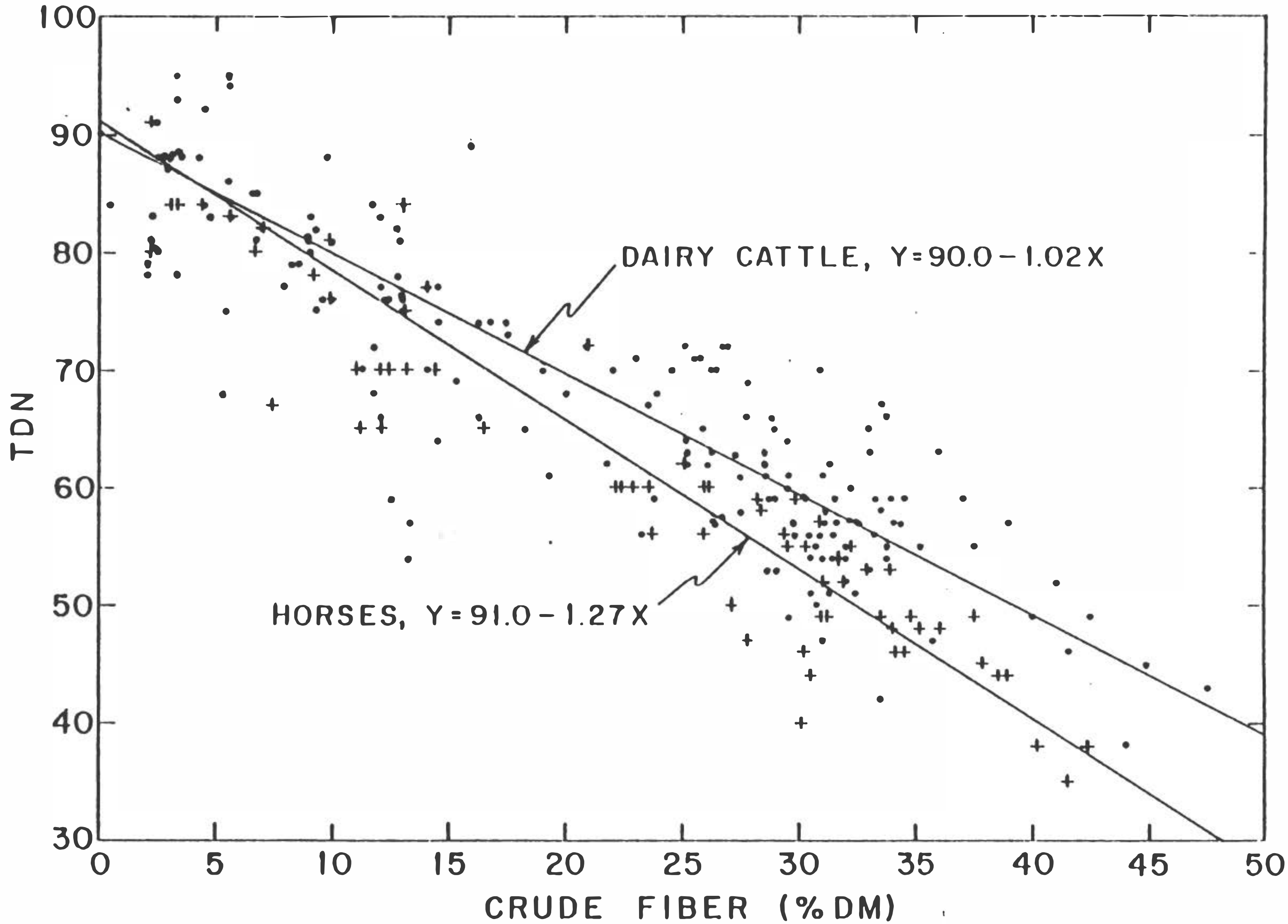

Figure 14. Data from the NRC (1973, 1976) for TDN of plant foods for cattle and horses regressed against crude fiber. These data sets suggest a linear relationship for both species. Horses show progressively lower TDN with increasing fiber content than cattle.

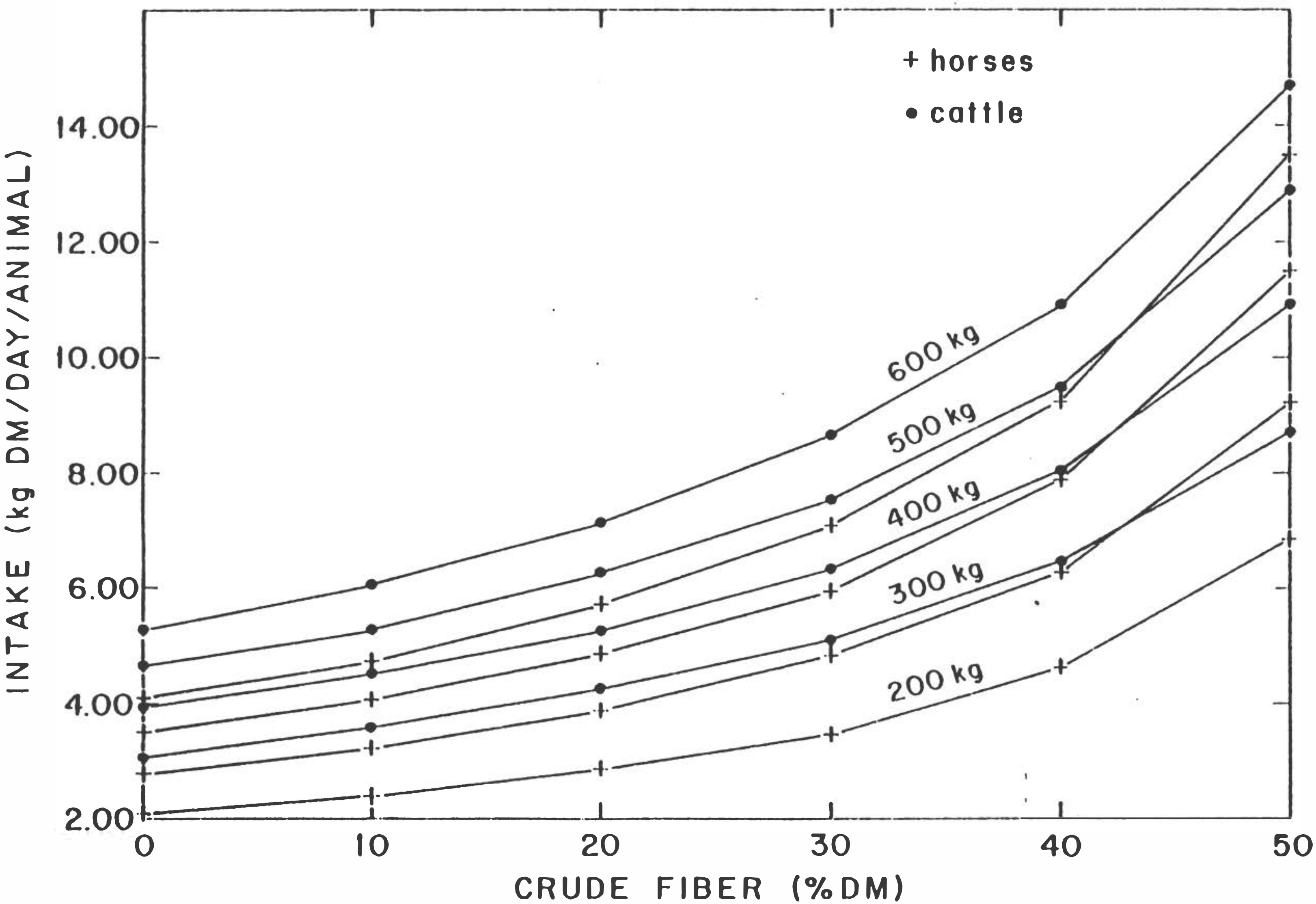

Figure 15. Predictions of intake for cattle and horses plotted as a function of crude fiber. Intake values are generated from equations in the text.

Since no estimate of fermentation losses in the horse have been made by the NRC (1978) (i.e. ME = DE), the equation for horse should be used, along with these comparisons, with caution. It would seem highly unlikely that caecal microbes do not respire or produce some nonmetabolizable byproducts.

Addendum

I was unable to complete this analysis in time to include the results in the appropriate position within the text (under Digestive Capacity of Equids). These data are values from the NRC (1973, 1976) for TDN (% DM) as a function of crude fiber (% DM). These regressions show a linear response, very similar (especially for the horse) to those measured by Axelsson (1949). There is no indication of the curvilinear response reported by Olsson (1949). These data show that the TDN in forages decreases more rapidly for horses than cattle. The equations presented here are incorporated with others relating TDN, DE and ME to predict intake of the two species (see Energy requirements and intake calculations).

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Appendix B

A Selected Annotated Bibliography on Grazing Hydrology

by

Gerald F. Gifford and Everett Springer
Watershed Science Unit, College of Natural Resources,
Utah State University, Logan

1. Adams, S. N. 1975. Sheep and cattle grazing in forests: a review. J. Appl. Ecol. 12:143-152.

Damage to trees by grazing animals and prevention of damage by fencing or use of unpalatable species; effects of grazing on forest soils, including compaction and loss of nutrients; grazing as a tool in forest management, and management practices favoring forest grazing, including fertilizer usage and stocking rates, are discussed.

2. Alderfer, R. B. and R. R. Robinson. 1947. Runoff from pastures in relation to grazing intensity and soil compaction. J. Amer. Soc. Agron. 39:948-958.

A type F rainfall simulator was employed in this study. Runs were for 1 hour with 1.4 inches of water applied. Generally the greatest amount of runoff came from the heaviest grazed plots. Heavy grazing was associated with low soil cover, high bulk density, and low porosity. Compaction was confined to the 0-1 inch layer.

3. Aldon, E. F. 1964. Ground-cover changes in relation to run-off and erosion in west-central New Mexico. For. Serv. Res. Rpt. RM-34: 4 p.

In 1952 a cooperative study on three San Luis Experimental Watersheds in New Mexico was begun to determine the feasibility of restoring the more deteriorated portions of this region. Grazing management was started, but full control of the livestock through over winter use was not achieved until 1958. The periods 1952-58 and 1959-62 have been examined to determine the effect this different grazing years had on sediment, surface run off, and ground cover.

In three years average ground cover, measured by three key grass species, doubled from 3 to 5% up to 6 to 12%. Bare ground also decreased. Sediment production decreased between 0.2 and 0.7 acre-foot per year on the watersheds.

4. Allis, J. A. and A. R. Kuhlman. 1962. Runoff and sediment yield studies on rangeland watersheds. J. Soil and Water Conserv. 17:68-71.

Describes a study initiated in 1957 to establish effects of grazing on watershed values in the northern Great Plains. Results are inconclusive since no information on grazing was given.

5. Ames, C. R. 1977. Wildlife conflicts in riparian management: grazing. In Importance, Preservation and Management of Riparian Habitat--A Symposium. For. Serv. Gen. Tech. Rpt. RM-43: 49-51.

Grazing has a negative impact on riparian zones which constitute a small but important range resource. Protection of the riparian zone where fencing is an established use can only be effectively achieved through fencing.

6. Bailey, R. W. 1945. Determining trend of range-watershed conditions essential to success in management. J. For. 43:733-737.

Accurate determination of the condition and trend of the plant cover and soil mantle, site by site, is considered the key to satisfactory range-watershed management. Many unsatisfactory range-watershed situations are attributed largely to an inadequate understanding of condition and trend, including a tendency to rely upon single-factor indices rather than to consider all of the observable site factors. As a solution, the author advocates further research in ecology and soils, a fuller use of range condition and trend in surveys and inspections, and higher professional qualifications for range-watershed managers.

7. Barnes, F. F., C. J. Krabel, and R. S. LaMotle. 1939. Effect of accelerated erosion on silting in Morena Reservoir, San Diego, County, California. U.S.D.A. Tech. Bull. No. 639: 22 p.

The kinds and locations of sediment in Morena Reservoir are described, and it is shown that the reservoir had lost 10.5 percent of its useful storage capacity through sedimentation in the 25.7 years since its constructtion. Physical and vegetation features of the watershed are described. The severe slope erosion and valley trenching that characterize the watershed area are reported to be the result of overgrazing and burning.

8. Barnett, A. P., E. R. Beaty, and A. E. Dooley. 1972. Runoff and soil losses from closely grazed fescue, a new concept in grass management for the Southern Piedmont. J. Soil and Water Conserv. 27:168-170.

Simulated storms of 5.3 and 4.28-in of 2-hour duration were applied to a 4-year old tall-fescue pasture which was close-grazed all year round. Runoff, soil loss and an erosion index are reprroted for each event. Computations are made for rotation cropping of the site.

9. Bentley, J. R. and M. W. Talbot. 1945. How many head? West. Livest. J. 23:21, 40, 42, 43.

Discusses the effects of the degree of grazing on the forage and soil.

10. Branson, F. A., R. F. Miller, and I. S. McQueen. 1962. Effects of contour furrowing, grazing intensities and soils on infiltration rates, soil moisture and vegetation near Fort Peck, Montana. J. Range Manage. 15:151-158.

Contour furrowing was applied to slick and semi-slick soils with three grazing intensities. Infiltration rates were greater on semi-slick soil than slick and decreased with grazing intensity.

11. Bransons, F. A. and J. B. Owen. . Plant cover, runoff, and sediment yield relationships on Mancos Shale in western Colorado. Water Resour. Res. 6:783-790.

Relationships between vegetation and hydrologic measurements for 17 watersheds near Grand Junction, Colorado, were subjected to correlation analyses. Six years of vegetation measurements, four vegetation measurement methods, and 15 years of hydrologic records were used in the analyses. Highly significant correlation coefficients were found for percent bare soil and runoff, but the relationships were found for percent bare soil and runoff, but the relationships between bare soil and sediment yields were not statistically significant. Geomorphic parameters such as angle of junction, mean slope, drainage density, relief ratio, length-width ratio, and watershed area were more highly correlated with sediment yields than with runoff. Correlation coefficients for spring vegetation measurements and runoff were higher than for autumn measurements. First contact methods and step point vegetation measurement methods were superior to the loop method and the all contacts point method. Curves for the relationship of runoff to bare soil were strikingly different for three sets of watersheds from different precipitation zones. Bare soil measurements may provide rapid and inexpensive estimates of runoff for watersheds similar to the ones studied.

12. Brown, D. E., C. H. Lowe, and J. F. Huusler. 1977. Southwestern riparian communities: their biotic importance and management in Arizona. In Importance, Preservation and Management of Riparian Habitat: A Symposium. U.S.D.A. For. Serv. Gen. Tech. Rpt. RM-43: 201-211.

The various riparian communities occurring in Arizona and the southwest are described and their biotic importance discussed. Recommendations are made concerning the management of streamside environments and their watersheds. These include recommendations pertaining to the classification and inventory of riparian habitats; the establishment of study areas; the regulation and elimination of livestock grazing; the greater consideration of streamside vegetation in authorizing water management projects; and the more conservative use of our watersheds.

13. Brown, H. E., M. B. Baker, Jr., J. L. Rogers, W. P. Clary, J. L. Kovner, F. R. Larson, C. C. Avery, and R. E. Campbell. 1974. Opportunities for increasing water yields and other multiple use values on ponderosa pine forest lands. For. Ser. Res. Paper RM-219: 36 p.

Multiple use productivity is described, with special emphasis on the Beaver Creek Pilot Watershed near Flagstaff, Arizona. Changes in productivity and environmental quality are described following livestock grazing and various levels of forest thinning and clearing. Preliminary analytical procedures allow the user to estimate the tradeoffs in production and environmental quality.

14. Bryan, K. 1940. Erosion in the valleys of the southwest. New Mexico Quart. 10:227-232.

Discusses problems or arroyo cutting in the southwestern United States. Points out that there have been at least 3 alternating periods of cutting and deposition. The last period of channel cutting, which is still active, began since 1880. Attributes arroyo cutting to mainly fluctuations in climate and states that over-grazing is merely a trigger force which precipitated the most recent event of arroyo cutting.

15. Bryant, H. T., R. E. Blaser, and J. R. Peterson. 1972. Effect of trampling by cattle on bluegrass yield and soil compaction of a Meadowville loam. Agron. J. 64:331-334.

Increasing experimental trampling pressures (corresponding to 0, 60, and 120 cow trips repeated four times during the season) resulted in increased penetrometer resistance and the occurrence of maximum resistance nearer to the soil surface. Neither of these factors was affected by the height of the herbage at trampling. Bluegrass yields from plots clipped at 2.5 cm prior to trampling were slightly lower than from plots not clipped prior to trampling. Increasing trampling pressures caused decreased forage yields particularly for tramplings in June and September.

16. Buckhouse, J. C. and G. B. Coltharp. 1976. Soil moisture responses to several levels of foliage removal on two Utah ranges. J. Range Manage. 29:313-315.

Range plant clipping studies were conducted at two elevations on Utah's Wasatch Plateau during 1966 and 1967. It was found that extreme clipping treatments (complete denudation) resulted in significantly less soil moisture withdrawal than the unclipped controls at the mid-elevation location. No significant differences were found among clipping treatments at the subalpine location, however.

17. Buckhouse, J. C. and G. F. Gifford. 1976. Water quality implications of cattle grazing on a semiarid watershed in southeastern Utah. J. Range Manage. 29:109-113.

During 1973 and 1974 wildland water quality analyses were performed on a semiarid, chained and seeded, pinyon-juniper site in southeastern Utah. The area was treated in 1967 and protected from grazing until 1974. In 1974 livestock grazing was introduced and investigations continued to determine if any deleterious land use effects were present from fecal contamination by cattle. No significant changes were noted in fecal and total coliform production (fecal pollution bacterial indicators) from grazing use. There is an element of risk involved whenever data generated from a small area are projected to larger land areas. However, it appears that this level of livestock grazing (2 hg/AUM) did not constitute a public health hazard in terms of fecal pollution indicators on the semiarid watershed.

18. Burke, W., J. Galvin, and L. Galvin. 1967. Measurement of structure stability of pasture soils. Trans. 8th Int. Congr. Soil Sci. 1964, 2:581-586.

Various moisture values, the Atterberg limits and undrained shear strengths at saturation and at pF =2 were determined for six soils known to be subject to treading damage. The resulting classification of soils according to their resistance to treading damage agreed with practical experience.

19. Buttery, R. F. 1956. Range conditions and trends resulting from winter concentrations of elk in Rocky Mountain National Park, Colorado. J. Range Manage. 9:148.

Reports range conditions and trends in condition observed by the line-intercept and Parker three-step methods on two concentration areas of elk winter range.

20. Cable, D. R. 1975. Range management in the chaparral type and its ecological basis: The status of our knowledge. For. Ser. Res. Paper RM-155: 30 p.

Chaparral in Arizona is used far below its potential. Conversion to grass can greatly increase water and grass production, and improve wildlife habitat. Management options include conversion to grass, maintaining shrubs in a sprout stage, changing shrub composition, reseeding, and using goats to harvest shrub forage.

21. Cable, D. R. and S. C. Martin. 1975. Vegetation responses to grazing, rainfall, site condition, and mesquite control on semidesert range. For. Ser. Res. Paper RM-149: 24 p.

Over a 10-year period, mesquite control increases perennial grass production 52 percent. Perennial grass production was highly dependent on both the previous and current summer's rainfall, indicating 2 years are required for recovery from a 1-year drought. Stocking rates could be estimated as accurately from rainfall as from grass production.

22. Campbell, A. G. 1966. Effects of treading by dairy cows on pasture production and botanical structure on a Te Kowhai soil. N.Z. J. Agric. Res. 9:1009-1024.

The effect of pasture dry matter (D.M.) production and botanical composition of treading by dairy cows while grazing autumn-saved pasture in late winter was examined over three years. The silty clay soil was close to field capacity when trodden. Levels of treading in these ways were compared with controls from which the grass was cut and removed or cut and returned to the plots at the same time as the treading treatments were imposed.

The effects of heavy treading on D.M. production were not great in any year, nor was there any evidence of cumulative effects when pastures were trodden for three years in succession. Differences between years in D.M. production and botanical composition were much greater than those caused by treatment effects within years.

It is concluded that for this soil type a single period of severe treading when grazing off autumn-saved pasture in late winter will have little effect on animal production from such pastures unless utilization of the pasture is so high that the small pasture production loss is critical for animal production.

23. Chandler, R. F., Jr. 1940. The influence of grazing upon certain soil and climatic conditions in farm woodlands. J. Amer. Soc. Agron. 31:216-230.

Eighteen paired grazed and ungrazed woodlands in New York were compared. Results indicated taht grazed sites had lower organic matter, higher bulk density, lower moisture content, and higher surface soil temperatures.

24. Chapman, H. H. 1933. Influence of overgrazing on erosion and watersheds. Civil Eng. 3:74-78.

Points out that too little control of grazing and of other agencies harmful to the natural cover is a cause of flood damage and the rapid increase in erosion in the Intermountain region of the United States. Notes that engineering works alone cannot prevent erosion damage and restore the protection given by nature. Cites examples of destructive erosion and gullying. Suggest an intensive scientific study of the causes of erosion so as to determine control measures.

25. Chichester, F. W., R. W. Van Kuren, and J. L. McGuinness. 1979. Hydrology and chemical quality of flow from small pastured watersheds. II. Chemical quality. J. Environ. Qual. 8:167-171.

A beef cattle-pasturing system involving four rotationally grazed summer pastures with winter-feeding on one pasture was studied on sloping upland watersheds in Ohio to determine its effect on chemical quality of water. The concentrations of chemicals in runoff from the pastures, which were summer-grazed only, increased relative to that of incoming precipitation but not enought to significantly impair water quality. No measurable sediment was lost from the pasture used only for summer grazing, allowing no chemical movement via that pathway. Much soil and plant-cover disturbance on the pasture used for winter-feeding, however, resulted in increased runoff, some surface erosion, and more chemical movement as compared with the pastures grazed only in summer. Considerably more chemicals moved in subsurface than in surface flow from the summer pastures while amounts of chemicals transported from the winter-feeding pasture were equally as great in surface runoff and subsurface flow. Watershed surface management was a key factor in determining the flow route of water in excess of that used for evapotranspiration and, hence, the pathways and amounts of chemical transport from the pastures.

26. Chisholm, T. S. 1971. Runoff from a pastured watershed in Louisiana. Louisiana Agr. Exp. Sta. Bull. No. 799: 15 p.

Data for the period 1966-69 is presented and analyzed to describe rainfall-runoff relationships for a 50-acre, pastured watershed.

27. Clary, W. P. 1975. Range management and its ecological basis in the ponderosa pine type of Arizona: The status of our knowledge. For. Ser. Res. Pap. RM-158: 35 p.

Summarizes and evaluates available information about Arizona ponderosa pine-bunchgrass ranges. It covers physical-biological characteristics, factors influencing livestock production, grazing allotment conditions, and economics, and correlates grazing with other uses. Several knowledge gaps are also identified.

28. Clemm, D. L. 1977. Survival of bovine enteric bacteria in forest streams and animal wastes. M.S. thesis, Central Washington Univ., Wenatchee, Wash.: 19 p.

This study was designed to determine the survival capacity of fecal indicator bacteria in fecal material and forest streams in central Washington.

Results indicated taht fecal coliforms and streptococci can survive for four to five weeks in streams and over a year in fecal material.

29. Colborg, A. E. 1972. Soil compaction effects of livestock grazing on a crested wheatgrass seeding in southern Idaho. M.S. thesis, Univ. of Idaho, Moscow, Idaho: 50 p.

Grazing did not increase soil compaction to a great extent, rather the opposite was frequently observed with pulverizing action of hooves, loosening the soil surface. Infiltration rates were reduced, but not enough to require corrective measures.

30. Cottam, W. P. and G. Stewart. 1940. Plant succession as a result of grazing and of meadow dissication by erosion since settlement in 1862. J. For. 38:613-626.

Ecological changes in the vegetation of mountain meadow-lands in the West have recently attracted much attention as a phase of the erosion problem. Ordinarily, too little information regarding the specific history of these changes is available to permit accurate analysis. The history of the case treated in the following paper is, however, unusually well known. Mountain meadows in southwestern Utah is a spot of much local historical interest. Moreover, the rapid invasion of heavily grazed sagebrush and grasslands by junipers is an ecological change of major consequence from the standpoint of both rangeworkers and foresters.

31. Cottam, W. P. and F. R. Evans. 1945. A comparative study of the vegetation of the grazed and ungrazed canyons of the Wasatch Range, Utah. Ecol. 26:171-181.

A study of two adjacent canyons, one of which has been protected for 40 years, while the other has been heavily grazed for 100 years, showed the danger of complete extermination of palatable species of grass and shrubs through over-grazing. Some highly palatable shrubs have a density in the grazed canyon of less than one-third that in the ungrazed, while shrubs of low palatability have a density 13 times as great as in the ungrazed canyon, and advanced gully erosion is common along a sheep trail.

32. Coupland, R. T., N. A. Skoglund, and A. J. Heard. 1960. Effects of grazing in the Canadian Mixed Prairie. <u>In</u> Proc. 8th International Grassland Congr.: 212-215.

Principal effects of grazing on 8 natural pastures and adjoining climax vegetation were a decrease in mid-grasses, increases in low-growing grasses and sedges, decreased cover, reduction in mulch, decrease in infiltration rate on fine textured soils, and some reduced root production.

33. Craddock, G. W. and C. K. Pearse. 1938. Surface run-off and erosion on granitic mountain soils of Idaho as influences by range cover, soil disturbance, slope, and precipitation intensity. U.S.D.A. Circ. No. 482: 21 p.

Results indicated the superiority of wheatgrass in controlling erosion and runoff. Calls for maintenance of wheatgrass ranges in order to meet both range management and watershed protection objectives.

34. Croft, A. R., L. Woodward, and D. A. Anderson. 1943. Measurement of accelerated erosion on range-watershed land. J. For. 41:112-116.

Soil losses, physical and chemical changes caused by accelerated erosion are greatest on watersheds where grazing has been heaviest and smallest on lightly grazed sites.

Results suggest that grazing management must not only take into account forage management, but also the effects grazing may have on the soil. Disturbance can be either through mechanical action or cover removal.

35. Croft, A. R. and L. Ellison. 1960. Watershed and range conditions on Big Game Ridge and vicinity, Teton National Forest, Wyoming. U.S. Forest Service, Ogden, Utah. 37 p.

Discusses causes of accelerated erosion and deterioration of vegetation (mostly subalpine with some Pinus flexilis and Abies lasiocarpa) observed at ca. 10,000 ft. alt. in Yellowstone Park. Fire, livestock and pocket gophers contribute to the effects, but the primary cause is the grazing and trampling of elk (Cervus canadensis).

36. Crouch, G. L. 1978. Effects of protection from livestock grazing on a bottomland wildlife habitat in northeastern Colorado. In Proc. Lowland River and Stream Habitat in Colorado, Symp. Oct. 4-5, 1978, Greeley, Colo.: 118-125.

Vegetation on a bottomland wildlife habitat protected from grazing for 7 to 25 years was compared to an adjacent grazed tract. Overall cover and height of the understory was about twice as great on the ungrazed area for each evaluation, but did not change appreciably over the 18-year interval.

37. Currie, P. O. and H. L. Gary. 1978. Grazing and logging effects on soil surface changes in central Colorado's ponderosa pine type. J. Soil and Water Cons. 33:176-178.

Measurement of soil surface elevation on ponderosa pine-bunchgrass lands in central Colorado showed that 35-years of grazing and winter logging had not caused serious erosion. All measurements indicated an aggradation of soil surface material in relation to differences in ground cover, grazing, and timber removal. Aggradation on ungrazed areas exceeded aggradation on grazed or logged areas by less than 7 millimeters.

38. Currie, P. O. 1975. Grazing management of ponderosa pine-bunchgrass ranges of thecentral Rocky Mountains: The status of our knowledge. For. Serv. Res. Pap. RM-159: 24 p.

Pine-bunchgrass ranges have historically been important livestock-producing areas in the central Rocky Mountains. Grazing will continue to be important, but in conjunction with other uses of the land. Livestock-management techniques are well developed and soundly based on research within the pine bunchgrass type. There is a need, however, to understand the interrelationships of other land uses, particularly as they relate to human population pressures. Research needs, as well as what is known, are described for several vegetation cover types. Other resources, such as timber, soil, and water, are evaluated in relation to grazing.

39. Darling, L. A. and G. B. Coltharp. 1973. Effects of livestock on water quality of mountain streams. In Proc. Symp. Water-Animal Relations, Southern Idaho College, Twin Falls, Idaho, June 1-8: 1-8.

This study was designed to determine the type and extent of livestock grazing effects on the water quality of streams passing through grazing compartments. Emphasis was placed on the effect of livestock grazing on the bacteriological indicator groups of total coliform, fecal coliform and fecal streptococci, with less attention given to selected physical and chemical parameters. The study was conducted on three mountain streams in the Bear River Range of northern Utah.

Significant increases in the bacterial counts were noted during the grazing of cattle and sheep at stream locations immediately down-stream from the grazing activity. Bacterial counts in streams draining grazed watersheds reached seasonal maximum values during the grazing period, while counts from the ungrazed watershed remained relatively low and constant.

The chemical and physical water quality parameters showed no clearcut effect from livestock grazing.

40. Davis, G. A. 1977. Management alternatives for the riparian habitat in the southwest. In Importance, Preservation and Management of Riparian Habitat: A Symposium. For. Ser. Gen. Tech. Rpt. RM-43: 59-67.

Management and environmental consequences of different uses of riparian habitat are considered. Grazing was indicated as causing 1) increased potential for devastating floods due to elimination of vegetative cover on the adjacent watersheds; and 2) removal of herbaceous material and seedlings and/or sprouts of woody riparian species in the bottoms. Wildlife management in the riparian zone is also considered.

41. Dee, R. F., T. W. Box, and E. Robertson, Jr. 1966. Influence of grass vegetation on water intake of Pullman silty clay loam. J. Range Mange. 19:77-79.

Ring infiltrometers were used to compare water intake rates on four different grass types representative of various successional stages. Results indicated higher infiltration rates for plants with a higher successional stage. Infiltration was correlated to standing vegetation, litter, and litter and vegetation combined.

42. Dobbin, C. E. 1933. Sudden floods initiate erosion (letter to editor). Civil Engin. 3 (comments on influence of overgrazing on erosion and watersheds): 334.

Discusses historical growth of arroyos in Chaco Canyon and concludes that climatic phenomena as well as overgrazing may be causes of erosion.

43. Doran, J. W. and D. M. Linn. 1979. Bacteriological quality of runoff water from pastureland. Appl. and Environ. Microbiol. 37:985-991.

Runoff from a cow-calf pasture in eatern Nebraska was monitored for bacteriological parameters. Counts in runoff from both grazed and ungrazed sites generally exceeded recommended water quality standards.

The fecal coliform to fecal streptococci ratio was used to distinguish between wildlife and cattle. Also, the use of Streptococcus bovis for evaluating the effectiveness of management practices on minimizing contamination of surface water is discussed.

44. Dorignac, E. J. and L. E. Love. 1961. Infiltration studies on Ponderosa Pine Ranges of Colorado. Rocky Mtn. Forest and Range Exp. Sta., Sta. Paper No. 69: 34 p.

During the years 1941 through 1954, infiltration studies were conducted on six range pastures at the Manitou Experimental Forest.

Using the Rocky Mountain infiltrometer the following conclusions were reached:

1. Infiltration varies with cover type on Ponderosa Pine ranges.
2. Weight of dead organic matter and the amount of noncapillary pores in the surface soil were the most important measured factors influencing infiltration rates of granitic alluvium soils occurring in the Manitou pastures.
3. Providing protection from cattle grazing resulted in an increase in infiltration rates from those measured at the start of the experiment in 1941. Rather rapid recovery of infiltration rates was observed on pine grass, which showed most of the increase taking place in the first six years of protection. In the grassland, recovery infiltration rates continued through 1954, or 13 years after the start of the experiment.
4. Infiltration rates in grassland and pine-grass can be estimated by measuring the quantity of dead organic material and non-capillary pores in the surface soil.

45. Dragoun, F. J. and A. R. Kuhlman. 1968. Effect of pasture management practices on runoff. J. Soil & Water Conserv. 23:55-57.

Field trials were conducted over a 22-year period to determine the effects of contour furrowing, light and heavy grazing regimes, and eccentric-disking on soil-water storage and forage production in a bromegrass-legume pasture of 6% slope on a Holdrege silt loam soil receiving 25 in. average annual rainfall. Contour furrowing conserved, on the average, 1.2 in/year more precipitation than untreated plots, but the increase in soil moisture did not produce better pasture. Runoff from eccentric disked plots was 15-30% less than from untreated plots and runfof duration from heavily grazed plots was more than twice that from lightly grazed plots.

46. Duce, J. T. 1918. The effect of cattle on the erosion of Cañon Bottoms. Sci. 47:450-452.

Outlines the effect of cattle on the erosion of the arid Cañon Country in southeastern and southwestern Colorado. Describes the formation and growth of arroyos.

47. Duley, F. L. and C. E. Domingo. 1949. Effect of grass on intake of water. Univ. Neb. Agr. Exp. Sta. Res. Bull. 159: 15 p.

Infiltration tests were made on a number of grassland soils by means of a 16- x 72-inch sprinkler type infiltrometer. Tests were made on native meadow and range pasture land in a moist subhumid to dry subhumid climate.

The various types of grasses tested were effective in inducing a high intake rate of water into the soil. However, the total cover, including live grass and associated litter, was more significant than the kind of grass or the type of soil.

On an area affected by overflow deposits and trampling by animals, the intake rate on blue grass land was reduced to a very low point.

48. Dunford, E. G. 1949. Relation of grazing to runoff and erosion on bunchgrass ranges. Forest Serv., Rocky Mt. For. & Range Exp. Sta. Res. Note No. 7: 2 p.

Runoff and sediment were collected from six 1/100 acre plots. Two plots were controls; two were moderately grazed; and two were heavily grazed.

Runoff from rainfall increased for both treated plots but significant increase in sediment yields were observed on the heavily grazed plot only.

49. Dunford, E. G. 1954. Surface runoff and erosion from pine grasslands of the Colorado Front Range. J. For. 52:923-927.

Heavy grazing (2-1/2 acres per cow-month) appeared to increase erosion and surface runoff. Moderate grazing (4-acres per cow-month) does not appear to have any effect on runoff and erosion. Conclusion for the Front Range is moderate grazing is best from both economic and watershed standpoint.

50. Dunford, E. G. and S. Weitzman. 1955. Managing forests to control soil erosion. In Water, U.S.D.A. Yearbook 1955: 235-242.

Outlines principles of integrating timber and watershed management to control erosion from forest lands. Describes factors responsible for accelerated erosion from forest lands. Recommends measures of fire prevention, grazing control, logging, and construction of logging roads for erosion control.

51. Dunne, T. 1979. Sediment yield and land use in tropical catchments. J. Hydrol. 42:281-300.

Analyzes sediment yields from 61 Kenyan catchments on a regional basis and concluded land use is the dominant control within each region. Rangeland was included in this analysis.

52. Edmond, D. B. 1958. The influence of treading on pastures: a preliminary study. N.Z. J. Agric. Res. 1:319-328.

Treading damaged the pasture; most of the effect followed the first treading but repeated treadings altered botanical composition. Increased treading had increased influence on plant and soil.

53. Edmond, D. B. 1963. Effects of treading perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pastures in winter and summer at two soil moisture levels. N.Z. J. Agric. Res. 6:265-276.

Reduced yields appeared, in the main, to be due to the lower vigor of a lesser number of grass tillers in trodden pastures.

Particularly in wet soil, direct effects on plants, such as root damage, plant displacement, and burial in mud, appeared to be important. There also appeared to be significant changes in the soil itself, such as limitation of soil air, indicated by gleying at 1 to 1-1/2 in. depth in winter.

54. Edmond, D. B. 1974. Effects of sheep treading on measured pasture yield and physical condition of four soils. N.Z. J. Exp. Agric. 2:39-43.

Treading of sheep at 49.4 equivalent/ha on Manawa ryegrass and Manawa-Huia white clover pastures on four soil types (yellow brown loam, yellow brown pumice, fine sandy loam and silt loam) reduced pasture production significantly. There was a slight increase in herbage N in trodden plots, but no difference in K, P or Mg in white clover. The average height of growing points in tillers in ryegrass was reduced by treading. Soil bulk densities were higher in the 0-2.5 cm layer on trodden plots on all soils.

55. Ellison, L. 1946. The pocket gopher in relation to soil erosion on mountain range. Ecol. 27:101-114.

Study conducted along the Wasatch Plateau in Utah indicated the pocket gopher to be an agent of geologic normal and accelerated erosion. The accelerated erosion activities of the pocket gopher are initiated by overgrazing and are related to degree soil mantle is dissected and percent of bare soil.

56. Fisser, H. G. 1975. Study of rangeland soil movement characteristics. In Watershed Management, Proc. ASCE Symp., Aug. 11-13, Logan, Utah: 421-422.

Study initiated in 1963 in Wyoming used erosion transects to measure soil movement from four treatments: 1) protected, 2) no protection from grazing; 3) herbicides; and 4) no herbicides.

Results indicated no significant soil movement associated with the grazing treatment. Sites treated with chemicals had significant soil movement, and sites with herbicides and grazing had extremely significant movement.

57. Forsling, C. L. 1928. The soil protection problem. J. For. 26:994-997.

Cites the main effects of tearing down factors such as grazing, logging, and fire to be 1) reduction of plant cover, thereby allowing erosive forces to operate; and 2) removal of plant material which lowers the fertility of the soil and its productive capacity. Examples are cited as to effects of cover on erosion. Emphasis is on overgrazing.

58. Forsling, C. L. 1931. A study of the influence of herbaceous plant cover on surface run-off and soil erosion in relation to grazing on the Wasatch Plateau, Utah. U.S.D.A. Tech. Bull. No. 220: 72 p.

Results of 15 years of rainfall and runoff measurements and seven years ofsnow runoff measurements for two watersheds in central Utah indicated that increased plant cover from 16 to 40 percent reduced rainfall-runoff by

64 percent, erosion by 57 percent, and snowmelt-runoff by 57 percent.

59. Forsling, C. L. 1932. Erosion on uncultivated lands in the intermountain region. Sci. Monthly 34:311-321.

Discusses the impact of unmanaged grazing and public land use on the native plant cover and erosion in this region.

60. Frank, E. C., H. E. Brown, and J. R. Thompson. 1975. Hydrology of Black Mesa watersheds, western Colorado. For. Ser. Gen. Tech. Rpt. RM-13: 11 p.

Eleven years of runoff and suspended sediment data show no relationship to bare soil intercept, which decreased although grazing utilized an average of 40 percent of the grass. By current classification schemes, sediment yields indicate very minor amounts of geologic erosion.

61. Gard, L. E., R. F. Fuelleman, C. A. Van Doren, and W. G. ammlade. 1943. Runoff from pasture land as affected by soil treatment and grazing management and its relationship to botanical and chemical composition and sheep production. J. Amer. Soc. Agron. 35:332-347.

Follow up of study reported by Van Doren et al. (1940) relating soil treatment and grazing management. Results conclude that soil treatment and moderate grazing produce the lowest runoff. Soil loss was low from all plots.

62. Gary, H. L. 1975. Watershed management problems and opportunities for the Colorado front range ponderosa pine zone: The status of our knowledge. For. Ser. Res. Pap. RM-139: 32 p.

Soils in the region were developed from granites, are relatively infertile, and erode easily after abuse. Water yields are relatively low. Plot studies corroborated with large-scale studies on timbered and grazed areas have provide guidelines for maintaining satisfactory watershed conditions.

63. Gifford, G. F. 1975. Beneficial and detrimental effects of range improvement practices on runoff and erosion. <u>In</u> Watershed Management, Proc. ASCE Symp., Aug. 11-13, Logan, Utah: 215-248.

Reviews hydrologic impacts of various range improvement practices, including grazing, with results on water quantity and quality.

64. Gifford, G. F., J. C. Buckhouse, and F. E. Busby. 1976. Hydrologic impact of burning and grazing on a chained pinyon-juniper site in southeastern Utah. Utah Water Res. Lab. PRJNR012-1: 22 p.

Results of several studies conducted at Blanding, Utah on a chained pinyon-juniper site with several different slash disposal techniques and grazing superimposed are presented.

Results indicated minimal impact on bacterial water quality by grazing at a rate of 2 ha/AUM; lower infiltration rates on grazed vs. ungrazed sites, and no apparent trends were detected in sediment production.

65. Gifford, G. F. and R. H. Hawkins. 1978. A preliminary approach towards hydrologic modeling of rangeland grazing management systems. In Proc. First Intern. Rangeland Congress, Denver, Color.: 279-283.

This paper briefly presents a preliminary attempt at modeling rangeland grazing management systems. The model is synthesized around grazing intensity as the key to impacting infiltration rates in future projected grazing patterns. Impacted infiltration rates are then converted to runoff curve numbers for appropriate vegetation types, cover conditions, and infiltration rates for use in calculating runoff volumes by the U.S. Soil Conservation Service technique.

66. Gifford, G. F. and R. H. Hawkins. 1978. Hydrologic impact of grazing on infiltration: A critical review. Water Resour. Res. 14:305-313.

The hydrologic importance of grazing is receiving increased attention on rangelands in the United States. The literature on this topic is fragmented. This paper explores the available literature for infiltration and runoff. Generally, data relative to range condition are not adequate for evaluating hydrologic impacts. Data relating grazing intensity to infiltration rates are not available, yet distinct limitations are evident. These limitations are discussed in terms of identifying future research needs. The greatest need appears to be a detailed definition of the long-term effects of grazing (by year and season) on infiltration rates as a function of site, range conditions, and grazing intensity. Once obtained, infiltration rates must be coupled with an appropriate method for generating runoff volumes, storm hydrographs, and long-term water yields.

67. Glinsk, R. L. 1977. Regeneration and distribution of sycamore and cottonwood trees along Sonita Creek, Santa Cruz, County, Arizona. In Preservation, Importance, and Management of Riparian Habitat: A Symposium. For. Ser. Gen. Tech. Rpt. RM-43: 116-123.

This study describes the effects of livestock grazing and streambed erosion on the regeneration and distribution of sycamore and cottonwood trees. Sycamores reproduced from root and truck sprouts and because of this their distribution is not as likely to change significantly. Cottonwood reproduction was nearly absent in areas grazed by cattle, and was confined to the narrow erosion channel. If this regeneration pattern continues, the future maximum width of the cottonwood forest will decrease nearly 60%.

68. Gradwell, M. W. 1974. Laboratory test methods for the structural stabilities of soils under grazing. Trans., 10th Intern. Cong. of Soil Sci. I:341-350.

Tests of resistance to penetration and of plasticity at field capacity failed to correlate with the observed susceptibilities of some New Zealand soils to plugging under animal treading. Resistance to pentration and plasticity change under treading in the wet season and the change may take different directions for different soils. The volumes of large pores in the soils after simulated treading correlated well with field performance. This is attributed to the influence of air content on the direction of the changes that occur.

69. Gunderson, D. R. 1968. Floodplain use related to stream morphology and fish populations. J. Wildl. Manage. 32:507-514.

For two contiguous sections of a Montana stream, the agricultural use of the floodplain was related to cover, stream morphology, and fish populations. In one section the vegetation of the floodplain had been reduced by clearing and intensive livestock grazing; in the other section, which had received light use by livestock, vegetation was relatively unchanged. This ungrazed section had 76 percent more cover (undercut banks, debris, overhanging brush, and miscellaneous) per acre of stream than the grazed section. Brown trout (+6 inches) were estimated to be 27 percent more numerous and to weigh 44 percent more per acre in the ungrazed section of the stream, although their rate of growth was similar in the two stream sections.

70. Hanson, C. L., A. R. Kuhlman, and J. K. Lewis. 1978. Effect of grazing intensity and range condition on hydrology of western South Dakota ranges. S. Dakota State Univ. Agr. Exp. Sta. Bull. No. 647: 54 p.

Studies showed that grazing intensity and changes in range condition affected vegetation, mulch and annual and summer runoff.

Effects on daily evapotranspiration rates indicated that low range condition had lower rates early in the summer with the maximum rate continued later in the summer than on the high range condition.

71. Hanson, C. L. and J. K. Lewis. 1978. Winter runoff and soil water storage as affected by range condition. In Proc. First Intern. Rangeland Congress, Denver, Colo.: 284-287.

These data cover seven winters from a range hydrology study conducted on Mixed Prairie of the northern Great Plains at Cottonwood, South Dakota. Watersheds in the high range condition with the most vegetation and mulch captured the most blowing snow and stored the most soil water. However, winter runoff was about the same from watersheds in medium and low range condition as it was from watersheds in high range condition.

72. Harms, L. L., P. Middaugh, J. N. Dornbush, and J. R. Anderson. 1975. Bacteriological quality of surface runoff from agricultural land. Part II. Water and Sewage Work 123:71-73.

Cultivated and noncultivated field under snowmelt and rainfall runoff conditions were compared.

Fecal coliform counts in snowmelt runoff were higher for the pasture and hayfields, exceeded water quality criteria more frequently, because cattle were pastured on these sites longer.

Rainfall runoff data from the pasture indicate potential pollution problems, but data were lacking for any conclusions.

73. Harper, V. L. 1953. Watershed management--forest and range aspects in the United States. Unasylvia 3:105-114.

This paper is a general review of such things as development of public concern about watershed values and effect of cover on watershed values. Some examples of forest and range watershed protection and improvement work are discussed.

74. Hawkins, R. H. and G. F. Gifford. 1979. Hydrologic impacts of grazing systems on infiltration and runoff: development of a model. Utah Wat. Res. Lab. Hydrol. and Hydraul. Series UWRL/H-79/01. 14 p.

The response of infiltration rate (f_c) to grazing systems is modeled, based on infiltration-grazing information available from past studies. As inputs the model used a grazing system schedule, initial infiltration rate, and a characteristic recovery time. The output is a sequence of infiltration rates, from which hydrologic impact inferences may be made. Background, development, usage, cautions, and future research needs are given. A computer program of the model is supplied.

75. Honczarenko, G. 1967. Effect of grazing on vegetal cover and physical properties of meadow soil. Zesz. Probl. Postep. Nauk Roln. 74:101-105.

Grazing on very wet soils results in a massive occurrence of Deschampsia caespitosa and Juncus effusus, associated with low porosity and excess moisture. Deterioration of physical properties is most likely to occur on sandy soils and peats, whereas finely-textured soils (alluvial soils, loess, clay soils) are less liable to structural deterioration.

76. Houston, W. R. 1965. Soil moisture response to range improvement in the northern Great Plains. J. Range Manage. 18:25-30.

The study was conducted in Montana during 1958. Various soil sites and improvement practices were implemented and measurements made during 1959 and 1961.

Rest from grazing reduced moisture stress on most clay soils, but moisture stress increased on fine sandy loam soils in 1959.

The data from 1961 represented a drought year and no difference in moisture was noted on any treatment.

77. Hurault, J. 1971. The erodibility of overgrazed soils in the Adamawa high plateau (Cameroon). Infiltration studies. Bulletin de l'Association Francaise pour l'Etude de Sol No. 1:23-56.

Vegetation, soil fauna, apparent density, infiltration and runoff were studied in soils of the Banyo region. The soils are mainly red ferrallitic soils with frequent stone lines and occasionally ferruginous concretions.

Precipitation is approximately 1850 mm, distributed over 8 months. The extent to which these soils are eroded appears to depend mainly on their infiltration capacity, which in turn is associated with soil fauna, particularly termites, whose abundance and activity depend on the amount of lignified material available. The presence of woody species is therefore essential for controlling erosion in these soils, but compaction and the high rate of runoff under savanna conditions could not be directly attributed to overgrazing.

78. Johnson, A. 1962. Effects of grazing intensity and cover on water intake rate of fescue grassland. J. Range Manage. 15:79-82.

The study was conducted in southwestern Alberta in Canada. Sites included ungrazed and areas which had been grazed at four different rates for ten years.

Infiltrometer results indicated that even after ten years of heavy grazing, soil erosion by water was not a critical factor in management. Infiltration rates increased as the amount of mulch and vegetation increased.

79. Johnson, E. A. 1952. Effect of farm woodland grazing on watershed values in the southern Applachian Mountains. J. For. 50:109-113.

The effects of 11 years of grazing cattle on a forested Appalachian watershed are reproted. The experiment is described; the effects of grazing on vegetation, soil, and water are presented; and practical implications of grazing mountain watersheds are discussed.

80. Johnson, S. R., H. L. Gary, and S. L. Ponce. 1978. Range cattle impacts on stream water in the Colorado Front Range. For. Ser. Res. Note RM-359: 8 p.

Studies on two adjacent pastures along Trout Creek in central Colorado indicated only minor effect of cattle grazing on water quality. Bacterial contamination of the water, however, significantly increased. Following removal of the cattle, bacterial counts dropped to levels similar to those in the ungrazed pasture.

81. Johnston-Wallace, D. B., J. S. Andrews, and J. Lamb, Jr. 1942. The influence of periodic close grazing and pasture fertilization upon erosion control. J. Amer. Soc. Agron. 34:9630974.

. Pastures treated with adequate lime and fertilizers did not show an increase in water loss or erosion with periodic close grazing. Untreated pastures were less effective in controlling erosion.

82. Jones, B. E. 1933. Grazing control stops no floods (letter to editor). Civil Eng. 3 (comments on "The Influence of Overgrazing On Erosion and Watersheds"): 333-334.

Silting of Arrowrock Reservoir with a loss of 6% of capacity was due in part to wave action on the borders and placer mining on the south and middle forks of Boise River. The watershed of Boise River is in a National Forest but never-the-less is a source of silt. Discusses floods in Manti, Ephraim, and Six Hill Canyons in relation to rainfall and vegetative cover. Over grazing as a cause of erosion is not proven.

83. Keen, B. A. and G. H. Cashen. 1932. Studies on soil cultivation. II. The physical effects of sheep folding on the soil. J. Agric. Sci. 22:126-134.

In this study the depth of the compaction effect was 10 cm with the maximum effect at 3-4 cm.

84. Kennedy, C. E. 1977. Wildlife conflicts in riparian management: water. In Importance, Preservation and Management of Riparian Habitat: A Symposium. For. Serv. Gen. Tech. Rpt. RM-43: 52-58.

Discusses some changes and effects caused by uncontrolled grazing on riparian habitat, which includes type conversion in riparian zone, interruption of food chain, and maintenance of unstable stream channel conditions.

85. Knoll, G. and H. H. Hopkins. 1959. The effect of grazing and trampling upon certain soil properties. Trans. Kansas Acad. Sci. 62:221-231.

Ring infiltrometers were used to study infiltration on ungrazed, moderately-grazed, and heavily grazed sites. Infiltration in a 2-hour period was 2.58, 2.08, and 1.58 inches, respectively. Bulk densities were 1.08, 1.17, and 1.27 g/cc, respectively. The effect on available soil water was seen in May when there was none below 2 feet in the profile on the heavily grazed site. There was much less mulch on the heavily grazed site.

86. Kotok, E. I. 1931. Vegetative cover, the water cycle and erosion. Agr. Eng. 12:112-113.

With accelerated erosion, management must check the abuses at their source whether they are fire, destructive logging, or overgrazing, and the best possible mantle of vegetation must be established.

87. Kotok, E. I. 1932. Solving the forest and water riddle. Am. For. 38:488-491.

Summarizes surveys investigating the contribution of forest devastation, overcutting, destructive fires, overgrazing and other abuses of forest and uncultivated lands to present soil and water problems.

88. Kotok, E. I. 1932. Solving the water riddle. Illus. Can. Forest and Outdoors 28:415-418.

Provides proof of the costly effect of throughtless removal of forest cover, of forest fires, and of unregulated grazing practice.

89. Kunkle, S. H. 1970. Source and transport of bacterial indicators in rural streams. In Interdisciplinary Aspects of Watershed Management, Symp., Montana State Univ., Bozeman, Montana. August 3-6, ASCE: 105-132.

Water quality studies were conducted on the Sleepers River Basin in Vermont during 1967-1971. Various land uses were present and all were sampled for bacterial indicators.

Stream bacterial counts were very dependent on the hydrology involved, regardless of the source. Sources of bacteria were: 1) land surfaces; 2) the channels; and 3) direct inputs (sewers).

90. Kunkle, S. H. and J. R. Meiman. 1967. Water quality of mountain watersheds. Hydrol. Paper No. 21, Colorado State Univ., Fort Collins: 53 p.

Water quality was investigated from April 1964-September 1965 on mountain watersheds of limited use in the Colorado Front Range. Physical, chemical, and bacteriological parameters were measured.

Analysis indicated that the bacteria were closely related to physical parameters of the stream, particularly the "flushing effect". Seasonal trends and relationships to physical water quality parameters are discussed.

91. Lassen, L., H. W. Lull, and B. Frank. 1952. Some plant-soil-water relations in watershed management. Cir. U.S. Dept. Agric. No. 910: 64 p.

A review, diagrammatically illustrated, of available technical knowledge on the relations of vegetation with infiltration, runoff, streamflow, etc., and its application to the management of catchment areas.

92. Laycock, W. A. and P. W. Conrad. 1967. Effect of grazing on soil compaction as measured by bulk density on a high elevation cattle range. J. Range Manage. 20:136-140.

Bulk density of the soil in grazed plots was similar to that in ungrazed exclosures both in early summer before grazing and in late summer after grazing. Increases in bulk density during the summer both in grazed and ungrazed areas were attributed to changes in soil moisture. Soils in early summer were moist and swollen and thus weighted less per unit volume than did the dry soils in late summer.

93. Laycock, W. A., H. Buchanan, and W. C. Drueger. 1972. Three methods of determining diet, utilization, and trampling damage on sheep ranges. J. Range Manage. 25:352-356.

Results of this study indicated one-half to two-thirds of the herbage removed by grazing could be accounted for by trampling.

94. Leithhead, H. L. 1959. Runoff in relation to range condition in the Big Bend-Davis mountain section of Texas. J. Range Manage. 12:83-87.

According to studies with infiltration rings, runoff is increased in this area as ranges deteriorate in range condition because the soil absorbs moisture slower. A range site in good condition absorbs moisture 5 to 6 times faster than the same range site in poor condition.

The loss of moisture by evaporation from the first foot of soil is about three times greater in closely grazed, poor condition range than it is from the same site in good condition that has been properly grazed.

95. Liacos, L. G. 1962. Water yields as influenced by degrees of grazing in the California winter grasslands. J. Range Manage. 15:34-42.

Heavy grazing for more than 35 years had resulted in a shallower soil than the ungrazed sites during the same period.

Increases in water yield were attributed to reduced infiltration and percolation rates, and shallow rooted plants. Both of these were caused by heavy grazing.

96. Lodge, R. W. 1954. Effects of grazing on the soils and forage of mixed prairie in southwestern Saskatchewan. J. Range Manage. 7:166-170.

Four sites were established with a grazed and ungrazed treatment for each site. Soil analysis indicated differences in moisture content and bulk density between treatments.

97. Love, L. D. 1958. Rangeland watershed management. Proc. Soc. Amer. Foresters, 1958:198-200.

In this general discussion paper, Love points out some of the factors needed to maintain or foster good grassland watershed conditions. These are as follows:

1. A cover of herbaceous vegetation consisting of a high percentage of bunchgrasses.
2. A large amount of litter covering the soil surface.
3. A small percentage of bare or exposed soil.
4. High non-capillary porosity of surface soils consistent with soil profile characteristics.

98. Lull, H. W. 1949. Watershed condition and flood potential. J. For. 47:45-48.

A watershed condition classification utilizing plant density and extent of visible erosion as criteria was used on the Ephraim Creek watershed in Utah to determine flood potential zones. Runoff production from these zones was indexed by infiltrometers and remedial measures for the watershed are described.

99. Lull, H. W. 1959. Soil compaction on forest and rangelaands. U.S.D.A. Misc. Publ. No. 768: 33 p.

Describes the process of compaction (a) by logging, (b) by trampling of men and animals, analyses the site factors that affect compaction (soil texture and structure, soil density, soil m.c., organic-matter content, frost), discusses the effects of compaction on infiltration and percolation and on vegetation, and suggests measures to reduce it.

100. Lusby, G. C. 1970. Hydrologic and biotic effects of grazing versus nongrazing near Grand Junction, Colorado. U.S. Geol. Surv. Prof. Paper 700-B:232-236.

Over a period of 10 years, 4 grazed watersheds on salt-desert rangeland have ahd a slight increase in the amount of bare soil and rock, and a decrease in ground cover; cover on paired ungrazed watersheds has remained virtually unchanged. Runoff in the ungrazed watersheds has been about 30% less than in the grazed watersheds, and sediment yield has been about 45% less. The greatest changes occurred about 3 years after livestock was excluded from 1 watershed of each of the pairs. Within areas of similar physiography, runoff appears to be directly related to the percentage of bare soil on the watershed.

101. Lusby, G. C. 1973. Hydrologic and biotic effects of grazing vs. non-grazing near Grand Junction, Colorado. J. Range Manage. 23:256-260.

The effect of grazing on the hydrology of salt-desert type rangeland has been studied near Grand Junction, Colorado for the past 14 years. Measurements of precipitation, runoff, erosion, and vegetation have been made in four pairs of watersheds. One of each pair has been grazed by cattle and sheep as is normal in the region, and the other has not been used since the beginning of the study. Measurements made 10 years apart show that all four grazed watersheds have had a slight increase in the amount of bare soil and rock and a decrease in ground cover; cover on ungrazed watersheds has remained essentially unchanged. Runoff in the ungrazed watersheds has been about 30 percent less than in the grazed watersheds and sediment yield has been about 45 percent less. The greatest change in each of the relationships occurred about 3 years after livestock were excluded from one watershed of each of the pairs. Preliminary studies indicate that within similar physiography, runoff is directly related to the percentage of bare soil present on a watershed.

102. Marston, R. B. 1952. Ground cover requirements for summer storm runoff control on aspen sites in northern Utah. J. For. 50:303-307.

Results from 23 summer storms showed erosion to be negligible (less than 1 cubic foot per acre) when 5% or less of the rainfall ran off as overland flow. Erosion increased rapidly with greater amounts of storm runoff. Because stable soil is a first requisite in land management, 5% storm runoff appears to be the maximum allowable for watershed protection purposes on this type of land.

During major storms, with rainfall rates in excess of 3.00 inches per hour, a ground cover of at least 65% is needed to keep runoff to less than 5%.

103. Marston, R. B. 1958. Parrish Canyon, Utah: A lesson in flood sources. J. Soil & Water Conserv. 13:165-167.

Runoff was measured for 11-years on an undisturbed site. Following this calibration period, cover was removed and runoff and erosion were greatly increased.

High erosion rates on catchment slopes in the area have been aggravated by heavy grazing and burning.

104. Martin, S. C. 1975. Why graze semidesert ranges? J. Soil and Water Conserv. 30:186-188.

Population increases are dramatically changing land use in the arid Southwest. Range livestock, however, require little fossil fuel to make high-quality food from forage that is otherwise uneconomical to harvest. Good grazing management can control erosion, and improve forage, wildlife habitat, esthetics, and recreation.

105. Mason, L. R. 1970. A look at range relicts. J. Soil & Water Conserv. 25:18-19.

A range site of 2,700 to 8,075 ft which had never been grazed had an estimated vegetation production of 1,100 lb/acre. Vegetation was mainly shrub with about 4% grass. Erosion and other features usually interpreted as an indication of over grazing were present. Two other range sites showed wind and water erosion not due to grazing use.

106. Meehan, W. R., F. J. Swanson, and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. In Importance, Preservation and Management of Riparian Habitat: A Symposium. Forest Serv. Gen. Tech. Rpt. RM-43: 137-145.

The riparian zone has important influences on the total stream ecosystem including the habitat of salmonids. Shade and organic detritus from the riparian zone control the food base of the stream and large woody debris influences channel morphology. Temporal and spatial changes in the riparian zone, the indirect influences of riparian vegetation on salmonids, and the effects of man's activities are discussed.

107. Meehan, W. R. and W. C. Platts. 1978. Livestock grazing and the aquatic environment. J. Soil & Water Conserv. 33:274-278.

Reviews livestock grazing impacts on water resources, quantity, quality, and fish habitat. Suggestions for future research in the aquatic habitat area are made.

108. Meeuwig, R. O. 1965. Effects of seeding and grazing on infiltration capacity and soil stability of a sub-alpine range in central Utah. J. Range Manage. 18:137-180.

Seven years after discing and seeding to grass, main effects were: decreased organic matter and capillary porosity in the surface soil, greater soil bulk density, and decreased plant and litter cover. Seeding did not significantly effect infiltration or soil stability. Grazing during the previous 4 years decreased plant and litter cover and non-capillary soil porosity, but increased capillary porosity in the surface soil and decreased infiltration and soil stability.

109. Meeuwig, R. O. 1960. Watersheds A and B--A study of surface runoff and erosion in the subalpine zone of central Utah. J. For. 58:556-560.

Flood-source areas cannot be restored by exclusion of grazing alone. Other remedial measures are required to restore watershed stability.

110. Meeuwig, R. O. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. J. Range Manage. 23:185-188.

The influences of vegetation, soil properties, and slope gradient on infiltration capacity and soil stability of high-elevation herbland on the Wasatch Front in northern Utah were investigated under simulated rainfall conditions. Results emphasize the importance of vegetation and litter cover in maintaining infiltration capacity and soil stability. Infiltration is also affected significantly by soil properties, notably bulk density, aggregation and moisture content.

111. Meiman, J. R. and S. H. Kunkle. 1967. Land treatment and water quality control. J. Soil & Water Conserv. 22:67-70.

Comparisons of turbidity, suspended sediment, and indicator bacteria between an unimpacted and impacted, by grazing and irrigation watersheds.

Results showed bacteria to be a better indicator of land use than either suspended sediment or turbidity. The study indicated a strong relationship between bacteria and overland flow, stream discharge, and season of the year.

Storms magnified differences between impacted and un-impacted streams.

112. Milne, C. M. 1976. Effect of livestock wintering operation on a western mountain stream. Trans. ASAE 19:749-752.

Animals may be confined during harsh winter conditions experienced in the intermountain western United States.

Results of this study concluded that such practices have little effect on stream chemical properties; a significant effect on bacteriological parameters which is short-lived from the source; and bacteriological parameters appear to be more suitable for this type of analysis.

113. Mullen, G. J., R. M. Jelley, and D. M. McAleese. 1974. Effects of animal treading on soil properties and pasture production. Irish Agric. Res. 13:171-180.

In a three year experiment treading increased bulk density and surface roughness and decreased aggregate stability, soil permeability and herbage production. There were no significant differences between the effects of the two treading rates (2.0 and 6.2 animals/ha). Herbage growth was better on ploughed and paraquat-treated soil than on undisturbed pasture soil, in two of the three years.

114. Munns. E. N. 1947. Hydrology of western ranges. J. Soil & Water Conserv. 2:139-144.

In this paper the author reviews early development of the rangelands of the west and their over-use, abuse and eventual deterioration. From this he reviews very briefly some of the early work done in the west to control overland flow and mud rock flows from principally high elevation watershed lands. Most of the described work comes from that done at Davis County, Utah.

115. Murai, H., Y. Iwasaki, and M. Ishii. 1975. Effect on hydrological conditions by the exchanging of ground cover from forest land to grass land. Intern. Assoc. Sci. Hydrol. Pub. 117:457-464.

Conversion from forest to grass decreased infiltration rates in mountainous land. Livestock grazing superimposed on the conversion decreased infiltration rates even further.

116. Olson, O. C. 1949. Relations between soil depth and accelerated erosion on the Wasatch Mountains. Soil Sci. 67: 447-451.

Shallow soils or those with a light clay subsoil require additional measrues, such as contour trenching and reseeding, besides reduction or elimination of heavy livestock use to restabilize.

117. Orr, H. K. 1960. Soil porosity and bulk dnesity on grazed and protected Kentucky bluegrass range in the Black Hills. J. Range Manage. 13:80-86.

Soils samples from four exclosures and adjacent grazed sites were analyzed for bulk density and pore volume to determine the effects of grazing. Compaction was detected in only the top 4 inches of the soil at two sites, top 2 inches at a third site, and not readily apparent at the fourth site. Texture classes and age of the exclosures appears to be important considerations.

118. Orr, H. K. 1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. For. Ser. Res. Pap. RM-60: 12 p.

Growth of seeded species in combination with reestablishment of native vegetation reduced overland runoff and soil erosion to tolerable levels within one to four growing seasons. Gross rainfall was a poor indicator of runoff and soil erosion from small plots. Trende were best defined by declining rates of runoff and sediment production per unit of excess rainfall. Sixty percent ground-cover density (live vegetation plus litter) is postulated as the minimum necessary for soil stabilization. This cover density almost certainly could not have been reached within the 4-year study period without seeding. Seeded grasses-timothy and Kentucky bluegrass on coarse-textured soil and timothy and smooth brome on fine-textured soil-were especially important because of their dispersion and abundance, and persistence of litter production.

119. Orr, H. K. 1975. Recovery from soil compaction on blue-grass range in the Black Hills. Trans. ASAE 18:1076-1081.

Not until the second year after fencing did soils on heavily grazed bluegrass range show significant increase in macropore volume. Infiltration capacities also increased and summer runoff decreased. Results indicated that more than one season of protection is necessary for significant soil recovery.

120. Osborn, B. 1952. Storing rainfall at the grass roots. J. Range Mange. 5:408-414.

Range condition and water intake are discussed for sites in Texas and Oklahoma. Generally, infiltration was higher with better range condition, unless there was an impermeable layer restricting moisture movement.

Relationships between bulk density and organic matter to water loss were also included.

121. Packer, P. E. 1953. Effects of trampling disturbance on watershed condition, runoff, and erosion. J. For. 51:28-31.

This study was carried out on a portion of the Boise River watershed in Idaho. The study was designed to find out what influence trampling had on bluebunch wheatgrass and cheatgrass ranges which normally had sufficient protective cover (approximately 70% cover or more). The 70% figure includes aerial plant cover plus litter and rock cover. Following the artificial trampling, a modified type F infiltrometer was used.

The study showed that if the given site had 90 to 95% initial ground cover that overland flow and soil erosion was maintained at a safe level even under 60% trampling disturbance. If initial ground cover on wheatgrass and cheatgrass sites were in the range of 70 to 85 percent, then a trampling disturbance of from 20 to 40% caused increases in overland flow and soil erosion beyond that which was considered a safe maximum amount.

122. Packer, P. E. 1963. Soil stability requirements for the Gallatin Elk winter range. J. Wildl. Manage. 27:401-410.

From various plots which were installed to measure ground cover density, soil bulk density, and soil eroded by high-intensity rainfall, it was found that management objectives for restoring and maintaining soil stability on this elk winter range include ground cover densities of at least 70% and soil bulk densities no greater than 1.04 g/cc.

123. Paulsen, H. A., Jr. 1975. Range management in the central and southern Rocky Mountains: A summary of the status of our knowledge by range ecosystems. For. Ser. Res. Pap. RM-154: 34 p.

Summarizes a series of comprehensive reports on the seven recognized ecosystems: Semidesert grass-shrub, southwestern chaparral, pinyon-juniper, central Rockies ponderosa pine-bunchgrass, Arizona ponderosa pine-bunchgrass, mountain grassland, and alpine. Includes what is known, what can be recommended, and what additional information is needed for each ecosystem.

124. Pearson, G. A., G. A. Jung, R. E. Fowler, and D. M. Mitchell. 1975. Effects of grazing on infiltration rates in waste-water spray fields. Soil Sci. Soc. Am. Proc. 39:954-957.

Many food-processors use grass-covered sprayfields for treating waste water. These fields are generally mowed one or more times each year. To eliminate mowing costs, such fields could be fenced and used as irrigated pastures. However, since the primary purpose of such fields is waste water treatment, adverse effects on infiltration must be avoided, particularly in areas with shallow soils that cannot be manipulated for overland flow.

A portion of a food-processor's wastewater treatment field was fenced and grazed for approximately 5 months during the summer and fall of 2 successive years. The soil series was Sassafras sandy loam and the grass species were 'Kentucky 31' tall fescue (Festuca elatior var. arundinacea (Schreb.) Wimm.) and orchardgrass (Dactylis glomerata, L.).

The infiltration rate at saturation was measured frequently throughout the period of grazing. It was found that trampling reduced the infiltration rate from an initial value of 2-2.5 cm/hr to a final value of 0.3 cm/hr.

125. Pickford, G. D. 1932. The influence of continued heavy grazing and of promiscuous burning on spring-fall ranges in Utah. Ecol. 13:159-171.

Primarily concerned with vegetation type changes following grazing, burning, and grazing-burning treatments. Results indicated for heavy grazing a decrease in total plant density with a shift from perennial grasses to sagebrush.

126. Platts, W. S. 1978. Livestock interactions with fish and aquatic environments: Problems in evaluation. In Trans. 43rd North Amer. Wildlife and Natural Resour. Conf.: 498-504.

Present grazing systems are not compatible with the environmental needs of streams.

A methodology is presented to determine more quantitatively the impacts of grazing on fisheries. Needs include removing the natural variation and unbiased evaluation of stream environment conditions.

127. Platts, W. S. 1978. Livestock interactions with fish and their environments: A symposium summary. In Cal.-Nev. Wildlife Trans.: 92-96.

Assesses the influence livestock have on aquatic and riparian environments, provides recommendations for more compatibility between livestock grazing and fisheries, lists management objectives for protecting, restoring, or enhancing fish and riparian habitats, and describes beneficial management practices. The importance of recognizing the riparian ecosystem as a separate management unit within the range system was emphasized.

128. Ratliff, R. D. and S. E. Westfall. 1971. Non-grazing and gophers lower bulk density and acidity in annual-plant soil. For. Ser. Res. Note PSW-254: 4p.

After 34 years of non-grazing use, the soil exhibited lower surface bulk density and acidity than an adjacent grazed site.

129. Rauzi, F. 1956. Water-infiltration studies in the Bighorn National Forest. Wyoming Agr. Exp. Sta. Cir. No. 62. 7 p.

One hour infiltrometer runs were made on pastures which were pitted and non-pitted. Generally, lightly grazed pastures had higher infiltration rates at the end of the test period.

The pitted range held 39% more water during the second 30-min. period of the test from the adjoining non-pitted range.

130. Rauzi, F. 1960. Water-intake studies on range soils at three locations in the Northern Plains. J. Range Management. 13:179-184.

One hour infiltrometer tests were made at one North Dakota and two Montana sites. Vegetation and litter analyses were also concluded in conjunction with the infiltrometer runs. Sites were classed as high or fair range condition and low or poor condition.

Ranges rated in high condition absorbed almost three times as much water as those rated in low conditions.

Regression analysis was employed to determine the effects of vegetation and mulch on infiltration, and it was found these two variables could account for 45-84 percent of the variation depending on the site.

131. Rauzi, F. 1963. Water intake and plant composition as affected by differential grazing on rangeland. J. Soil & Water Conser. 18:114-116.

Infiltration studies were conducted on native pasture grazed at three different intensities. Results indicated that loss of surface cover and heavy grazing reduced water intake. Total infiltration on the moderately grazed site was 1.6 times greater than the heavy grazed sites. The ungrazed area had a cumulative of 1.8 times that on the moderately grazed site.

132. Rauzi, F. and A. R. Kuhlman. 1961. Water intake as affected by soil and vegetation on certain western South Dakota rangelands. J. Range Management 14:267-271.

During the summer months of 1957 and 1958, water intake studies were conducted on rangeland watersheds in the ten- to fourteen-inch precipitation belt new Newell, South Dakota.

Data from four range sites on four watersheds showed that water-intake rates were correlated with range sites, as mapped by the SCS, where the range condition class was comparable. The effects of surface conditions such as texture, cracking, and amount of cover are important factors but during prolonged rainfall sub-surface features become important in determining the amount of water absorbed during a storm event.

133. Rauzi, F. and C. L. Hanson. 1966. Water intake and runoff as affected by intensity of grazing. J. Range Management 19:351-356.

Water intake rates on differentially grazed rangeland watersheds had a nearly linear relationship with the heavily grazed watershed the lowest and the lightly grazed watershed the highest rate. Annual runoff was greatest from heavily grazed watersheds and least from the highly grazed. Storm characteristics were a factor in the production of runoff.

134. Rauzi, F., C. L. Fly, and E. J. Dyksterhuis. 1968. Water intake on mid-continental rangelands as influenced by soil and plant cover. USDA Tech. Bull. No. 1390: 58p.

Infiltration studies were conducted with a sprinkling infiltrometer on rangeland sites in six states in the northern and central plains. Analysis indicated that infiltration in the second thirty minutes of the 1 hour run was most clearly correlated with vegetal cover or total weight of herbage. Soil structure was the most important soil parameter in terms of infiltration.

135. Rauzi, F. and F. M. Smith. 1973. Infiltration rates: Three soils with three grazing levels in northeastern Colorado. J. Range Management 26:126-129.

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 after 20 minutes of simulated rainfall.

136. Read, R. A. 1957. Effect of livestock concentration on surface-soil porosity within shelter belts. J. For. 55:529-530.

Bulk density, total pore space, and large pore space of surface three inches of soil were compared for three South Dakota shelter belts. Results indicated statistically significant differences between protected and grazed sites.

137. Reed, M. J. and R. A. Peterson. 1961. Vegetation, soil and cattle responses to grazing on northern Great Plains Range. USDA Tech. Bull. No. 1252: 79 p.

Study was conducted from 1932-1946 on both winter and summer ranges; information on stocking rates was given. Heavy summer grazing reduced litter cover, volume of roots, and organic matter of the surface soil. Bulk density increased, and infiltration rate decreased as did depth of water penetration. Intermediate and light stocking levels during the summer as well as winter grazing did not indicate as much of an effect.

138. Reigner, I. C. 1951. Erosion studies on the Schoharie Watershed, New York. For. Ser., Northeast Forest Exp. Sta., Sta. Paper 44:17 p.

Sedimentation of Schoharie Reservoir was measured in 1950, when drought had dropped water levels to record lows. Accumulated sediment had reduced total capacity by 1.75 percent in 24 years. Fifty-five percent of the watershed is covered with forest and 43.5 percent is in grass. Forty-six percent of the watershed was moderately eroded; 80 percent of this area was in grass. Only 0.39 percent of the watershed was severely eroded. Road banks, streambanks, and reservoir shore lines contributed about 6 percent of the sediment. Better grazing practices could do much to prevent erosion. A thorough study of the watershed, with view to planning a land-use program, is recommended.

139. Rhoades, E. D., L. F. Locke, E. H. McIlvain, and H. M. Taylor. 1964. Water intake on a sandy range is affected by 20 years of differential cattle stocking rates. J. Range Management 17: 185-190.

Study was conducted in northwestern Oklahoma with four levels of continuous cattle grazing imposed for 20 years. Infiltration rates were inversely proportional to grazing intensity. Bulk density and penetrometer measurements indicated that grazing compacted the soil. Little soil loss was observed even on the heavily grazed sites.

Infiltration rates were correlated with quantity of vegetative cover, living and dead, and range condition class.

140. Rich, J. L. 1911. Recent stream trenching in the semi-arid portion of southwestern New Mexico, a result of removal of vegetation cover. Amer. J. Sci. 32:237-245.

Describes the nature of the recent stream trenching in the semi-arid portion of southwestern New Mexico and gives evidence that this condition is the result of the removal of vegetative cover. Gives a description and history of Cane Springs Canyon as a typical valley and discusses the features and conditions of the valley filling. Notes that existence of course stream gravel overlying finer alluvial matter in the bottom of trenches indicates that its deposition is recent and due to increased volume of flood waters. Increased volume of flood waters is a result of increased runoff due to the removal of vegetative cover brought about by over stocking. Sights historical evidence that the reduction in cover as a result of over stocking has taken place and flood increases coincident with trench formation are of recent date.

141. Rich, L. R. 1961. Surface runoff and erosion in the lower chaparral zone-Arizona. For. Serv., Rocky Mtn. Forest and Range Exp. Sta., Sta. Paper No. 66: 35 p.

Two watersheds in this 9 watershed experiment were opened to grazing and comparisons were made. Comparisons of the areal average infiltration capacities for a ten year period 1932-41 indicated no grazing effects.

142. Rich, L. R. and H. G. Reynolds. 1963. Grazing in relation to runoff and erosion on some chaparral watersheds of central Arizona. J. Range Management 16:322-326.

These data suggest that chaparral lands of central Arizona, where characterized by an interspersion of shrubs and perennial grass on moderate topography, can be properly grazed without detriment to soil stability or water regime. If no more than 40% of perennial grass production is removed at the end of the summer growing season, ground cover does not deteriorate and appears sufficient to maintain a stable soil.

143. Robbins, J. W. D. 1978. Environmental impact resulting from unconfined animal production. Environmental Protection Agency Rpt. EPA-600/2-78-046: 34 p.

This report outlines and evaluates current knowledge related to environmental problems resulting from unconfined animal production. Animal species directly addressed are cattle, sheep, and to a limited extent, hogs. Information for the report came from literature and current research reviews plus direct inputs from a group of 17 specialists in the subject field.

Unconfined animal production utilizes about 40% of U.S. land area, consists of hundreds of thousands of individual units, receives almost 50% of all livestock wates, and is compatible with a high quality environment. Associated environmental problems are limited to those that affect surface water quality. These nonpoint source problems are not directly related to number of animals involved; they are intimately dependent on hydrogeological and management factors and are best described as results of the erosion/sediment phenomenon.

144. Sampson, A. W. and L. H. Weyl. 1918. Range preservation and its relation to erosion control on western grazing lands. U.S. Dept. Agr. Bull. 675: 35 p.

Discusses erosion damages and factors determining the amount of erratic runoff and erosion. Notes the effect of silt on fish and other aquatic life. Comments on excessive erosion and debris deposition due to flood of July 28, 1912, at head of Ephraim Canyon and to flood of July 30, 1912 in Becks Canyon in the Manti National Forest, Utah. Gives preventative and remedial measures.

145. Sarkisyan, S. S. and E. F. Shur-Bagdasaryan. 1967. Interaction of vegetation and soils of various mountain steppe pastures overgrazed and eroded to different extents. Pochvovedenie No. 12:37-44.

On lightly grazed, non-eroded soil in Armenia, the sub-aerial and subterranean biomass was 5-10 times greater than on heavily or very heavily grazed and eroded soils. Thickness of the humus horizons (A + B) of soil decreased with increased grazing intensity, and those horizons were absent from very heavily grazed soils.

146. Sartz, R. S. 1970. Effect of land use on the hydrology of small watersheds in southwestern Wisconsin. In Symposium on the Results of Research on Representative and Experimental Basins, Wellington, N.Z., IASH/AIHS/UNESCO: 286-295.

Runoff was compared between a heavily grazed catchment (grazed throughout the growing season) and a lightly grazed catchment (grazed only at the end of the growing season). Peak flow rates were three times higher from the heavily grazed pasture for 5 large events measured. Maximum sediment concentrations also indicated the effect of increased grazing intensity.

147. Severson, K. E. and C. E. Boldt. 1978. Cattle, wildlife, and riparian habitats in the western Dakotas. In Management and Use of Northern Plains Rangeland. Reg. Rangeland Symp., Bismarck, N.D., Feb. 27-28: 91-103.

Impact of cattle on riparian zones is considered. Particularly important is the fact that these zones occupy relatively little area and will be overused no matter what the stocking rate. There is an indication that winter grazing does not seem to damage riparian zones as much as summer grazing. Common grazing systems two- and three-pasture deferred rotation did not appear to benefit riparian zones. Rest rotation has not been evaluated.

148. Sharp, A. L., J. J. Bond, J. W. Neuberger, A. R. Kuhlman, and J. K. Lewis. 1964. Runoff as affected by intensity of grazing on rangeland. J. Soil & Water Conserv. 19:103-106.

In studies initiated near Cottonwood, South Dakota, in 1963, runoff was measured on ranges that had been subjected to light, moderate, and heavy grazing since 1942.

The measurements of runoff made during 1963 indicate that runoff normally increases with increases in pressure and that heavy grazing is particularly condusive to increasing the proportion of rainfall that occurs as runoff. However, the data also show that with unusually abundant rainfall over a period of time, runoff from lightly grazed areas may be greater than from those moderately or heavily grazed. The antecedent soil moisture is important when considering this latter point.

149. Smeins, F. E. 1975. Effects of livestock grazing on runoff and erosion. In Watershed Management, Proc. ASCE Symp., August 11-13, Logan, Utah: 267-274.

Review of domestic livestock production impacts on vegetation and soils of the watershed. Concludes that moderate grazing may not increase erosion, but could increase runoff in relation to lightly grazed and ungrazed areas.

150. Smith, D. R. 1967. Effects of cattle grazing on a ponderosa pine-bunchgrass range in Colorado. USDA Tech. Bul. No. 1371: 60 p.

Three grazing intensities were employed: 1) light 10-20 percent removal of current growth and dominant forage grasses; 2) moderate 30-40 percent; and 3) heavy greater than 50 percent.

Erosion rates measured by an infiltrometer were two to four times higher under heavy grazing than light grazing.

Infiltration rates decreased in an area protected from cattle grazing for 11 years, while they remained about the same for the intensity of grazing over the other sites.

151. Springfield, H. W. 1976. Characteristics and management of southwestern pinyon-juniper ranges: The status of our knowledge. For. Serv. Res. Paper RM-160: 32 p.

The major problem in the pinyon-juniper type is widespread deterioration of the range resources due to overgrazing and increases in tree density. General guidelines are available for judging the condition and grazing management of pinyon-juniper ranges, as well as for deciding where and how to control trees.

152. Steinbrenner, E. C. 1951. Effect of grazing on floristic composition and soil properties of farm woodlands in southern Wisconsin. J. For. 49:906-910.

Grased and ungrazed sites were compared in six woodlots located in Wisconsin. Water permeability indicated that ungrazed sites could transmit water from 3.3 to 245 times faster than grazed soils. Porosity was greater on ungrazed vs. grazed sites, as was organic matter content.

153. Stephenson, G. R. and L. V. Street. 1978. Bacterial variations in streams from a southwest Idaho rangeland watershed. J. Environ. Qual. 7:150-157.

Sources and variations in bacterial indicators are reported from stream sites over a 3-year period on a 233 km^2 rangeland watershed in southwest Idaho. The occurence of fecal coliforms was indirectly related to the presence of cattle on summer range and winter pastures. Fecal coliform counts in adjacent streams were found to increase soon after cattle were turned in and remained high for several months after cattle were removed.

Runoff from rainstorms increased both total and fecal coliform concentrations in streams on summer range with limited management and adjacent to winter pastures, but runoff from snowmelt had little effect. Total coliform counts varied mroe with change in streamflow than did fecal coliform counts. In fenced summer range allotments, under deferred grazing management, the effects were the same, except bacterial counts were not as high or persistent.

The decrease in bacterial concentrations at several downstream sampling sites indicated that certain stream segments were self-purifying. The presence or absence of livestock along the streams overshadow any effect variations in chemical concentration of the water might have on bacterial concentrations.

154. Stewart, G. and C. L. Forsling. 1931. Surface run-off and erosion in relation to soil and plant cover on high grazing lands of central Utah. J. Amer. Soc. Agron. 23:815-832.

Results are presented from 2 experimental watersheds of approximately equal area in central Utah, at an elevation of about 10,000 feet.

Of the total run-off from the depleted area (16% plant cover) during 1915-1920, 4.16% was due to summer rainfall and 95.4% due to melted snow. The summer rainfall, however, carried 80.1% of the total sediment removed. After the plant cover had improved to 40%, only 1.3% of the total run-off resulted from summer rains.

By increasing the cover on the depleted area to 40% cover, the total sediment eroded decreased 46% and the amount carried in each 1000 cubic feet of run-off water decreased 57%.

Even when the previously depleted area was restored to 40% cover the runoff and sediment production was greater than the continuously well-vegetated area. Roughly, 3 to 5 times as much total water ran off the area with the poorer plant cover.

155. Stewart, G. R. 1933. A study of soil changes associated with the transition from fertile hardwood forest land to pasture types of decreasing fertility. Ecol. Monogr. 3:107-145.

Typical soil conditions associated with the growth of hardwood forest, pasture grasses, and moss and fern were investigated in central New York. Change from trees to grass resulted in a loss of permeability to water, smaller water-holding capacity, and lessened air space. Forest soils and better pasture types have significantly deeper A and B horizons than did the poor grazing land, or the moss and fern areas. Root growth of better pasture grasses was more extensive than that of the poorer. Forest soils possessed the highest initial content of nutrates. Kentucky blue grass soils had the highest level of mineral nutrients.

156. Striffler, W. D. 1964. Sediment, streamflow, and land use relationships in northern Lake Michigan. For. Ser. Res. Paper LS-16: 12 p.

Various land uses were compared within a drainage basin. Pasture occupied 18 percent of the land area and contributed 24 percent of the average sediment load. Fluctuations in stream discharge were theoretically higher from pastures.

157. Swift, T. T. 1926. Date of channel trenching in the southwest (letter to editor). Sci. 63 (letter refers to "Date of Channel Trenching in the Arid Southwest" by Bryan): 70-71.

Cites writers observations on bank erosion, increased channel width, floods of the Gila River, and arroyo cutting on Sansimon Wash as a result of overgrazing.

158. Talbot, M. W., H. H. Biswell, P. B. Rowe, and A. W. Sampson. 1942. The San Joaquin Experimental Range. Other studies and experiments in the program of the San Joaquin Experimental Range. Calif. Agr. Exp. Sta. Bull. 663:136-142.

Describes studies on artificial reseeding of rangeland, runoff, and erosion as affected by cattle grazing, and the chemical composition of important range plants. Nine 1/40-acre plots were established on gentle slopes with grass cover for the runoff and erosion studies. The plots were left ungrazed during 4 rainy seasons for purposes of calibration. During the next two seasons grazing of light and moderate intensity of cattle showed no significant increase in surface runoff and erosion. The study did not investigate total water yield nor the effects of heavy grazing.

159. Tanner, C. B. and C. P. Mamaril. 1959. Pasture soil compaction by animal traffic. Agron. J. 51:329-331.

Animal traffic caused serious compaction of fine textured pasture soils, severely decreased pore-space open to aeration, and caused a 20% decrease in alfalfa-brome-Ladino yields during the first pasturing year on Ontonogan clay loam.

160. Thilenius, J. F. 1975. Alpine range management in the western United States -- principles, practices, and problems. The status of our knowledge. For. Ser. Res. Pap. RM-157: 32 p.

Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

161. Thomas, G. W. and V. A. Young. 1954. Relation of soils, rainfall and grazing management to vegetation -- western Edwards Plateau of Texas. Texas Agr. Exp. Sta. Bull. 786: 22 p.

Ring infiltrometer were used in this study. Results indicate the sod effects on initial infiltration, but in terms of a final constant rate the effects were seen in only 1 sod forming type.

162. Thompson, J. R. 1968. Effect of grazing on infiltration in a western watershed. J. Soil & Water Conserv. 23:63-65.

Infiltrometer experiments and measurements of ground cover and soil bulk density were made on grazed and ungrazed plots of sparse, desert-shrub type vegetation growing on poor, shallow soils developed on Mancos shale. Results indicate that infiltration is affected less by grazing than by seasonal changes in soil-surface characteristics.

163. Tiedemann, A. R. and H. W. Berndt. 1971. Vegetation and soils of a 30-year deer and elk exclosure in central Washington. Northwest Sci. 16:59-66.

Quantity of vegetation and litter were higher in an exclosure than the adjacent area still accessible to wildlife. No differences in the soils of the two sites were noted.

164. Trimble, G. R., C. E. Hale, and H. S. Potter. 1951. Effect of soil-water relationships. For. Serv., Northeastern For. Exp. Sta. Pap. No. 39: 44p.

In this study, grazing was indicated as having the greatest effect on soil-water relationships. Organic matter content was reduced by 32 percent and bulk density increased by 80 percent. Water movement and detention storage were reduced in the upper layers (A horizon).

165. Tromble, J. M., K. G. Renard, and A. P. Thatcher. 1974. Infiltration for three rangeland soil-vegetation complexes. J. Range Manage. 27:318-321.

A rotating disk rainfall simulator was used to examine infiltration-runoff relations from selected rangeland sites as influenced by a soil-vegetation complex. The simulator assisted in quantifying infiltration rates for different management practices on different soil types. Infiltration was greater for brush dominated plots than for either grazed plots or grass plots without grazing. Antecedent soil moisture decreased infiltration rates. Crown cover was approximately twice as much as brush plots as on grass plots and significantly influenced infiltration.

166. Turner, G. T. 1971. Soil and grazing influences on a salt-desert shrub range in western Colorado. J. Range Management 24:31-37.

Responses of vegetation and ground cover to winter grazing by livestock and to exclusion of livestock for 10 years were observed on soils derived from shale, sandstone, and a mixture of shale and sandstone. Although distinct soil-vegetation relationships were evident, changes attributed to grazing were relatively small. Vegetation and other cover on nongrazed range was practically the same at the end as at the beginning of the study. Overall reductions in galleta, shadscale and snakeweed were attributed to drought, while differential responses of Salina wildrye, Gardner saltbush, Greenes rabbitbrush, and annual plants were ascribed to grazing. Inherently low site capability and subnormal precipitation were believed responsible for the general lack of response of vegetation to exclusion of livestock.

167. Turner, G. T. and H. A. Paulson, J4. 1976. Management of mountain grasslands in the central Rockies: The status of our knowledge. For. Serv. Res. Pap. RM-161: 24 p.

Knowledge is generally adequate for proper grazing management of these grasslands, but management and improvement costs tend to be relatively high because of their remoteness. Suggested improvements to increase range usability, improve forage production, and control livestock must be coordinated with water and timber production, and wildlife and recreation needs.

168. U.S. Forest Service. 1940. Influences of vegetation and watershed treatments on runoff, silting, and streamflow. U.S.D.A. Misc. Publ. 397: 80p.

This paper is a summary progress report of research dealing with land-water relationships, particularly the basic relationships between land use and runoff, debris deposition, the shoaling of stream channels, silting of reservoirs, and other phenomena that have followed logging, cultivating, burning and grazing. Includes a discussion on reservoir silting.

169. Van Doren, C. A., W. L. Burlison, L. E. Card, and R. F. Fuelleman. 1940. Effect of soil treatment and grazing management on the productivity, erosion, and runoff from pasture land. J. Amer. Soc. Agron. 32:877-887.

Plots were treated with limestone and phosphorous and regulated and intensive grazing were superimposed. On treated plots, regulation of grazing increased vegetal cover 3 to 4 times over the treated-intensively grazed plots; no difference in cover was noted for untreated plots under either grazing scheme. Essentially the same pattern held for runoff and sediment with treated-intensive grazing having more runoff and about the same soil loss. Land with no soil treatment indicated no response to grazing management.

170. Van Keuren, R. W., J. L. McGuinness, and F. W. Chichester. 1979. Hydrology and chemical quality of flow from small pastured watersheds: I. Hydrology. J. Environ. Qual. 8:162-166.

Surface runoff, soil loss, and subsurface flow were measured from four rotationally grazed summer pastures. One of these pastures was also used as a winter-feeding area. Surface runoff volumes and peak rates from the three pastures used only for summer grazing were generally less as compared with values for earlier years when the fields were in meadow and light pasturing; however, runoff from the winter-feeding area was markedly increased. Both before and after the initiation of grazing, the area used only for summer grazing had but a trace of soil loss.

More soil was lost from the winter-feeding area, particularly during the dormant season. Water-balance studies indicated that during the growing season surface run-off and subsurface outflow were higher and evapotranspiration (ET) was less from the winter-feeding area than from areas summer-grazed only. During the dormant season, surface runoff was higher and subsurface outflow was lower from the winter-feeding area than from the summer-grazed areas, whereas ET was similar.

171. Whitman, W. C., D. Zellar, and J. J. Bjugstad. 1964. Influence of grazing on factors affecting water intake rates of range soils. Abstract from Proc. N. Dakota Acad. Sci. 18:71.

Comparisons between ungrazed or lightly grazed and moderately to heavy grazing on seven range soil types in North Dakota were made for the period between 1962-63.

No effects were detected on organic matter content between uses and bulk density was 1.16 g/cc on ungrazed versus 1.23 g/cc on grazed sites.

Infiltration rates for the second inch of applied water averaged 6.0 in/hr for ungrazed and 3.1 in/hr for grazed areas. Reduction in mulch was given as the reason for reduced infiltration rates.

172. Wind, G. P. and C. J. Schorthorst. 1967. The influence of soil properties on suitability for grazing on soil properties. Trans. 8th Int. Congr. Soil Sci., 1964, 2:571-580.

The bearing capacity depends mainly on the bulk density of the topsoil; during grazing, bulk density increases by compaction until the bearing capacity equals the hoof pressure of the cattle. Trampling damage, instead of compaction, occurs when the soil is wet to saturation. To avoid trampling damage, depth of the ground-water table in peaty soil must be at least 60 cm during grazing in wet periods. Aeration and bearing capacity showed an inverse relationship.

173. Woods, C.N. 1948. Floods and the grazing of livestock on the watersheds of Utah. J. For. 46:387-389.

A letter concerning generation of the disastrous floods in Utah. The author takes issue with a G. S. G. S. Water Supply Paper No. 994, Cloudburst Storms in Utah, which indicated natural phenomenon not land use activities caused floods. Mr. Woods provides information to contradict the conclusion reached in Water Supply Paper No. 994.

174. Woodward, L. and G. W. Craddock. 1945. Surface runoff potentials of some Utah range-watershed lands. J. For. 43:357-365.

How much, when, and why surface runoff occurs on mountainous range-watershed lands is of vital concern to wildland managers who must husband limited soil moisture to maintain productivity and at the same time protect down-stream areas from damage by floods and sedimentation. This paper describes the rainfall and infiltration characteristics responsible for overland flow on some of the mountain lands in Utah. Basic data are combined in three theoretical analyses to show (1) the amount of surface runoff to be expected for a number of sites when subjected to a major storm; (2) the minimum storm that will produce runoff; and (3) the frequency at which runoff can be expected. The results indicate that great diversity of surface runoff on the mountain lands and the ways in which resource management can augment or reduce the hazard of overland flow.

175. Woolhiser, D. A., C. L. Hanson, and A. R. Kuhlman. 1970. Overland flow on rangeland watersheds. In Results of Res. on Representative and Experimental Basins, Wellington, N.Z.: 23-39.

Describes the application of the kinematic cascade to model overland flow from watersheds which have different grazing intensities. Roughness for these conditions is discussed.

176. Woolley, R. R. 1933. Floods in well forested regions (letter to editor). Civil Engin. 3 (comments on the article "Influence of Overgrazing on Erosion and Watersheds: by Chapman): 296-287.

Erosion due to rainfall and topography rather than over-grazing. Serious floods also occur in Vermont where overgrazing is unreported. Floods near Pueblo, Colorado were greater before grazing than after. The Wasatch Plateau in Utah provides favorable conditions for cloud bursts, hence floods result.

177. Yamamoto, T. 1963. Soil moisture contants and physical properties of selected soils in Hawaii. For. Ser. Res. Note PSW-2: 10 p.

Data representing known land use are grouped into four categories: Forest, cultivated area, pasture, and idle grassland.

178. Yamamoto. T. and P. Duffy. 1963. Water storage capacities of soil under four different land uses in Hawaii. For. Serv. Res. Note PSW-5: 4 p.

Pore volume and size were higher under forest cover than under cultivation, pasture, or idle grassland.

179. Yates, M. E. 1971. Effects of cultural changes on Makara Experimental Basin: Hydrological and agricultural production effects of two levels of grazing on unimproved and improved small catchments. J. Hydrol. (N.Z.) 10:59-84.

The effects of hard and lax grazing of unimproved and over-sown and topdressed pastures on small catchments of 0.6 - 1.5 hectares are discussed.

The oversowing and topdressing has resulted in a trebling of pasture production and, when hard grazed, a trebling of stock-carrying capacity. Under lax grazing, the stock-carrying capacities of both unimproved and improved pastures have been reduced to two-thirds of those pertaining under hard grazing.

Oversowing and topdressing decreased annual runoff, increased surface retention, reduced the number of days on which flow occurred, and reduced the percentage of occurrence of given daily runoffs over the greater part of flow range. Individual hydrographs have shown no increase in rise time but an increase in lag and depletion time, decreased flow before the peak, decreased peak discharges and decreased runoff. The magnitude of these changes was greater when the improved pastures were lax grazed.

Appendix C

Annotated Bibliography on Economic and Socio-Political Issues

Books

Bean, M. 1971. The Evolution of National Wildlife Law. Government Printing Office, Washington, D.C.

Comprehensive analysis of the development of federal, as opposed to state, wildlife laws and management programs. Especially useful regarding historic definition of wild animals and the development of the state ownership doctrine. In addition, it discusses the history of the Act and of wildlife management on federal lands.

Brrokshier, Frank. 1974. The Burro. University of Oklahoma Press, Norman, 370 p.

Eloquent and appealing account of the burro's past and present, emphasizing value to man because of faithful and useful service. Qualitative.

Calef, W. 1960. Private Grazing and Public Lands: Local Management of the Taylor Grazing Act. University of Chicago Press, Chicago.

Case study approach to management of the public lands under the Taylor Act with focus on the impact of grazing advisory boards.

Ching, C. T. K. (compiled by). 1978. Forum on the Economics of Public Land Use in the West. Sponsored by the Farm Foundation and the Division of Agricultural and Resource Economics, University of Nevada, Reno.

March 1977 gathering of researchers and others interested in the problems of public land use in the Western states. Contains an excellent bibliography of work conducted by the participants of the forum.

Clawson, Marion. 1971. The Bureau of Land Management. Praeger Library of U.S. Government Departments and Agencies. New York: Praeger Publishers.

Clawson reviews the history of BLM, describes policies, deals with conflicts taking place, and discusses BLM's future. Of main interest are the sections on grazing, environmental management, and outdoor recreation.

Dana, S. T. and Fairfax, S. K. 1980. Forest and Range Policy (2d Edition). McGraw Hill Publishing Co., New York.

Comprehensive history of the development and evolution of forest and range management policy from colonial times to the present. Special attention is given to analyzing continuing policy trends and the influence of various interest groups.

Dobie, J. Frank. 1952. The Mustangs. Little, Brown, Boston: 376 p.

Highly anecdotal and sympathetic history of the wild horses. Emphasizes values of freedom and wildness. Early classic work .

Foss, A. 1960. Politics and Grass. University of Washington Press, Seattle.

This book analyzes the implementation of the Taylor Grazing Act, the role of the various interest groups, and their impact on BLM decision-making.

Gates, P.W. 1968. History of Public Land Law Development. Government Printing Office, Washington, D.C.

Comprehensive history prepared for the Public Land Law Review Commission. Useful in order to understand the development of land ownership patterns and the forces impacting the enactment and implementation of the major federal land management laws.

Henry, Marguerite. 1966. Mustang: Wild Spirit of the West. Rand McNally, Chicago: 224 p.

Young adult book on the early history of the horse and Velma Johnston's fight to save it. Displays humane, preservationist attitude.

Henry, Marguerite. 1953. Brighty of the Grand Canyon. Rand, New York.

Classic children's account of a Grand Canyon burro. The antics and love of life of Brighty personify the humane, "right-to-life" attitude.

Nathan, Harriet, editor. 1972. America's Public Lands: Politics, Economics and Administration, Conference on the Public Land Law Review Commission Report, December 1970. Institute of Governmental Studies, Berkeley: University of California.

The conference analyzes the PLLRC'S report of 1970. The Economics and the Public Lands section was handled well by Marion Clawson. Policies for the future were also discussed.

Peffer, E. Louise. 1951. The Closing of the Public Domain. Stanford University Press, Stanford.

Comprehensive discussion and analysis of the fight to close the public lands to disposition under the homestead acts, including a thorough critique of those laws, the legislative history of the Taylor Grazing Act and its implementation.

Ryden, Hope. 1979. America's Last Wild Horses. Dutton, New York: 311 p.

Comprehensive survey of history, habits, and struggles for protection of wild horses. Some qualitative description of attitudes of various groups. Pro-horse; emphasizes symbolic, freedom and wildness values.

Ryden, Hope. 1972. Mustangs, Return to the Wild. Viking Press, New York: 111 p.

Primarily natural history, profusely illustrated with the author's photographs. Expresses protectionist position.

Stanford Environmental Law Society. 1971. Public Land Management -- A Time for Change? Stanford Law School, Stanford: Stanford University.

The papers presented are an attempt by the Stanford Environmental Law School, to objectively present the major issues involved in the controversy over public land use and to analyze the various reform proposals. The paper of most interest is entitled "Public Land Grazing Management" and covers the statutory guidelines for grazing management; the controversy over grazing fees; the condition of the public lands and how it might be improved; the economic effect of public land grazing; and conflicts between grazing and other uses of the public land.

University of Nevada, Reno, Cooperative Extension Service. 1977. Proc. National Wild Horse Forum, April 4-7.

Presents view of various organizations and groups involved in horse and burro issue. Two articles are of particular interest.

Reavley, William L. Views of wildlife agencies and organizations. Explains views of wildlife agencies towards horses and burros.

Shanks, Bernard. Wild horses and conservation organizations. Discussed involvement of conservation organizations (or lack thereof) in the wild horse and burro problem. Animal protection and wildlife organizations are excluded from the discussion.

Wyman, Walker. 1945. The Wild Horse of the West. Caxton Printers, Caldwell, Idaho: 348 p.

Early classic history of the horse, primarily since 1890. Details influence of horses on Indians and stockmen up to the present, with some qualitative descriptions of their attitudes.

Scientific Journal Articles

Applegate. 1978. The multiple use planning process: Descent into the maelstrom? Environmental Law 8:427.

Analysis of current multiple use planning process from the perspective of citizen action groups. Overview of the planning process followed by discussion of problems such as uneven economic analysis, the lack of effective opportunity for citizen involvement and administrative discretion.

Arizona Law Review. 1979. Symposium: The Federal Land Policy and Management Act of 1976. Ariz. Law Rev. 21(2): 267.

Bean, M. 1977. Developing law of wildlife conservation on the national forest and national resource lands. Contemporary Law 58.

The author analyzes the conflict between the states and the federal government over the authority to manage wildlife on federal lands and the impact of this conflict on the development of national policy toward wildlife conservation on these lands. The article discusses the Act in detail, as well as the Sikes Act and other laws affecting wildlife management on federal lands.

Behan, R. 1967. Succotash syndrome or multiple use: A heartfelt approach to forest land management. Nat. Res. Journ. 7:473.

After discussing the development of the multiple use concept, the author thoroughly criticizes three underlying assumptions (fixed productivity, high demand, and inadequacy of single use management to meet demand). The author then analyzes how deficiencies in theory spawn difficulties in practice.

Burt, Oscar R. 1971. A Dynamic Model of Pasture and Range Investments. Amer. Agr. Econ. 53 (2): 197-205.

The traditional economic replacement problem is extended to accommodate a situation where quasi-rents of future replacements are influenced by replacement age of the currently held asset. This generalized replacement model is applied to optimal timing of the clearing of brush and scrub timber from pasture and range. Dynamic programming is applied to the problem and the structure of the decision rule analyzed. An approximately optimal decision rule is deduced by an analysis of the limiting behavior of the optimal policy. An illustrative example is given for pinyon-juniper control in southwestern United States.

Carothers, S. W.: Stitt, M.E.; Johnson, R.R. 1977. Feral asses on public lands; an analysis of biotic impact, legal considerations, and management alternatives. Trans. North American Wildlife Nat. Res. Conf. 41: 396-406.

Largely biological study showing habitat destruction by feral burros. Gives public sentiment of burro lovers as reason for passage of PL92-195. Believes protection of burros incompatible with sound management of Grand Canyon ecosystem (the study area).

Clauson, M. 1978. Concept of multiple use forestry. Environmental Law 8:281.

Recent analysis of the multiple use concept with emphasis on forest production functions and trade-offs between outputs. the author then discusses problems in valuing both inputs and outputs and the potential application of time discount methods. Concludes that while multiple use can be a vague directive, it can guide a land manager to decisions which provide users with the most of what they want with minimum sacrifice to others.

Comment. 1976. The conservationists and the public lands: Administrative and judicial remedies relating to the use and disposition of the public lands administered by the Department of the Interior. Michigan Law Review 68:1200.

The author examines the structure and function of the Department of the Interior with respect to the use and disposition of the public lands and discusses methods of achieving administrative and judicial review of Departmental decisions. The authors criticizes the amount of discretion available to officials and suggests removing obstacles to judicial review and third party intervention.

Comment. 1973. Managing Federal Lands: Replacing the multiple use system. Yale Law Journ. 82: 767.

The author discusses the multiple use management systems of BLM and the Forest Service contrasting multiple use and limited use directives. After criticizing the multiple use decision-making process, the author suggests establishing more limited use agencies and Congressional allocation of lands among such agencies.

Council for Agricultural Science and Technology. 1974. Livestock Grazing on Federal Lands in the 11 Western States. Journal of Range Management May 1974: 174-181.

Report covers the economic and environmental impacts of grazing on federal lands. Was prepared by a task force consisting of 15 range specialists, none of whom are employed by either BLM or FS. Federal land supplies approximately 12% of all grazing resources in the West. Loss of the products that this grazing supplies would mean more scarcity of feed, meat and wool. Elimination of grazing on public lands would mean a shift of animals to other lands or their loss from production. Authors feel that this would be wasteful of natural resources.

Council for Agricultural Science and Technology. 1975. Multiple Use of Public Lands in the Seveteen Western States. Headquarters Office, Ames, Iowa: Department of Agronomy, Iowa State University.

Multiple use of public lands means a harmonious use of land under which food, fiber, wood and mineral products can be produced for market while recreational opportunities, water, aesthetics and wild life, though non-market commodities, can contribute to the enjoyment of living and to the economies of local communities. The report describes multiple use, analyzes six sources of conflicts, and defines several problems in the application of multiple use.

Culhane, P. and Friesma, P. 1979. Land use planning for the public lands. Nat. Res. Jour. 19:43.

Discussion of the Federal Land policy and Management Act and the National Forest Management Act and their long range planning provisions. Special attention to the impact of these laws on agency planning and the planning process as a formalized policy/decision-making process.

Fulcher, Glen D. 1977. Economic Issues and Future Resource Planning on Public Lands. Paper presented at the Forum on the Economics of Public Land Use in the West, Reno, Nevada, March 10, 1977.

States reasons why the BLM has been hamstrung in its past efforts to administer the public lands, but that with passage of the "Federal Land Policy and Management Act of 1976" a new era in public lands management is beginning. Delineates the new tools that BLM will have at its disposal and stresses the role of the economist in future land policy decisions.

Gordon, Stanley, 1974. One ranch family's adaptation to changing resource demands and social values. J. Range. Mgt. 27(6): 485.

Personal account by author of changes in his own family's attitudes from negative to positive with regard to necessity of planning, management, and regulation for preservation and wise multiple use of the public rangelands.

Hall, G. 1963. The myth and reality of multiple use forestry, Nat. Res. J. 3:276.

The author describes the multiple use doctrine and considers its application on one national forest. The process is then evaluated to determine whether the doctrine promotes the socially best administrative decisions. The author concludes that it is a myth that multiple use forestry is capable of resolving all conflicting demands. The reality is that multiple use decisions are primarily judgments about the costs and benefits of various goods and services.

Houghton, Ruth M. 1978. Sociocultural research for planning and management of a Nevada Bureau of Land Management grazing district. Proc. First International Rangeland Congress: 87-89.

Anthropological research conducted in 1976. Describes socio-cultural groups and values of the district residents with regard to fellow residents and to a limited extent toward land and other natural resources, as well as towards BLM grazing policy. Sample size is not indicated.

Johnson, V. 1972. Fight to save a memory. Texas Law Rev. 50:1055.

This article by "Wild Horse Annie" describes the legislative battle for passage of the Act and the remaining unfinished business as of the date of the article.

__________, and M. J. Pontrelli. 1969. Public pressure and a new dimension of quality - horses and burros. Trans. No. Am. Wildl. Nat. Res. Conf. 34: 240-252.

Detailed history of Johnston's effort and steps in her fight to save wild horses. Key events and their dates. Qualitative account of importance of public reaction in building the protection/management movement. Emphasis on controversy about the establishment of the Pryor Mountain Wild Horse Refuge.

Knott, J. and Willowsley, A. 1979. If Dissemination is the solution, what is the problem? Unpublished Draft M.S.

Koehler, James W. 1960. The California undomesticated burro. Bull. Calif. St. Dept. of Agric. Jan. - Feb.: 1-16.

Concentrates largely on biology and management problems, but includes short section describing California legislation to protect burros as a result of citizens' and humane organizations' lobbying.

Leistritz, F. Larry, and Steven M. Murdock. 1977. Research Methodology Applicable to Community Adjustments to Public Land Use Alternatives. Paper presented at the Forum on the Economics of Public Land Use in the West, March 11, 1977, Reno, Nevada.

Article speaks about adjustment that will have to be made in the West as public land uses change. Describes "local impact analysis," the methodology that the authors have developed for assessing the nature and extent of community adjustments to major resource use changes. This integrated model for developing economic and demographic projections is discussed. Uses input-output (I-O) analysis to project changes in business volume resulting from alternative levels of resource use.

Mack, L. E., and R. G. Taylor. 1979. Some Economic Effects of Restricted Grazing on Public Land in Colorado. Fargo: North Dakota State University of Agriculture and Applied Science.

Federal lands comprise 36% of the total area of Colorado. At present the primary use of these lands is livestock grazing. Pressures present the primary use of these landsis livestock grazing. Pressures exist to reduce, or in some instances eliminate, livestock grazing. This study, through the use of typical ranch models structured by herd size and regional characteristics, examines how the range livestock industry would respond to hypothesized reductions in federal forage availability. Sheep ranchers in Colorado are extremely dependent on federal forage, while cattle ranchers are generally less dependent on federal forage sources. A complete phase-out of grazing on federal lands in Colorado would reduce direct livestock production at a minimum, 50%. Total economic activity in many areas of the state would be virtually eliminated.

Martin, W. 1969. Conflict resolution through the multiple-use concept in Forest Service decision-making, Nat. Res. Jour. 9:226.

The author discusses decision making difficulties and the need to establish system maintenance mechansims, especially if decisions generate conflict. The author theorizes, on the basis of a study of planning on one national forest, that multiple use controls organizational behavior by facilitating adjustment of competing views.

McConnen, R. J. 1977. Research Methodology Applicable to Regional and National Impact of Public Land Use Policy. Paper presented at the Forum on the Economics of Public Land Use in the West, March 11, 1977, Reno, Nevada.

Discussion similar to that of Leistritz citation, but rather than stressing the empirical and positive approach, stresses the conceptual and normative methodological problems involved in changing public land use policy.

McKinney, Harley J. 1977. Economic Issues and problems associated with the National Environmental Policy Act as it Applies to Western Public Lands. Paper presented at the Forum on the Economics of Public Land Use in the West, Reno, Nevada, March 10, 1977.

McKinney's paper discusses the National Environmental Policy Act (NEPA) of 1969, which declares environmental quality to be a national policy and instructs all federal agencies and departments to make a bona fide examination of ecological and environmental factors before making any decision that might affect the environment. With the passage of NEPA, development of the public lands

McKnight, Tom L. 1958. The feral burro in the United States: distribution and problems. J. Wild. Mgt. 22(2): 163-179.

Largely biogeographical study on population numbers and distribution of feral burros, based on a detailed mail questionnaire plus field checking. Pp. 173-176 discuss four management strategies and likely public reaction, based on some literature review plus the author's personal opinions. Whether public opinion was solicited on the questionnaires is not mentioned.

_______________. 1959. The feral horse in Anglo-America. Geog. Rev. 49: 506-525.

Largely biogeographical study on current distribution of feral horses and land-use problems resulting from it, based on 900 mail questionnaires plus field interviews and observations. Pp. 522-524 discuss problems and attitudes toward wild horses elicited by the questionnaire. Includes development of protectionist sentiment.

Nielsen, Darwin B. 1972. Economic Implications of Variable vs. Single Grazing Fees. Journal of Range Management 25 (1):2-6.

The economic implications of variable grazing fees and single grazing fees on Federal lands are important considerations relative to further policy changes. Many factors must be considered when establishing fees on different grazing units. Quantity and quality forage are only two of these factors and generally not the most important ones. Variable grazing fees will have to be implemented if the government is going to minimize the problem of having some of its land over-priced and some under-priced.

O'Hare, M. 1979. Information management and public choice. Energy impacts project. Laboratory of architecture and planning, M.I.T.: Cambridge, Mass.

Pearson, Erwin W. 1974. Sheep-raising in the Seventeen Western States: Populations, Distribution, and Trends. Journal of Range Management 28(1):27-31.

Provides information on numbers and locations of domestic sheep in the 17 western states, which raise about 80% of the United States stock sheep. There has been a downward trend in sheep populations since 1960. The data suggest a gradual shifting of sheep-raising from mountains to plains and a gradual conversion from sheep to cattle.

Sanchez, Peter G. 1977. Native animal habitat protection: a solution becomes a problem. Proc. Symp. Desert. Tortoise Council: 32-40.

Author is Natural Resources Specialist at Death Valley National Monument. Pp. 35-39 analyzes responses of a non-random sample of 241 respondents on 38 alternatives for managing Death Valley's natural and cultural resources. The alternatives were presented in the 1976 Death Valley Environmental Assessment, and responses sought by an accompanying questionnaire. Ten alternatives discussed burro management. Only close-ended questions are analyzed. An analysis of open-ended questions and completed questionnaires may be examined at Death Valley.

Schectman. 1978. The "Bambi Syndrome" How NEPA's public participation in wildlife management is hurting the environment. Environmental Law 8:611.

The author discusses the problem confronting field level wildlife biologists who have identified needed population reduction programs but are impeded by various environmental protection statutes, particularly their public participation requirements. Includes discussion of San Miguel, Death Valley, Grand Canyon and Bandalier burros. Concludes with suggestion that public input be limited, reduced delay and public education.

Scott, L. 1967. The range cattle industry: Its effect on western land law. Montana Law Review 28:155.

The author examines the effect of the range cattle industry, its needs, customs, and practices, on the federal public land laws and states' fence and herd laws. Particular attention is given to the means used to acquire and control range lands and the importance of possession and use in establishing legal rights. The author concludes that the industry made its own law and ignored or disobeyed laws later enacted which did not meet industry needs.

Shanks, Bernard. 1978. Social and institutional barriers to rangeland management innovations. Proc. First International Rangeland Congress: 92-94.

Survey of line managers in BLM, Forest Service, the National Park Service, and the Fish and Wildlife Service to determine how their socioeconomic backgrounds might affect rangeland resource management. Concluded that public range managers in the U.S. accept and apply new rangeland policies and programs slowly, which bears on the horse and burro issue, among others. Sample size approximately 400.

Smith, A. E. 1968. An approach to burro management in California. Trans. Desert Bighorn Council: 59-62.

Describes initiation of interagency effort in California to develop a management plan for feral burros. Advocates management, not elimination of burros on BLM land to benefit burros, wildlife, livestock, and the range. Author is a BLM staff member.

Smith, A. E. and William E. Martin. 1972. Socioeconomic behavior of cattle ranchers, with implications for rural community development in the West. Am. J. Agric. Econ. May: 217-225.

Socioeconomic survey of goals and attitudes of 89 Arizona ranchers toward ranch ownerships, arguing that social and psychological benefits derived from ranging are an important component of economic valuation of ranches. Identifies 11 goals and attitudes held by ranchers toward ranch ownership.

Smith, Arthur H., and William E. Martin. 1972. Socioeconomic Behavior of Cattle Ranchers, with Implications for Rural Community Development in the West. American Journal of Agricultural Economics 54 (2):217-225.

This paper extends the argument that cattle ranching and ranchers can be better understood by viewing the ranch resource as generating both production and consumption outputs. It was found that non-monetary outputs of ranch ownership are the most significant factors in expaining high sale prices of Arizona ranches. The analysis suggest that small town viability and growth in the arid Southwest, and possibly in the West as a whole, may be more likely to occur if rural development policies are not predicated on the economic impact of surrounding ranches.

Stevens, Joe B., and E. Bruce Godfrey. 1972. Use Rates, Resource Flows, and Efficiency of Public Investment in Range Improvements. American Journal of Agricultural Economics 54 (4):611-621.

A theoretical model of interactions between use rates and resource flows over space and time is developed, and a static empirical model is derived for ex post analysis of public range investments on the Vale Project (Oregon). Five investment practices varied widely in their marginal productivities. For every AUM of grazing produced directly by investment, and additional 0.5 AUM was obtained by manipulation of use rates to allow increased natural regeneration. Overall, the Vale Project was inefficient in terms of an implicit redistributional objective as well as the explicit national income objective.

Thomas, Gerald W. 1973. Livestock Grazing on Public Lands: Unity for Political, Economic and Ecological Reasons. Journal of Range Management 26 (4):248-252.

The increased pressure on public lands due to conflicting interests, combined with the increased concern on the part of each individual for the environment, makes it imperative that each land use alternative be carefully examined. Decisions on land use must take into consideration the economic importance of the ranching industry to the nation, the soical and political climate of the times, and most importantly, sound ecological principles.

University of Wyoming, College of Law. 1970. Land and Water Law Review, A symposium presenting an Analysis of the Public Land Law Review Commission Report. Laramie: University of Wyoming.

Symposium came into being to analyze the Public Land Law Review Commission's report to the President, entitled "One third of the Nation's Land." Three sections are of interest, those on range resources, recreation, fish and wildlife; and land planning.

Wilson. 1978. Land management planning processes of the Forest Service. Environmental Law 8:461.

Description of the Forest Service planning process by the Director for planning of the Pacific Northwest Region of the Forest Service.

Wyckoff, J.B. 1977a. Public Lands and the West -- Economic Problems of Neo-Colonialism. Paper presented at the Forum on the Economics of Public Land Use in the West, Reno, Nevada, March 10, 1977.

Public land use is very important to the economy of the West and much work has been done to alleviate problems associated with its use. But, there are many economic problems in the public lands which still need considerable research input. Wyckoff delineates three problem areas: (1) the basic allocation of the public land resources among uses, and among users within uses; (2) problems related the spatial distribution of uses and users; and (3) intertemporal distribution of public land resources and their outputs. He then does a commendable job of delving into the specific problem areas where research is necessary.

Bulletins and Reports

Araji, A. A., W. A. Krasselt and R. W. Schermerhorn. 1978. Impact of the Idaho Beef Industry. Agricultural Experiment Station Bulletin No. 563, Moscow: University of Idaho.

Examines cash receipts from the ranching, feeding, and processing sectors of the Idaho beef industry. In 1971, the direct and indirect impact of the beef industry on the Idaho economy was $357.7 million. In 1973 it had increased to $422.1 million. In 1973, the beef industry's contribution amounted to 12% of the state's total personal income. Has good aggregate figures for the Idaho beef industry. Notes that Idaho ranges are in need of improvement; questions whether private investment will meet the needs.

Bromley, D. W., G. E. Blanch, and H. H. Stoevener. 1968. Effects of Selected Changes in Federal Land Use on a Rural Economy. Agricultural Experiment Station Bulletin 604, Corvallis: Oregon State University.

Examines the extent of grazing of livestock on public lands to ascertain the extent of economic activity attributable to the use of these lands as a source of cattle forage. Projects the impact of a 20% reduction in federal grazing in Grant County in Eastern Oregon. Major impacts of the grazing reduction were a reduction of gross income for the dependent ranch sector of 10.88% and 5.65% reduction of gross income for the Agricultural Service Sector.

Clark, Richard T., Robert R. Fletcher, and Harley J. McKinney. 1974. The Star Valley Economy - an Interindustry Analysis. Agricultural Extension Service Research Journal 85, Laramie: University of Wyoming.

The study provided information to be used in community planning and decision making. It (1) inventoried types of economic activities in the Star Valley; (2) measured interactions between the various economic sectors; (3) estimated the relative importance of the sectors; and (4) identified potential development alternatives for the area's economy.

Cordingly, Robert V. and W. Gordon Kearl. 1975. Economics of Range Reseeding in the Plains of Wyoming. Agricultural Experiment Station Research Journal 98, Laramie: University of Wyoming.

Much of Wyoming's grazing land is not producing forage at its potential economic or physical level. Range reseeding is a good alternative for increased forage without increased acreage. This study determined practices and inputs used, costs, and returns from reseeding. Reseeding not only increased the carrying capacity of the range, but also gave increased livestock gains from feeding and increased reproductive efficiency of the cattle.

Cornelius, Jim. 1977a. Enterprise Costs, 200 Cow-Calf Ranch, Madison County. Cooperative Extension Service Bulletin 1171, Bozeman: Montana State University.

Data was gathered in 1976 from cow-calf enterprises in Northern Madison County and representative costs were calculated for a typical ranch operation in the area. The goal of the bulletin was to help Madison County operators evaluate the feasibility and profitability of operation. Study showed that a typical operation owning its own land with a very modest debt would be losing money. When assumptions were changed to increase real estate debt, the revenue generated barely covered basic cash flow requirements and long term losses mounted.

Cornelius, Jim. 1977b. Enterprise Costs, 200 Cow-Calf Ranch, Powder River County. Cooperative Extension Service Bulletin 1172, Bozeman: Montana State University.

Same format as previous citation and same conclusions: an operation with limited debt would be losing about $36 per calf sold at Fall 1976 cattle prices. If the operation didn't own its land, it would be losing much more.

Cornelius, Jim. 1977c. Enterprise Costs, 250 Head Cow-Calf Ranch in Blaine County. Cooperative Extension Service Bulletin 1173, Bozeman: Montana State University.

Same format as previous two citations and same conclusions: an operation with limited debt would be losing nearly $15 per calf when sold at Fall 1976 prices. An increase of long-term debt increased the loss per calf to roughly $250.

Gee, C. Kerry, and Melvin D. Skold. 1970. Optimum Enterprise Combinations and Resource Use on Mountain Cattle Ranches in Colorado. Colorado State University Experiment Station Bulletin 546S, Fort Collins: Colorado State University.

This bulletin presents an analysis of alternative organizations which may increase returns to ranch businesses in the mountain areas of Colorado. It describes changes that may be required in livestock enterprises and grazing programs if optimum use is to be made of ranch resources. It also evaluates the effect of certain livestock and crop management practices on ranch income.

Gee, C. Kerry. 1972. Economic and Operational Characteristics of Colorado Range Cattle Businesses. Experiment Station Bulletin 550S, Fort Collins: Colorado State University.

This bulletin describes economic and operating characteristics of range cattle businesses in Colorado based on a sample survey of 194 ranches. Range cattle production in Colorado is typified by small, privately owned ranches, with an average of 400 animals per operation. Annual feed sources are hay -- 25%, private range -- 55% and public range -- 10%. Grazing is important to Colorado with about 60% of its land area in livestock grazing. Article details the lack of range management practices by the businesses involved. Mentions the role of recreation, mainly hunting and fishing, in bringing income to the ranchers, with 22% having an income from each of these sources. The ranchers with recreation enterprises derived 4% of their 1969 gross income from these activities. Possible range management practices mentioned were: fertilizer application, land levelling, land reseeding, sagebrush control and irrigation improvement, none of which are done on more than 5% of total acres being used by the ranchers.

Gee, C. Kerry, and Richard S. Magleby. 1976. Characteristics of Sheep Production in the Western United States. U.S. Economic Research Service, Agricultural Economics Report No. 345, Washington, D.C.: U.S. Department of Agriculture.

About 80% of sheep in the U.S. are raised in the Western U.S. where private and public ranges provide the bulk of the feed requirement. About half the feed requirement for commercial sheep comes from private range, while public range supplies about one-third. Over half of the commercial sheep are grazed by herders, usually on open (unfenced) range. Sheep graze more readily on shrubs and brush, where as cattle prefer grasses. Sheep also have less need for water and are better able to traverse rocky and steep terrain.

Gee, C. Kerry. 1977. Enterprise Budgets for Western Commercial Sheep Businesses, 1974. U.S. Economic Research Service, Washington, D.C.: U.S. Department of Agriculture.

Sheep enterprise budgets for 1974 are presented for major producing areas of the seventeen Western States. Summaries of production, costs, returns and operating practices are given for enterprises of various sizes and with different management systems. Most sheep businesses did not have sufficient sales to cover all expenses in 1974, and about 35% were unable to pay cash costs.

Godfrey, E. Bruce. 1978. Multiple Use Management on the Public Lands, A Study of the Morgan Creek Area of Central Idaho. Agricultural Experiment Station Bulletin 566, Moscow: University of Idaho College of Agriculture.

This study spells out the way in which the FS and BLM evaluate individual areas and decide on management plans for these areas. Godfrey uses the Morgan Creek area management plan of the FS as an example and analyzes the FS reasons for setting up the plan as they did. Provides a good understanding of the mechanics of a multiple use management plan. Multiple use -- the management of all the various renewable surface resources of the national forests so that they are utilized in the combination that will best meet the needs of the American people.

Godfrey, E. Bruce. 1976. Costs and Returns for Cattle Ranches in Custer County, Idaho. Agricultural Experiment Station Bulletin No. 567, Moscow: University of Idaho.

One reason for the predominance of cattle production in Idaho's agriculture is the large volume of forage obtained by domestic animals from federally administered land in Idaho. The cattle and sheep of 3594 operators who held permits with either BLM or FS consumed roughly 1,700,000 AUMS of forage during the calendar year 1972. Report shows that many ranchers in the Morgan Creek area are probably subsisting on their lands at relatively low returns as part of a way of life; to some return on investment is 1-2% to some there is no return on investment.

Godfrey, E. Bruce. 1979a. The Economic Role of Wild and Free-Roaming Horses and Burros on Rangelands in the Western United States, A final report submitted to the Intermountain Forest and Range Experiment Station, Logan: Utah State University.

Godfrey first relates the history of WFRHB legislation. He then presented the economic impacts of WFRHB management from the viewpoints of federal land management agencies, other user groups, regions/states, adoption and other interest groups. Most obvious impact of WFRHB management is on the budgets of the federal land management agencies, with BLM having spent 1.7 million dollars during Fiscal 1978. Discusses research ne[illegible] in the area of WFRHB, the greatest of which stems fro[illegible]ie fact that very little is known of the value of th[illegible]demand for WFRHB.

Godfrey, E. Bruce. 1972. Rangeland Improvment Practices in Idaho. Forest, Wildlife and RangeExperiment Station, Information Series Number 1, Moscow: University of Idaho.

In an effort to increase the amount of grazing on the range lands in Idaho, administrators of public and private lands have invested large amounts of capital for range improvements. This report provides a summary of the range improvement work (brush control, seeding, water developments, etc.) that has been completed in Idaho and assesses some of the possible impacts of these investments on the economy of the state.

Gray, James R. 1974. Economic Benefits from Small Livestock Ranches in North-Central New Mexico. Agricultural Experiment Station Research Report 280, Las Cruces: New Mexico State.

Study analyzed benefits derived from small livestock ranches in northern New Mexico during 1972-1973. By definition, ranches had less than 40 head of cattle and horses or 200 head of sheep. Information was acquired through interviews with a random sample of 150 ranchers and farmers. Results were: cow and calf sales provided almost all the cash income received -- average was $1,586 annually; crops, livestock and livestock products produced and consumed on the ranges were important sources of subsistence -- average value was $901/year; average rancher used 5 to 10 times more labor per AU than other studies have shown; most operators of small ranches had other employment, with only 33% of livelihood from the ranch; BLM grazing permits supplied 5% of total grazing, while FS permits supplied over 20% of total grazing.

Lewis, Eugene P. and David T. Taylor. 1977. Impact of Public Lands Policies on the Livestock Industry and Adjacent Communities, Big Horn County, Wyoming, Agricultural Experiment Station Research Journal 116; Laramie: University of Wyoming.

Federal government controls 79.5% of the total land area of Big Horn County and leased grazing is an important use of this public land, while use of federal lands for recreation and timber has been of lesser importance. The dollars generated by the livestock sector are important to Big Horn County. Changes in public lands administration policies will restrict the county's output, with the livestock sector being hurt by increased fees or grazing reductions. Policies which reduce herd size and the number of AUM's available for export have the largest impact on the country economy. Impact on the communities will be small as long as ranchers can absorb all the loss, but these ranchers are already operating at a low net income, and the question will be whether they can stay in business if this income is reduced even further. The overriding policy question is the federal agency's responsibility to the local communities. If the agency has an objective as the support of the regional economy, then the economic impact on such areas as Big Horn County and the Big Horn Basin Region should be assessed when assessing grazing fees and deciding availability of public-land resources.

Lewis, Eugene P., and Garnet E. Premer. 1978. The Economic Value of Recreation and Tourism, Park County, Wyoming, 1976. Community Services Division, Agricultural Extension Service Bulletin B 664, Laramie: University of Wyoming.

Studies the Park County economy, and specifically, the economic impact that the recreation-tourism industry has on the county's economy. The Park County economy is extremely diverse. It has four primary industries, including agriculture, mining, manufacturing and recreation-tourism. The recreation-tourism industry, in 1976, accounted for 15% of total county employment; and 11% of all direct economic activity.

Lewis, Eugene P. 1977a. Hot Springs County Economy, an Input-Output Analysis. Community Service Division, Ag. Extension Service Bulletin B645, Laramie: University of Wyoming.

Study furnishes economic input data for the decision-making process. It (1) presents the sources of output, household income, and employment in Hot Springs County; (2) identifies the important or leading business activities in the economy; (3) presents the interdependencies between the various segments of the economy; and (4) provides a gauge to measure the impact of change in the economic base of Hot Springs County.

Lewis, Eugene P. 1977b. Big Horn County Economy, an Input-Output Analysis. Community Service Division, Agricultural Extension Service Bulletin B 646, Laramie: University of Wyoming.

Study furnishes economic input data for the decision-making process. It (1) presents the sources of output, household income, and employment in Big Horn County; (2) identifies the important or leading business activities in the economy; (3) presents the interdependencies between the various segments of the economy; and (4) provides a gauge to measure the impact of change in the economic base of Big Horn County.

Lewis, Eugene P. 1977c. Washakie County Economy, an Input-Output Analysis. Community Service Division, Agricultural Extension Service Bulletin B 647, Laramie: University of Wyoming.

Study furnishes economic input data for the decision-making process. It (1) presents the sources of output, household income, and employment in Washakie County; (2) identifies the important or leading business activities in the economy; (3) presents the interdependencies between the various segments of the economy; and (4) provides a gauge to measure the impact of change in the economic base of Washakie County.

Mitchell, Burke and James R. Garrett. 1977. Characteristics of the Range Cattle Industry, 1972, Region III, Northeastern Nevada. Agricultural Experiment Station Bulletin B 42, Reno: Max C. Flesichmann College of Agriculture, University of Nevada.

Costs and returns and management practice for range livestock operations in Northeastern Nevada were estimated from data collected from personal interviews. Net ranch receipts were low and there was a return to assets of only about 2%. Federal grazing permits furnished a large portion of the feed requirements in this region.

Olson, Carl E., William A. Daley, and Charles C. McAfee. 1977. An Economic Evaluation of Range Resource Improvement. Agricultural Experiment Station Bulletin B 650, Laramie: University of Wyoming.

The primary avenue of growth for the range livestock industry is through internal expansion, that is, to obtain more forage output from rangeland. The booklet describes a method for determining the profitability of rangeland improvement over time. The method is a three step process. First, estimate the production function of the practice. The next step is to estimate the expected returns from improvement practices. Lastly, estimate the cost of improvement practices and determine whether returns are greater than costs.

Peryam, J. Stephen, and Carl E. Olson. 1975. Impact of Potential Changes in BLM Grazing Policies on West-Central Wyoming Cattle Ranches. Agricultural Experiment Station Research Journal 87, Laramie: University of Wyoming.

Publication examines the effects of increases in the grazing fees charged by the BLM and/or decreases in permit numbers on the ranch operator's income and methods of production. Ranches were identified as to degree of dependence on BLM forage, high dependence group had an average of 59% of forage from BLM; low dependence group used an average of 24.6% of BLM forage; ranchers in study were split evenly in the two dependence categories and a model ranch was determined for each group. Linear programming was used to analyze the effects of changes. Fee increases and permit reductions were both found to have detrimental effects on ranchers in both categories. It was better for the rancher to have his permit numbers reduced than to have a fee increase. Returns to operator's labor, management and capital were reduced more by the fee increase to achieve a given reduction in use is achieved with permit reduction.

Quenemoen, M.E., G. Robert Johnson, and Charles E. Egan. 1970. Costs and Returns Estimates for a Farm Flock Sheep Enterprise in Southcentral Montana. Cooperatives Extension Service Circular 1102, Bozeman: Montana State University.

Circular shows typical cost-return relationships for a farm flock of sheep in the Southcentral area of Montana. Was written by two farm advisors and one agricultural economist, mainly for the benefit of sheep ranchers in the area. Report shows a discouraging negative return to the operator's labor and management. The implication is that, given the prices, yields and costs given in the report, the rancher would be better off to lease his pasture, sell his hay and grain at market and use his labor and capital in some other alternative.

Rey, Mark Edward. 1975. A critique of the Bureau of Land Management's management program for wild horses and burros in the western United States.

Chapter III: Interesting critique of BLM public involvement strategies, based on review of BLM planning documents.

Chapter V: Analyzed recreation visitor attitudes toward wild horses in Pryor Mountains to assess the value of the animals. Survey was conducted by a short questionnaire administered through interviews, which measured respondents' demographic characteristics, recreation preferences, interpretive and development preferences, attitudes, and values associated with wild horses. Sample size approx. 350. Analysis revealed favorable public attitudes toward value of horses and burros.

Chapter VI: Discussed visitor use and preferences for recreational development of the Pryor Mountain complex.

Rey, Mark Edward. 1975. An evaluation of the recreational and interpretive potential of the Pryor Mountain Wild Horse Range. BLM, Billings District Office, Montana.

To facilitate development of an interpretive and recreation plan, a set of questionnaires was administered in Lovell, Wyoming to determine tourist motivation for passing through the area (N=80). Another set of recreational and attitude questionnaires was administred to recreation users in the Pryor Mountain Compex. Demographic data, motivational data, and preferences for interpretation and development of the horse range were collected in these questionnaires (N=350).

Management alternatives and their corresponding interpretive emphases are evaluated. Relevant elements of visitor motivation and preference are discussed. Recommendations are made for management of horses and recreation users, and for interpretation of the horse range.

Reed, A. D., and L. A. Horel. 1973. An Analysis of Beef Costs and Returns in California. Agricultural Extension, Berkeley: University of California.

Compilation of cow-calf studies from the nine major counties in the state and stocker studies from the five major counties in the state, all point to the fact that it was difficult to be profitable in the cattle industry in the 1970-73 period. Major problems were high price for rangeland, increases in taxes, labor and other costs. Cattle and calves were the top-ranking agricultural enterprises in California in 1971, with sales of over $940,000,000, accounting for 19% of the agricultural income in the state.

Stevens, Delwin M. 1971. An Economic Analysis of Wyoming's Sheep Industry (1960, 1964, 1968) Agricultural Experiment Station Bulletin 546, Laramie: University of Wyoming.

Study analyzes economic aspects of range and farm flock sheep production for Wyoming, with separate sections for three important range areas and three different years. Sheep industry is having difficult financial problems; lamb and mutton face stiff competition from red meats and poultry; wool must compete with synthetic fibers and cotton; production costs are rising and prices for sheep and wool are variable. Did a comprehensive job of surveying the Wyoming sheep industry, and identifying and analyzing the factors important to a profitable enterprise.

Stevens, Delwin M. 1975. Wyoming Mountain Valley Cattle Ranching in 1973 and 1974 -- An Economic Analysis. Agricultural Experiment Station Research Journal 95, Laramie: University of Wyoming.

Does a very thorough job of analyzing the businesses of cattle ranchers in the Wyoming Mountain Valley area. Compares size of business and profitability for three different ranch sizes. Goes through a good enumeration of the factors influencing earnings in the Mountain Valley area. Covers range and meadow improvements that typical ranchers do, including fencing, brush spraying, fertilization of meadows and pastures and waterhole development. States that although about 10% of the forage used during the year comes from Forest Service lands, little development of any kind is done on these federal lands.

Government Planning Documents

Bureau of Land Management. --

1979 Proposed domestic Livestock grazing management program for the Caliente area. DES 79-28. Nevada State Office.

Pp. 2-96 to 2-99 describes attitudes of county residents toward their vocation, lifestyle, and federal policy for public lands. Based on a county value survey and informal discussions with local government officials, citizens, and ranchers.

Pp. 10-95 to 10-101. Appendix G, Social Economics, Section 5, Impact on Attitudes, Values and Lifestyles. Describes unfavorable feelings of ranching community toward wild horses, as well as attitudes toward past and present federal land policy, local control, and the ranching lifestyle. Sample was purposive, not random; consisted of 56 ranchers (66% of ES area ranchers); method used was guided conversation.

1979 Missouri Breaks Grazing DES. Montana State Office.

P. 2-64 mentions horses as an aesthetic resource with limited viewing opportunities. Pp.2-81 to 2-82 describe support of local residents for improving wildlife habitat, land and water use planning, and effective predator control, as long as livestock grazing is not prohibited. Based on a Montana State University 1977 attitudinal survey and on public participation responses.

1979 Grand Junction Resource Area Grazing Management DES. Colorado State Office.

Pp. 2-73 to 2-74 qualitatively discusses social and cultural attitudes of region residents toward ranching, their community and BLM's multiple use philosophy. Information gathered from public participation analysis contained in BLM planning documents.

1978 Proposed domestic livestock grazing management program for the Seven Lakes Area, FES. Rawlins, Wyoming District Office.

Pp. 2-68 and 3-41 briefly describe favorable sociocultural attitudes of ranchers and mineral industry personnel toward their vocations, towards continued multiple use of public lands, and increasing government regulation. Mentions strong support of certain population segments for protection of wildlife and open space. Information gathered from public participation meetings.

1978 Proposed livestock grazing management for the Tuledad-Home Camp Planning Unit. FES. Washington, D.C.

Pp. 2-102 to 2-103 describe sociocultural attitudes of local interest groups towards wild horses, stressing control of population, towards control methods, as well as several other wild horse issues. Attitudes toward ranching and recreation are also described. Based on academic and BLM data and informal telephone and person interviews. Table 9-1 on pp. 9-3 to 9-5 summarizes comments received on several resources uses on the DES, including wild horses.

1978 Revised range management program for the Challis Planning Unit. Final Supplemental ES. Idaho State Office.

Pp. 2-59 and 3-52 describe unfavorable attitudes of local residents toward wild horses and gives 9 reasons, based on 12 interviews. Information also included on attitudes toward federal management and local control; recreation development, subdivision, and wilderness; livestock operator/community relationships; and motivation for ranching.

P. A-191 describes methodology of survey and presents statements on wild horses with number of respondents making them. Sample was purposive, not random; method used was guided conversations.

1976 Second Report to Congress, Administration of Wild, Free-Roaming Horse and Burro Act of 1971. Washington, D.C.

P. 7 summarizes recent public sentiment, stating heavy support for protectionist position, but concluding that there is some support for maintaining horses and burros in balance with other species and with habitat.

1975 Livestock grazing management on national resource lands. FES 75-9. Programmatic Statement. Washington, D.C.

Appendix II-G presents a 2 page discussion of the social aspects of grazing management on national resource lands, based on the distribution of individual permitees by size of permit.

<u>National Park Service</u>. --

1979 Proposed feral burro management and ecosystem restoration plan and draft environmental statement, Grand Canyon National Park, Arizona. DES 79-4.

Appendix H gives a summary analysis of public comments on the original 1976 Feral Burro Management Plan and Environmental Assessment which proposed direct reduction (shooting) and exclusion fencing of burros.

Environmental impacts section describes qualitatively the impacts of direct reduction and herding/fencing on people concerned about burros. (Section H - Impact on Socioeconomic Environment).

1977 Grand Canyon National Park "Burro" Letter Synthesis, Phases I - V, June 1976--May 1977. Unpublished manuscript.

Analysis of letters and petitions responding to the 1976 Feral Burro Management Plan and Environmental Assessment. Responses are broken down by position, reason for position, geographic area of response, and number of names for each basic reason. Most opposed to shooting. Approx. 16,000 responses were received.

1977 Bandelier National Monument. Review of Alternatives. March.

86 participants at a 1976 workshop on the Feral Burro Management Environmental Assessment were polled by questionnaire on a variety of burro management alternatives. The Review describes the alternatives, and analyzes percentage of respondents favoring each. Sample was non-random and sample size is unclear, since some mail responses were received and total sample size is not given in the paper. Questionnaires are available for examination at Bandelier.

Other Government Documents

U.S. Congress. House. Committee on Interior and Insular Affairs. 1976. H.R. 2935, H.R. 4577, and H.R. 6763 to Amend the Federal Law Relating to the Protection, Management, and Control of Wild Free-Roaming Horses and Burros on Public Lands. Serial No. 94-37.

Positions for and against aircraft use and motorized vehicle use in roundups for management purposes; ability of Secretary to transfer title of adopted horses and burros to the adopters. Positions based on humane concerns, right of stockmen to use public grazing lands, need for management to conserve public rangelands and indigenous wildlife populations.

U.S. Congress. Senate. Committee on Interior and Insular Affairs. 1971. S. 862, S 1116, S 1090, and S. 1119 to Authorize the Secretary of the Interior and the Secretary of Agriculture to Protect, Manage and Control Free-Roaming Horses and Burros on Public Lands.

Both the above hearings expressed a number of concerns: need for management; competition with other species; need for humane protection, prevention of extinction; aesthetic, recreational, and historic heritage values.

U.S. Congress. House. Committee on Interior and Insular Affairs. 1971. H.R. 795 and H.R. 5375, Legislation to Authorize the

Protection, Management, and Control of Free-Roaming Horses and Burros on Public Lands. Serial No. 92-5.

U.S. Congress. Senate. Committee on Energy and Natural Resources. 1978. Public Rangelands Improvement Act of 1978. Publication No. 95-170.

Testimony on amending PL 92-195 to allow removal of excess horses and burro on Secretarial determination (to adoption or humane disposal) and to allow adoptors to receive title after one year. Usual interest group positions expressed as in H.R. 2935 et al. above.

U.S. Congress. Senate. Committee on Energy and Natural Resources. 1977. Oversight of the Wild Free-Roaming Horses and Burros Act of 1971. Publication No. 95-60.

Concerned mainly with biological and management questions in administration of the Act. Usual positions taken by various interest groups as in H.R. 2935 et al. above.

U.S. Congress. Senate. Committee on Interior and Insular Affairs. 1974. The Administration of Public Law 92-195 -- The Wild and Free-Roaming Horse and Burro Act of 1971.

Oversight hearing prompted by the Howe Massacre. Expresses humane values.

U.S. Departments of Agriculture and Interior. 1977. Study of Fees for Grazing Livestock on Federal Lands. U.S. Government Printing Office, Washington, D.C.

This joint study by the Departments of Agriculture and Interior describes the history of grazing fees and covers the issues related to the current system of fees. The report then put forth proposals from several different agencies, discussed these alternatives, and concluded that the 1969 fee system, with modifications, would be put into effect as of the 1978 grazing season.

U.S. Department of Commerce. 1970. The forage resource. Public Land Law Review Commission. U.S. Government Printing Office, Washington, D.c.

The report assesses the magnitude and importance of the forage resource on public lands and the livestock industry dependent on it. It examines the importance of the forage resource to local economies by drawing on existing studies and through a detailed analysis of eight counties that were selected because they have significant areas of public forage lands. The nature of conflicts between range uses and other resource values and uses are also examined in the study.

U.S. Department of Commerce. 1970. Impact of public lands on selected regional economies. Public Land Law Review Commission. Clearinghouse for Federal Scientific and Technical Information, Washington, D.C.

This study compared the relative economic importance of major commodities produced on public lands (timber, forage, energy fuels, minerals, outdoor recreation and intensive agriculture) for Washington State, a portion of the Colorado River Basin, and U.S. as a whole. The study then evaluated the effect of these public land outputs on other sectors of the regional economies, and by I-O analysis estimated the impacts of change in the level of these outputs on the regional economies. Based on the above, and on other relevant information, the study evaluated the role of public lands in both local and regional economies.

U.S. Department of Commerce. 1970. One third of the nation's land, a report to the President and to the Congress by the Public Land Law Review Commission, U.S. Government Printing Office, Washington, D.C.

This study was mandated by Congress when it created the Public Land Law Review Commission. The Study explores all salient areas of public land law and makes recommendations meant to help the federal agencies manage those lands that are under their jurisdiction. Sections of interest are the planning of future land use; range resources, and outdoor recreation.

U.S. Department of Commerce. 1970. User fees and charges for public lands, and resources. Public Land Law Review Commission. National Technical Information Service, Washington, D.C.

Objective of the study: develop and organize for the Public Land Law Review Commission information showing the manner in which various user fees and charges for public lands and resources are developed, the effect of the manner in which they are determined, the level of revenues derived from the fees and charges, and the probable effect of possible alternatives to the existing legal structure guiding the levying of fees and charges. Report covers fees and charges for timber, grazing and outdoor recreational use. Contains good statistical section.

U.S. General Accounting Office. 1977. Public rangelands continue to deteriorate. Special Report on Department of Interior's Management of Public Rangeland, Washington, D.C.

Report identifies management actions needed to minimize damage to the U.S. rangelands. Deterioration can be attributed to poorly managed grazing by livestock. If BLM is to comply with the intent of the Taylor Grazing Act, it must intensify its management of the public lands. To minimize further damage, it is recommended that: BLM

managers follow headquarters instructions on updating management plans and take measures to stop destructive continuous grazing. On lands where implementation of management plans is pending; an assessment needs to be made of BLM actions to improve rangeland conditions; and BLM field managers will be required to seek assistance from livestock operators in providing essential range improvement facilities.

Popular Journals

Amaral, Anthony. 1971 The wild horse - worth saving? National Parks and Cons., March: 21-24.

Article discussing primarily a massive roundup of 70,000 Nevada wild horses in 1950. Expresses need for management.

_______________. 1971. Threat to the free spirit: the question of the mustang's future. The American West, September: 13-17, 62-63.

Positions of wildlife managers, stockmen, BLM and the International Society for the Protection of Mustangs and Burros just prior to 1971 passage of PL92-195.

Anonymous. 1968. The last roundup? Newsweek. 12 May: 95-96.

Local citizens' views about the Pryor Mountain Range at the time the wild horse refuge was being established there.

Anonymous. 1974. Wild horse rights: return of the mustangs. Colorado Business. 1(4):23-24.

Discusses PL 92-195. Ranchers are distressed because in some cases they must now share leased federal land with wild horses and they are forbidden to round up wild horses to sell to rendering plants.

Atwill, Lionel A. 1979. Up to our ears in asses. Backpacker. 7(2).

Excellent summary of the burro problem on National Park Service lands. Qualitatively covers history of the problem, views of principal interest groups, biolgoical information, PL92-195, and management alternatives.

Brandon, William. 1972. Wild horses of the west. Sierra Club Bull. September: 4-10, 37.

Discussion of why PL92-195 was passed overwhelmingly and why wild horses have claimed so much attention and publicity. History of horse . Defense of wild horses as symbols of freedom and wildness.

DeFilippo, Florence. 1970. A plea for the wild horse. Horseman's Yankee Pedlar. 8(11): 92-93.

Strongly protectionist article describing slaughter and hunting of wild horses. Need for legislation is outlined.

DeWald, Bud. 1956. A he-man's sport. Arizona Days and Ways Magazine. 8 April: 6-9.

Article promoting burro roundup as a population control measure, as well as a tourist attraction. Reflects dominionistic attitude.

Dodge, Natt N. 1951. Running wild. National Parks, 25:104: 10-15.

Anecdotal account of problems of feral species in southwestern national parks and monuments, by an NPS chief naturalist. Short account of sentimental public objection to early burro control program. Sentiment attributed to humanistic and utilitarian attitudes.

Downer, Craig C. 1977. Man's attitudes toward the wild horse. In Wild Horses: Living Symbols of Freedom. Western Printing and Publishing Co., Sparks, Nevada.

11-page qualitative description of attitudes of American Indians, Spanish colonialists, early homesteaders, present stockmen mustangers, hunters and game managers, and wild horse enthusiasts. Biased strongly pro-horse.

Hamilton, Samantha. 1978. Myths, magic and the horse. Equus. 13, November: 31.

Light treatment of man's mythical and symbolic relationship to horses, illustrated mainly from Greek myth.

Hopson, Janet. 1977. A modest proposal for the desert ass. Outside, September.

Short and superficial treatement of burro history and management problems, including views of NPS managers and burro protectionists. Slightly anti-burro.

Leadabrand, R. 1956. Long-eared problem child of the desert. Desert Magazine, June: 10-12.

Outlines and discusses opposing protectionist and management views. Management view is that held by those opposing burros on grounds of being a feral species and of competition with native wildlife. Outlines legislation protecing the burro in California.

Libman, Joan. 1975. A battle in Nevada may decide the fate of the wild horse. Wall Street Jour., 4 Aug: 1,7.

Contention between BLM and Nevada over the Adopt-a-Horse Program. Highlights various stands of environmental groups, ranchers, and wild horse societies.

Most, Chuck, 1969. Wild horses of the Pryors. Defenders of Wildlife News, 45(1): 69-72.

Describes establishment of Pryor Mountain Wild Horse Range including public outcry at BLM management plan for the area, public meetings to determine sentiment on alternative proposals for the Pryor area, and establishment and work of advisory board in making recommendations for future management.

Oakley, Charles. 1976. Wyoming's free-roaming horses. Wyoming Wildlife, 40 (9): 28-31.

Espouses need for measures to control and conserve horse populations, native wildlife, and rangelands, despite understanding of sentimental value of horses to public.

Reiss, Bob. 1979. Wild horses: our runaway heritage. Equus, 20, June.

Excellent and comprehensive article outlining controversy over wild horse management, giving views and management alternatives of various interest groups, scientists, and BLM. Problems with enforcement of legislation and adoption program.

Pontrelli, Michael J. 1969. Protection for wild mustangs. Defenders of Wildlife News. 44(4):444-446.

Describes proposed Senate bill 2166 for mustang protection, describes positions of National Mustang Association, Spanish Mustang Registry, International Society for the Protection of Mustangs and Burros, describes author's suggested provisions for the bill.

Regenstein, Lewis. 1978. America's wild horses: protected by lawsuit but still threatened. In The Politics of Extinction. Macmillan Publishing Co., New York.

History of the fight to save the wild horses, from a humane/protectionist viewpoint. Presents views of several interest groups. Feels more effective protection is needed to save wild horses.

Ryden, Hope. 1971. Goodbye to the wild horse? Reader's Digest. May: 227-232.

Condensation of 1970 version of Ryden's book America's Last Wild Horses. Expresses strong protectionist sentiment.

__________. 1971. On the track of the west's wild horses. National Geographic 139 (1):94-109.

Describes the area in which wild horses live and her own experiencs with them. Largely natural history, with protectionist sentiment expressed. Illustrated with many photographs.

Spencer, Dick. 1959. Plight of the mustang. Sports Afield. December: 28-29, 91.

Early expression of protectionist sentiment. Describes situation of horses, recommends establishment of refuges and control of populations as necessary.

Taylor, Ronald B. 1977. The burro or the bighorn? National Parks and Conservation Magazine, 51 (9): 10-14.

Nonnative feral burro must be eliminated from Death Valley National Monument if native desert bighorn sheep is to survive in one of its last ranges. Strongly anti-burro.

Thomas, Heather. 1977. A cattle rancher views the wild horses. American Horseman, No month: Pp 27, 52-57, 61.

Critique of position of the American Horse Protection Association's position towards BLM and stockmen. Qualitative defense on biological and social grounds of horse management and ranchers' use of public lands for grazing, as part of use and preservation of public rangelands.

Thomson, David. 1972. One final fight for America's wild horses. True, The Man's Magazine, February: 27-29, 33-, 82-85.

Describes both positive and negative attitudes of western stockmen towards wild horses, based on interviews with two ranchers. Emphasizes symbolic value of horse representing America's western heritage as moving force behind PL02-195.

Trueblood, Ted. 1975. Disaster on the western range. Field and Stream, 79(9): 14, 22-23.

Expresses feeling of author for more management and control of wild horses and burros because of effects on native wildlife, range carrying capacity, and other reasons.

Weight, Harold and Lucille Weight. 1951. Death or refuge for our desert burros. Calico Print 7: 2.

______________________________. 1953. A word for brother burro. Calico Print 9: 2-4.

Two early articles advocating extreme protectionist position based on humanistic sentiment.

Willson, Roscoe G. 1957. Will it be life or death for Arizona nightingles. Arizona Days and Ways Magazine, March: 38-39.

Prompted by a bill introduced into the Arizona State senate to protect burros. The author favors protection, disputing biologists' claims of competition with bighorn sheep.

Wood, Harold William. 1974. Death Valley: desert wilderness in danger. National Parks and Conservation Magazine, 48(2):4-9.

Anti-burro sentiment expressed based on destruction of natural ecosystem and competition with bighorn sheep.

Wood, Nancy. 1969. The wild horses -- heritage or pest? Audubon, November: 46-51.

General discussion of problem. Includes early history of roundups; refuges; and attitudes of cattlemen, BLM officials, oldtimers, protectionists, weekend cowboys.

Interest Group Poll

Wild Horse Organized Assistance Inc. 1979. Informal poll of members on priorities of concern. Unpublished survey.

Poll done through WHOA newsletter. 43% response (N=6596) Priorities in descending order: protection, improvement of adoption program, habitat studies, greater place for horses, educating for wildlife.

Correspondence and Clipping Files

BLM Division of Wild Horses and Burros, Washington, D.C. --

1. Correspondence

   a. Private individuals
      Dates: 1967 - 68 (?) - present
      Subject: Horse and burro problems on private lands only; general comment and question letters are not kept after being answered.
      Location: 1975-76-present - BLM
                Pre-1975 - Federal Center storage
      Number: Unknown

b. Congressional
Dates: 1967-68 (?) - present
Subject: Letters from Congressmen and letters passed on from constituents on all aspects of the issue.
Location: 1975-76-present - BLM
Pre-1975 - Federal Center storage
Number: 100-200 year.

2. Clippings
Dates: 1974 - present
How filed: By year
Number: Approximately 200
Location: BLM

Contact for all material: Robert Springer

National Park Service, Grand Canyon. --

Correspondence
Dates: 1976-1977
Subject: Responses to 1976 burro removal proposal
Number: Approximately 16,000
Location: Grand Canyon
Contact: Jim Walters

National Park Service, Death Valley National Monument. --

Correspondence
Dates: 1974(?) - present
Subject: Burro management
Number: 500-600
Location: Death Valley
Contact: Peter Sanchez

National Park Service, Bandelier National Monument. --

Correspondence
Dates: 1974 - present
Subject: Burro management
Number: 75-100
Location: Bandelier
Contact: Dr. Milford Fletcher, NPS Southwest Region, Sante Fe, N.M.

Wild Horse Organized Assistance, Inc., Reno, Nevada. --

Correspondence
Dates: 1975 - present
Subject: Adoption program
Anti-cruelty concern
Public Lands
Horse Lovers
Freedom of horses

Number: Several thousand
Location: WHOA office
Contact: Mrs. Dawn Lappin

American Horse Protection Association, Washington, D.C. --

1. Correspondence
   Dates: 1969-present, filed by year
   Subject: Horse and burro issues
   Number: 1500-2000
   Location: AHPA

2. Clippings
   Dates: Horses: 1969 - present
   Burros: 1967 - present
   Filed by year
   Number: Over 1000
   Location. AHPA
   Contact: Mrs. Joan Blue

Humane Society of the U.S., Washington, D.C. --

1. Correspondence
   Dates: Early 1970's - present
   How filed: By individual writing letter, not by subject; would be difficult to pull out wild horse and burro concerns.
   Numbers: Unknown
   Location: HSUS

2. Clippings
   Dates: Uncertain
   Subject: Adoption program and roundups
   How filed: By subject
   Number: Several hundred
   Location HSUS
   Contact: Frantz Dantzler, Marc Paulhus

Still Seeking to be Analyzed

Books

Middleton, Christopher. 1975. Wild Horse. Sceptre Press, Knotting.

Thomas, Heather. 1979. The Wild Horse Controversy. A.S. Barnes, South Brunswick, N.J.

Articles. --

Ambler, Marwane. 1978. Activists Torn Over What's Best For Horses. High Country News, 10(14):1.

Ryden, Hope. 1977. Managing Mustangs in Deep Ignorance. Defenders, 52(5):290.