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An Approach to Range Inventory for the Annual Range Type of the Arid and Semi-Arid Regions of the Sudan

Farid D. Iskander

Utah State University

AN APPROACH TO RANGE INVENTORY FOR THE ANNUAL RANGE TYPE OF THE ARID AND SEMI-ARID REGIONS OF THE SUDAN

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Farid D. Iskander

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Farid D. Iskander

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INTRODUCTION

Range inventory, by definition, is the evaluation of the range resources to determine a proper and safe level of stocking and to provide a record of vegetation and vegetation changes (Stoddart and Smith, 1955). Range survey is defined by the Range Conservation Glossary, Soil Conservation Service (1944) as "a systematic and comprehensive inventory and analysis of the range resources and related management problems of a range area for the purpose of developing plans of management therefrom." Accordingly, range inventory is the quest for basic information about rangelands and the development of guides and procedures for their management, improvement and efficient use.

Complete standardization of range inventory, at the present time, is neither possible nor desirable due to the multivariable conditions that may face the surveyor. Ultimately, more uniformity in routine techniques must be sought, but the utmost freedom must be maintained.

The methods that can be applied in range inventory vary from the simple straight-forward techniques to the more sophisticated computerized models. Likewise, equipment can be either simple or complicated, and cheap or expensive. In the developing countries, surveyors should use simple, cheap and efficient equipment probably made from local materials for easy installment and replacement. The field equipment is more or less the same wherever used, but the correct interpretation of the data is usually the problem of greatest concern to most range researchers and managers.

REVIEW OF LITERATURE

Ecologists and range scientists have tended to develop synthetic indices as a means of condensing and representing the different parameters of the ecosystem. By assigning species indices to represent a variety of attributes, many aspects of the ecosystem can be simultaneously interpreted from a single sample (Goff and Cottam, 1967). Three main types of indices are considered. The first is a means of quantifying the importance of every species within each stand. This index is called the importance value (Curtis and McIntosh, 1951). The second type of index is applied to assess the central tendency of a species along an ecological gradient, such as the climax adaptation values of Curtis and McIntosh (1950), and the vegetation moisture index of Rowe (1956). All these can be described as species position indices. The third, the stand synthetic index, is usually computed as an average of the species position index values for all species within the stand for the gradient being considered. Indices of this type include the composition index of Curtis (1959) and synecological indices of Bakuzis (1959). The use of synthetic indices involves some problems in their computation and use. Among these problems are: (1) the relationships between several of the terms that are commonly combined into a single expression of species importance, and the effects of these relationships when the terms are used in computations of weighted stand averages; (2) the derivation and meaning of various types of species indices; and (3) the practical effects of different weighting terms on the stand synthetic index (Goff and Cottam, 1967). Nevertheless, the use of indices in range surveys will gain momentum in the developing countries where experienced range surveyors lag behind the challenging and highly demanding task of range inventory. In other fields related to range sciences, the use of indices has become a common practice and the urge to adopt some of these will become stronger in applied range research. Soil science, ecology and plant physiology are some of these fields. It is true that range sciences are dealing with a complex ecosystem that is ever changing by the interactions of biotic and abiotic elements, yet the attempt to develop representing indices should not be halted.

Reconnaissance surveys are quite common in the developing countries where a species-list is produced under every major vegetation type. Harrison and Jackson (1958), classified the vegetation of the Sudan along two ecological gradients; rainfall and soil types. Although these two are considered the major factors affecting vegetation distribution in the arid and semi-arid areas, there are other important factors that were not considered. Using vegetation as the basis for defining climatic zones, it has been found that precipitation and temperature alone do not provide reliable predictors and that other factors on which evaporation depends, such as wind velocity, barometric pressure, etc., need to be taken into consideration (UNESCO Arid Zone Research, 1955). Such shortcomings notwithstanding, reconnaissance surveys are still useful to range surveyors in their indication of species present or absent in the area. In some cases, they provide historical records of the past vegetation. In the Sudan, Harrison's Report (1955) serves as a valuable historical record, and gives some indication of the vast changes that have occurred in the vegetal cover since the time of the survey. Disturbances have reduced a perennial cover to an annual type in the central and northern parts of the country.

Annuals, not being exact in their habitat requirements, have high competitive abilities due to their wide ecological tolerances. When dealing with annual range types, range surveyors face a variety of problems that are not encountered in perennial range types. The annual range plant communities are very dynamic aggregations of plant species that fluctuate not only yearly but seasonally in response to factors and interrelationships of the ecosystem (Rossiter, 1966). Talbot and Biswell (1942) showed clearly that the dynamic annual range plant communities may have significantly different species composition each year. Heady (1956, 1958), Jones and Winans (1967) showed on a California annual range type that yearly variation in species composition is due to weather patterns in the early period of germination. Biomass yield is also subject to extreme annual fluctuations. For example, Klemmedson and Smith (1964) reported that <u>Bromus tectorum</u> L. production was 361 pounds per acre during one year, while in the following year it was 3461 pounds per acre, a tenfold increase primarily in response to favorable precipitation. One explanation for such differences is reported by McKell (1972) as the high incidence of a drouth period following the first rain of the season. Bedawi, Zoulfu and Iskander reported in 1968 that <u>Brachiaria obtusiflora</u> hardly formed six percent of the species composition in the Fung area of the Sudan that year, while in normal or good years it contributed up to 58 percent. As a result of all these factors, the range surveyor is faced with the following problems:

1. <u>Time of sampling</u>: Time of sampling should be designed to encompass all the possible variations of the species composition of a particular community. It is obvious that sampling at the beginning of the rainy season is unreliable

and sampling at the end of it is useless, because at the beginning of the rainy season the species composition, density, and frequencies are not stable and at the end of the rainy season the annual species should have passed the time for proper use that year. Time of sampling, if no records are available, should be at the start of the boot stage in grasses and flowering in forbs for the key range species, when positive identification can be made more easily.

2. Prediction of productive potential: Range surveyors should be able to predict the productive potential of the range from year to year, a task that presupposes experience and knowledge for deriving an estimate from factors that affect plant growth. The use of indices in this respect will be most helpful because range inventory information is obtained the same year that management decisions should be applied. Using the proper indices, the surveyor can evaluate the productivity of the range in a shorter time allowing the manager adequate time to develop and apply his plan.

3. Selection of sampling sites: The surveyor should have the ability to select an area representative of the community or the stand he is sampling. Uniformity in the representative area should be sought, otherwise extrapolation of his data will be inaccurate and misleading.

4. Determination of range condition: There is always the necessity of judging the range condition and trend by means different than the range potentiality. No relicts are found anywhere in the

Sudan because of grazing accessibility, fire and cultivation. Therefore, application of range condition analysis according to the principles of Dyksterhuis (1949) is precluded.

5. Use history: The range surveyor should be familiar with both the animal and the human factors, past and present use, and if possible, the history of the area he is working on. He should be communicative with the people of the area because they can furnish valuable information as to the history of use and the past vegetal cover. Biswell (1956) stated that the kind of plant cover existing over the region before white man came can never be determined precisely since there is no literature that adequately describes it and virtually no samples remain of it.

OBJECTIVES

The objectives of this report are to explore the methods of range inventory as they should be applied in the arid and semi-arid regions of the Sudan, stressing the possible use of indices for predicting forage productivity on a yearly basis. With a country as vast as the Sudan, surveys done by the classical methods would require time and personnel beyond the present capabilities of the country. Since most of the central and northern areas of the Sudan are characterized by an annual range type, they require quick methods of estimating forage productivity, prior to applying a management plan. There is usually a very short time span between germination and readiness of the range.

RATIONALE FOR THE USE OF INDICES

Usually the members of an entire community cannot be counted or measured, and even if this is done, the information would be no more useful or significant than an adequate set of data required by proper sampling. Observation and reconnaissance are still of extreme importance in determining where, how and what to sample (Oosting, 1956). They serve to form a basis for theories or ideas that may in turn be substantiated by quantitative evidence obtained by sampling.

Because vegetation is highly variable, generalizations cannot be made to fit all situations, and because management objectives are rarely the same in time and space, methods of sampling quite satisfactory in one instance may not be so in another. Therefore, it is advisable to work with a relatively small sample unit, otherwise a large number of samples may be required to give the desired degree of accuracy. This can be achieved by proportionally increasing the number of units (Jolly, 1954).

Although, ideally, a sample should be entirely unbiased, there are occasions when bias of a certain type will not upset results. If errors arising from bias are known, or can be safely assumed to be small compared with the random sampling error, they will not have any serious effect and their presence may be forgotten (Jolly, 1954). Also, it frequently occurs that differences occurring between two populations are of more interest than their absolute values, and, if two samples are equally affected by the same element of bias, the bias will not affect the difference between them.

Daubenmire (1959) summarized the principles of vegetation sampling in the following points:

1. A series of samples is superior to a single large one in the stand. It allows the sampling to encompass floristic variations from place to place over the stand without studying all the intervening area; it allows study of permanent plots and it allows an evaluation of frequency.
2. Adequacy of sampling of a stand is better achieved by increasing the number of plots rather than their size. Keeping plots small reduces observer error since the accuracy of estimation declines when the size of the observational unit exceeds that which can be seen without moving the eyes, and adding more plots, if scattered, allows better representation of the stand.
3. Elongate plots are superior to isodiametric shapes in that there is less possibility of a single plot coinciding with, or completely missing, the scattered isodiametric families by which most taxa are represented in a stand.
4. Large estimation classes are reasonably good assurance against significant personal error, yet when applied to many small plots, they yield relatively precise averages.
5. The series of plots used to sample one stand of vegetation must fall within an area sufficiently uniform that intrinsic environmental diversity cannot be suspected as causing variation from one place to another. The distribution of samples should cross perpendicularly with contours in belts rather than parallel contours, and if one accepts the ecosystem concept, a homogeneous population of plots should not overlap two soil series. This is not to deny that two contiguous soil

types may support apparently identical vegetation, but to point out that such a situation needs proof and should never be assumed.

6. Vegetation structure is variable owing to an element of chance in the timing of dissemination in relation to opportunities for seedling establishment, survival and maturity.

To be able to implement proper surveying techniques, we should discuss the range as an ecosystem and point out the parameters that can be measured and qualified.

RANGE AS AN ECOSYSTEM

The first principle to be recognized is that range is an ecosystem, involving the accumulation, circulation and transformation of energy and matter through such biological processes as photosynthesis, herbivory, and decomposition, with the non-living part involving evaporation, precipitation, erosion and deposition, reacting to the living part, and with locations between organisms (Dyksterhuis, 1958).

Fosberg (1948) said, "The problem of detecting, classifying and evaluating all the factors which affect plant growth in an environment has so far defied the ingenuity of even the best plant ecologists and physiologists." It is recognized that we have increased our understanding of some effects of these factors, but we still lack the power of prediction of the plant behavior to environmental factors far from extremes. The process of vegetation development is envisaged as dependent upon a relay of factors, with successive release from edaphic to biotic and finally to climatic control (Gorham, 1955). All these factors are operative everywhere and at all times. We may conclude that regional and temporal alignments of environmental controls are of necessity interrelated and depend on how effectively each ecosystem factor varies in both space and time. In this connection, the possibility of factor compensation must always be borne in mind (Billings, 1952). Single factors may undoubtedly control plant distribution over limited areas within which variations of other factors are insufficient to influence any of the floristic elements. It is assumed that at any given site the habitat is supporting the maximum possible density of vegetation (Greig-Smith and Chadwick, 1965). Perspectives, objectives, methods and techniques employed in the appraisal and interpretation of rangeland resources during the present century reflect gradually evolving demand for more basic knowledge. Intelligent intensification of the use and management of any resource must be based primarily upon extensive knowledge of that resource and its wise interpretation.

Soils

Dyksterhuis (1958) stated that early range inventory methods were concerned with the classification and interpretation of vegetation. Little attention was given to edaphic and climatic influences or to the ecological aspects of range resource inventory. Although inventories based primarily upon vegetation have undeniably been of considerable value to range managers, they have not provided the basis or information required for optimum management. If management is to be directed toward the realization of sustained high production consistent with protection of the resource, the range manager must know the capabilities of the different kinds of rangelands (Passey and Hugie, 1962).

Soil is a major physical component of the ecosystem. To ignore it or treat it superficially merely restricts knowledge of the resource. Soil provides one reliable criterion by which areas that look differently or alike today due to past treatment and successive stages of vegetation can be related to the original ecosystem. Soil has identifiable features which are relatively stable, and soil provides one good basis for comparing unknown to known areas in terms of potential. This is probably one of the most important uses of reliable soil data (Anderson, 1968).

To be useful as a criterion in range surveys, each kind of soil should be identified, described, differentiated, and named according to its physical properties such as texture, structure, depth, stoniness, slope and aspect. These soil taxonomic units are grouped within the various ecosystems which in turn relate the soil taxonomic units to the vegetational, treatment and management potentials. Each taxonomic unit consists of a phase of a soil series and this is important for stratifying the landscape soil-wise into delineations that are meaningful for range management.

Usually it is impractical or even impossible to draw a boundary around a pure soil taxonomic unit on a map. Areas of other taxonomic units would be included. Therefore, the soil mapping unit as shown on the map consists of the soil taxonomic units plus inclusions such as bare rock and other taxonomic units that can be identified and occur within allowable limits. The soil mapping unit is considered as a unit of land that has uniform behavior in terms of vegetation and management. Macvicar (1969) stated that by considering the nature of the soil and the ends which a classification must serve, principles are stated whereby a soil classification may be devised for application over extensive areas of varied soil composition. Naturally occurring bodies of soil, each with a high degree of homogeneity, are apparent rather than real individuals, as their properties overlap to form a continuum. For all practical purposes, range surveyors should regard soil types as discrete units that support a relatively homogenous vegetation type.

Oosting (1956) pointed out that there are close similarities between distribution of major vegetation types and zonal soil types. The soil and its processes do not constitute an independent system, but rather are part of the larger ecosystem which includes vegetation and all of its environment (Crocker, 1952). Soil by itself can serve as an important ecological gradient along which vegetation is arranged.

In the arid and semi-arid regions, soil and climate are the most influential factors upon plant distribution and growth. Anderson and Talbot (1965) found that on two different sites in the Serengeti plains in Tanganyika, where the grazing pressure was more or less equal, the percentage ground cover of the vegetation closely reflected soil texture and depth. Box (1961) stated that the narrow transitional zones between distinct plant communities in South Texas suggest that local edaphic conditions may be limiting factors in vegetational distribution. Cook (1965) showed that the population regulation of *Eschscholzia californica* can be explained by the genetic adaptation to soil type. Germination and establishment of range plants are closely related to the chemical and physical properties of the soil. Range surveyors should, then, be concerned about soil information that will give the manager a clue as to which management system he should apply.

Soil survey methods have been standardized, but due to the complex measurement involved, they can hardly be considered as field techniques. Detailed soil surveys are justified by the assumption that most soil characteristics are relatively stable through space and time.

Soil erosion takes place in any arid area by reason of prolonged drouth, excessive rain or excessive grazing pressure (Condon, Newman and Cunningham, 1969). It is well known that the ill effects of excessive grazing pressure upon natural plant communities are not measured only by the loss of valuable forage species; the environment may be so altered in the course of range deterioration that the process of restoration of a satisfactory forage cover becomes greatly complicated, and extensive damage through erosion and consequent deposition may be incurred (Daubenmire and Colwell, 1942).

What soil parameters should be measured by range surveyors? First: soil depth should be considered when evaluating the forage production potential of range soils. McColley and Hodgkinson (1970) concluded that it seems apparent that differences in soil depth have an effect on the kind and amount of vegetation produced. Second: the degree of stoniness should be expressed as a percent of an area to compute productivity and cover on area basis. Third: the degree of erodibility of the soil should be stated, stressing the problem areas. Classes of erodibility can be used such as highly, medium or low erodable. The surveyor should indicate whether erosion is natural (by wind or runoff) or indicate whether by human or animal factors. Fourth: texture of the upper soil is used as an indicator of infiltration. Fifth: relief which affects the microclimate around the plants.

These are not the only parameters that should be described, there are others that are associated with the precipitation and will be discussed separately.

Climate

Precipitation. It should be clear that any single atmospheric factor is insufficient in itself to explain the distribution and survival of species or plant communities. Precipitation records are only suggestive of the amount of rainfall in the area for they must be interpreted in terms of seasonal distribution and are not at all indicative of soil moisture conditions or the evaporating power of the air to which a plant must be responsive if it is to survive (Oosting, 1956).

The variation in the seasonal pattern of precipitation from place to place becomes particularly apparent when illustrated with twelve-point polygon diagrams which make possible easy comparison of amount and time of precipitation by months (Transeau, 1953).

In arid and semi-arid regions, the range surveyor can make little use of averages of precipitation whether monthly or annually. He can use them in a broad sense as "good years" for those above the mean or "poor years" for those below the mean. Meteorological data help in drawing isohytes of rainfall on maps and these can be used as a basis for climatic classification. Condon, Newman and Cunningham (1969) pointed to the fact that rainfall can never be predicted either from composing rainfall records for adjacent areas or even from the same area. Accordingly, range surveyors have little to do in this respect other than recording amount, intensity and duration. One of the major problems is to link point data (rain gage) to an area of incidence. This can only be possible if a grid of rain gages is distributed systematically in the study area. The cost of such a procedure is beyond the reach of any one country.

One important parameter is the frequency of occurrence of rainfall which is significant in promoting vegetative cover. The sporadic nature of rainfall in arid and semi-arid regions results in intermittent growth of the vegetation. Thus, it is important to assess the frequency of rainfall that merely serves to enable germination of annuals and those that make continued growth by the vegetation possible to complete their life cycle. Then we are discussing the effective rainfall and assigning two terms to describe it; (1) initial effective rainfall, and (2) effective carryover rainfall. In the annual range types, plant species germinate in waves according to the moisture available and initial effective rainfall can be more than one shower for every species and quite several in the whole community. There is an overlap in describing one fall as it will be the initial effective rainfall for a species and an effective carryover rainfall for another species.

Slatyer (1962) used a technique in the Alice Springs area in Australia where he assumed that sufficient rainfall occurred to result in positive soil-water storage for one week. This would enable the general requirements for effective rainfall to be satisfied. He also assumed that if sufficient rainfall over a period of one week exceeded 0.4 E_w[1] for that week, the general requirements would also be satisfied.

The range surveyor should be familiar with water requirements of the stand and the distribution of the rain storms where effective rainfall is the critical factor in the water balance. In assessing these critical values, recourse has to be made to saturation-deficit data to get a factor that can be used in obtaining E_w values.

Condon, Newman and Cunningham (1969) established a relationship between grazing capacity and average annual rainfall in Australia. Such relationships can help in predicting production of herbage, but there are limitations in the prediction for an annual range.

<u>Other climatic factors</u>. The effect of other climatic factors such as temperature, radiation, wind velocity, etc., on plant communities have been discussed in practically every ecology text. Such factors will be treated superficially in this report because range surveyors have

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[1] E_w = evaporation from the free water surface of a standard tank evaporimeter. 0.4 = constant.

little to do with measuring these factors. They may, however, be interested in getting the information from plant physiologists concerning some of the species for a specific behavioral analysis and interpretation.

Temperature has been used in association with precipitation to yield quotients representing the dryness of a region. The UNESCO report on arid zone hydrology (1953), used the L. Emberger formula to divide and arrange regions along an aridity gradient. The formula used is

$$Q = \frac{100\ R}{(M + m)\ (M - m)}$$

Where Q is the quotient representing dryness of an area, R is the normal total annual rainfall, M is the normal maximum temperature of the hottest month and m is the normal minimum temperature of the coldest month. Where Q ranges from 0-20 it represents a desert condition, 20-45 arid conditions, and 45-65 semi-arid conditions.

In arid areas seldom does temperature reach extremes to inhibit germination, growth and flowering of the native range plants. Its importance to range surveyors is encompassed in air drying and its effect on evapotranspiration.

Soil moisture

Estimated soil moisture offers considerable improvement over rainfall as a factor correlative with plant growth, both within and between years, especially when we investigate plant-soil relationships. Campbell and Rich (1961) showed clearly that with adequate data, statistically significant multiple relationships might be established between herbage production and soil moisture (Figures 1 and 2). Richards and Richards (1957) stated that "statistical studies for semi-arid climates show a significant correlation between effective precipitation and crop yield."

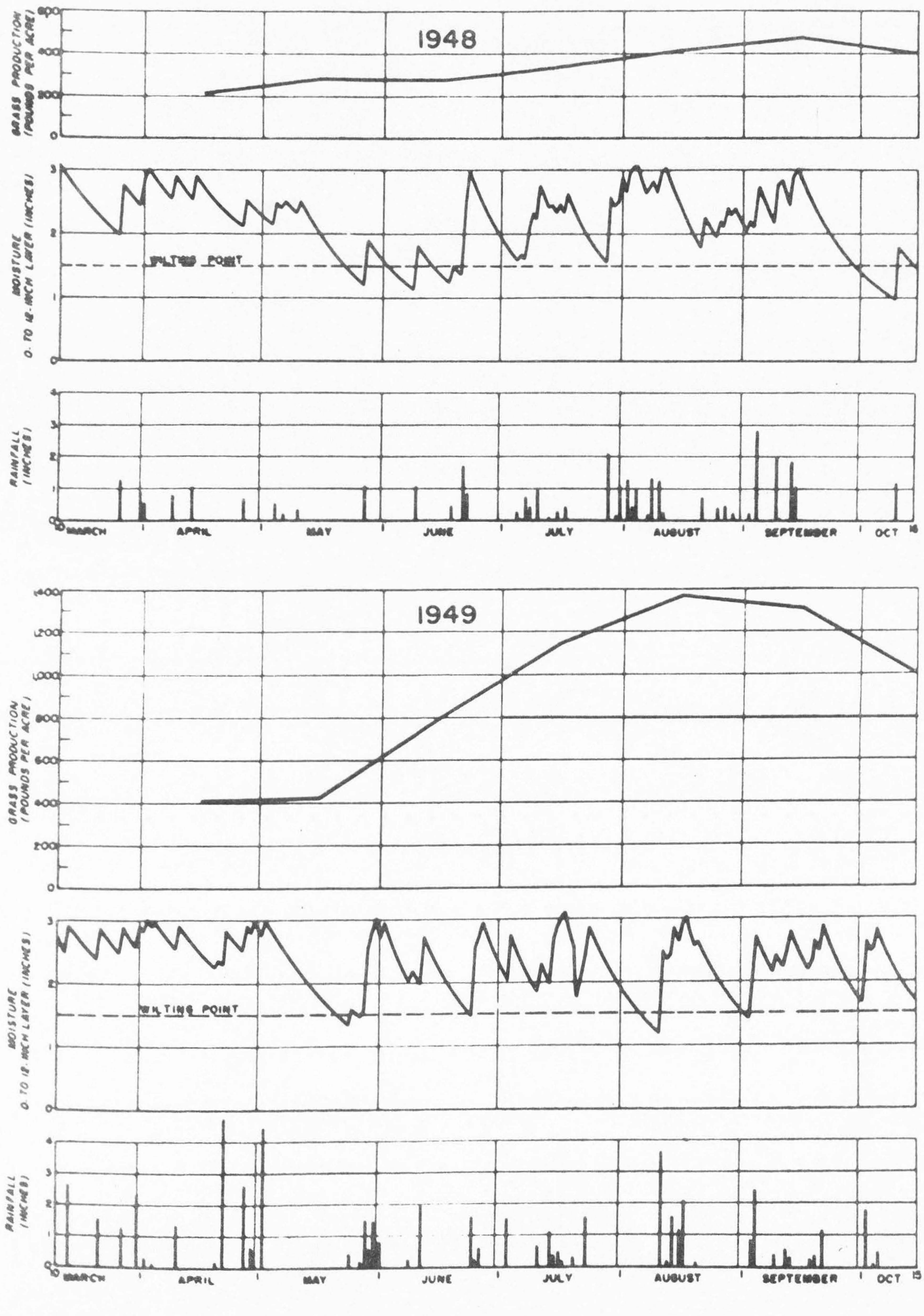

Figure 1. Daily rainfall, estimated moisture in surface foot of soil, and cumulative grass production by month. (Taken from Campbell and Rich, 1961)

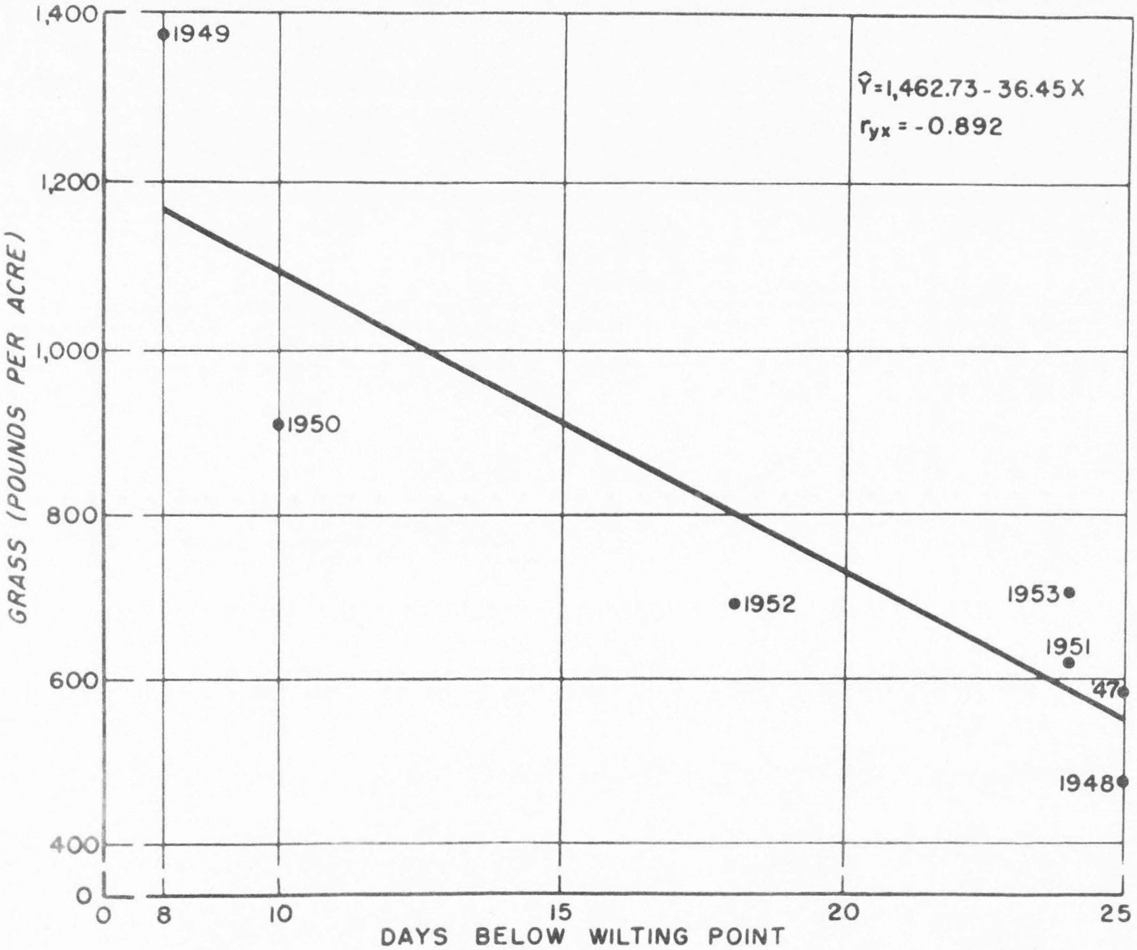

Figure 2. Regression of maximum annual grass production over number of days at or below the wilting point in upper foot of soil during the grand growth period. (Taken from Campbell and Rich, 1961)

Fine textured soils tend to have higher porosity than coarse textured soils. When all of the pores are filled with water, a fine soil usually contains more water than a coarse soil. During and following the entry of water, sandy soils with their large pores usually conduct water more rapidly than fine textured soils. Because they contain less water to begin with, sandy soils retain less water for plant use.

The effect of soil moisture on a plant community depends upon the current soil moisture status, and on factors which influence extraction of water by roots. It also includes climatic factors, soil texture, moisture release characteristics, the extent and concentration of absorbing rootlets, and the rate of movement of water through the soil. The term "exploitable water" describes that portion of the soil available water which can be taken up by particular plants under prevailing conditions (Winter, 1967).

It is comparatively easy to determine the total water content of the soil; however, it is not easy to decide how much of the total water content is available to plants or to specify the effects on water uptake and plant growth of a soil with moisture status below the maximum. Forces of moisture retention in the soil increase as the soil dries out and the energy that must be expended to remove each additional increment of water from the soil increases with drying (Taylor, 1957).

Wilcox (1962) proposed that the upper limit of available water should be defined as the highest moisture content of a soil which includes all moisture available for consumptive use, but excludes all drainage below the root zone. Available water is sometimes defined as the numerical difference between the soil water content at field capacity, the upper limit, and that present at permanent wilting percentage, the lower limit.

Salter and Williams (1965) showed that the available water capacity of a soil is closely related to its particle size composition. They concluded that the available water capacity of a soil can be predicted in the field from knowledge of its textural class with an accuracy of about ± 10 percent. In Salter and Williams (1967) method, soil samples obtained from each horizon were judged separately for textural class simply by rubbing the moistened soil between the fingers. Using a special pocket slide rule, the available water capacity in relation to texture and thickness of each horizon was totaled to give overall figures for the whole profile.

Campbell and Rich (1961) found a highly significant negative regression for annual grass production over number of days that moisture in the upper foot of soil was at or below the wilting point during the grand period of growth. Glover, Glover and Gwynne (1962) found in east Africa that during light showers penetration of rain water is much better beneath bare soil or litter covered soil than it is beneath the vegetation clumps. They studied the relationship between height of plant and depth of water penetration and developed the following equation:

$$\text{Depth of water penetration (in.)} = 3.85 + 0.96 \text{ plant height } (R^2 = 0.62)$$

The equation is good within the range 0-18 inches for the aerial height of the plant. It was found for the particular communities studied, the type of soil present and the amount of rainfall, the depth of rain-water penetration is equal to the height of the plant plus the normal penetration of a particular shower into the bare soil.

Liacos (1962) found that the rate of soil moisture depletion from field capacity to permanent wilting percentage is an important phenomenon of the soil water-plant system. Bunting and Lea (1962), stated that in the seasonally arid climate of the Fung, Sudan, the soil moisture regime exhibits a seasonal cycle of desiccation and percolation. At the end of the dry season, that part of the soil mass which is or has been permeated by plant roots is reduced first to wilting point and then to lower values by direct evaporation.

Box (1961) stated that water infiltration rates of the soil profiles were significantly different between the communities he studied in South Texas. He associated low production with the poor physical conditions of the soil and the undesirable water relationships in the community.

Veihmeyer and Hendrickson (1955) stated that for annuals and perennials, other than trees, the rate of moisture extraction is not influenced by the amount of water present in the soil when the soil moisture is above the permanent wilting percentage. Rauzi (1960) stated that the ability of rangelands to absorb and store rain-water is of great importance in the production of range forage, maintenance of stock water, and control of runoff and erosion. Hemming (1965) found in Somaliland that the permeability of all the soils with vegetation arcs is such that low intensity rainfall is fully absorbed but high intensity rainfall produces considerable runoff.

Greig-Smith and Chadwick (1965) concluded that the pattern of shrubs in the semi-desert scrub in the Sudan does not show evidence of the regularity which has commonly been postulated. They suggest that runoff may also be partially responsible for control of plant distribution. They quoted that "the water balance of isolated plants in arid regions is not as poor as is generally believed; in fact the vegetational cover is held to be proportional to the precipitation so that per unit area of transpiring surface, plants in these habitats receive the same quantity of water as those in humid climates."

They suggest that a close correlation exists between precipitation on one hand and dry matter production, leaf area and leaf weight on the other.

Gardner (1960) stated that with reasonable caution many of the processes involved in the uptake of soil water by plants should be susceptible to mathematical description. The pattern of water use in a root zone depends upon the root distribution, root permeability, and upon the water retaining and transmitting properties of the soil. All of these factors can easily be predicted by mathematical equations.

Rauzi (1960) used an infiltrometer to determine the effect of different kinds and amounts of grass cover on the ability of a soil to absorb water and to obtain a relative water-intake rating for major soil types under varying vegetation cover. By using the infiltrometer, Gifford (1968) was able to study infiltration rates, runoff, interception and sediment production.

By using the infiltrometer, the range surveyor can detect relationships of moisture movement in the soils, the recharging pattern and their moisture depletion curves. By knowing the amount, intensity and duration of storms, he can calculate the available water in the soil. By using a simple tensiometer, the range surveyor can determine how long the soil moisture has been below the permanent wilting point. From these data he can move his values to a graph showing the degree of drouth tolerance of a species or a stand, thus forming a basis for what will happen to a particular stand if the soil moisture is not replenished. This approach follows the same procedure used by Campbell and Rich (1961). There is an assumption here that the physical characteristics of the soil will remain stable over time and this assumption can be investigated should the surveyor suspect any unpredictable change.

Vegetation

Watt (1947) stated that "the plant community may be described from two points of view; for diagnosis and classification, and as a working mechanism." Patterns of vegetation changes should be recognized before proper evaluation of the annual type range can be made (Heady, 1956).

The distribution pattern and association of plant species in the form of communities is ruled by the environment and use history. As a result we find repeatedly similar composition which usually allows us to identify community types (Lieth, 1968). The various adjacent communities appear like links in a chain (catena concept). They show, however, a variable degree of intermixture which allows us to treat the natural occurrence of the various communities in the form of a gradually changing continuum. Both approaches are very valuable as working concepts. Neither one alone, however, can serve as the one and only principle basic philosophy to elaborate the nature of communities. The community-type system should describe the general pattern of distribution and the continuum concept might explain the fine structure on a provincial level, patterns from distinct and distant regions with no species in common (Leith, 1968).

Selection of stands by eye immediately introduces a subjective element which should be avoided. Therefore, it is better to use an arbitrary system of systematic sampling (Lambert and Williams, 1962). The vegetation-units extracted can be defined and characterized by reference to both plants and habitat, and can be ranked in importance according to the precision of the statistical definition. When species are arranged in a sequence from most to least important, they form a continuous progression from dominants through intermediates to rare species (Whittaker, 1965). Daubenmire (1966) stated that ordinarily one habitat type, differentiated by either soil or microclimate, is highly discontinuous. The individualistic and continuum concepts are still debatable among plant ecologists. Range surveyors are more or less concerned about vegetation units that can be investigated and treated as uniform. This is related to the feasibility of extrapolating sample data to a community.

Because the rainy seasons in the arid and semiarid areas of the Sudan are short and somewhat uncertain, both grasses and forbs tend to grow and set seed rapidly (Humphrey, 1958). Heady (1956) stated that plant succession does occur in the annual range type and therefore changes in floral composition can logically be used as a yardstick to aid in the designation of range condition. McNaughton (1968) showed that the annual grass land vegetation is a mosaic of floristic composition and ecological properties, shifting in response to habitat patterns but without abrupt discontinuities. Pratt (1969) working in the arid rangeland in Kenya, stated that the contribution of grasses fluctuates and depends on grazing pressure and recent rainfall. He observed that even under normal conditions, a high proportion of perennial grasses assume an annual life-cycle, and during cycles of dry years, perennial species are confined to the more favourable sites. Greenwood and Arnold (1968) working with Lolium rigidum noticed that seedlings emerged in two distinct waves, each following a rain system. Halwagy (1962) stated that in the arid regions, the dry climate which prevails throughout the greater part of the year does not allow the regeneration of plants once they are grazed or cut, even though the species in question may be endowed with the power of regeneration under a more humid climate. Because of this complexity in the vegetation of the arid regions, the range surveyor faces quite variable situations that call for a modification in his predetermined planning.

Lambert and Williams (1962) stated that it is possible to extract meaningful vegetation entities by routine mathematical processes quite independent of any previous ecological experience of the area. For the range surveyor, in these arid regions, shrubs and trees are the only indicators of the vegetation type. He should be cautious not to select species that have a wide tolerance for soils and climates such as Acacia nubica, but to select his key species according to their exclusiveness to certain soil types or habitat. The range surveyor will resume the role of an ecologist when he deals with plant communities. He should be able to classify, differentiate and name the communities he is working with. Without going into great detail at this point, range surveyors have to accustom the procedures discussed by Whittaker (1970) by computing an importance value for the different species.

One of the most important characteristics to be studied is the species diversity. This can be detected from a species list. Species diversity can be measured on the basis of number of species in sample units large enough to include some minor species. Variation in species diversity does not simply parallel variations in community production (Whittaker, 1965). Hyder et al. (1966) tested the assumption that the characteristics of species density and dispersion, as measured by frequency, are useful for the study of vegetation-soil and vegetation-grazing relations on the Short Grass Plains. McNaughton (1968) stated that within the grassland as a whole, productivity was inversely related to diversity and positively related to dominance.

Another important parameter is the degree of association between the species as this will give an indication of the behavior of the stand under grazing. Association between two species can be either positive or negative. Positive association is the degree to which two species are found sharing the same habitat in excess of that expected if the species are independently distributed (Ramsay and DeLeevw, 1964). Negative association is a measure of the inability of two species to share a habitat.

Whittaker (1971) indicated that a Chi-square test can indicate the probability that two species are distributed independently, or are associated with one another. An example of such an application is given in the following:

SPECIES A \ SPECIES B	Present	Absent	
Present	a = 17	b = 22	a + b = 39
Absent	c = 13	d = 48	c + d = 61
	a + c = 30	b + d = 70	F = 100

$$\chi^2 = \frac{(ad - bc) - 0.5F^2 \chi F}{(a + b)(a + c)(b + d)(c + d)} = 4.6 \ (P < 0.05)$$

This implies (with one degree of freedom) a probability of less than 0.05 that species A and B are independently distributed. Another measurement is the coefficient of association of Cole (1949) for the case $ad \geq bc$.

$$ca = \frac{ad - bc}{(a + b)(b + d)} = 0.194 \text{ (for the previous example)}$$

The values range from - 1.0 (for complete disassociation) to 1.0 (complete distributional association or correspondence). In this type of test, the χ^2 determination from a 2 X 2 contingency table dealing with the presence and absence of 2 species, is a test of association or independence of plant sociability. Plants may be associated because of mutual habitat requirements or tolerances or because one species may be dependent upon another. This means that associated species are responding in similar ways to the small-scale differences of environment within the community (Whittaker, 1970). Generally, only 2 species are compared at a time by χ^2 tests but this is of limited practical value unless some peculiar relation is suspected (Coot and Hurst, 1962). Goodall (1965) described two methods in which interspecific association is tested by measuring distances between individuals. In the first method pairs of individuals are counted in which each member of the pair is for its partner, the nearest neighbor of another species. In the second method, the distance from a random point to the nearest individual of one species to the nearest individual of the other.

To overcome such difficulty in getting practical significance from testing interspecific association, we have to resort to group interrelationships. Ramsay and LeLeevw (1949), explained that they defined the groups by their species composition and obtained a measure of the importance of each species in the different groups by means of their relative frequency and Importance Value Index (Curtis and McIntosh, 1951). The interrelationship of the groups is obtained by their coefficient of difference (Newbold, 1960). Basically, the method consists of comparing two lists or sites by the difference in the frequency of the same species in the two lists. Using these values as linear distance, it is possible to plot the groups diagrammatically as a two-dimensional figure.

To the range manager, the association of the species on the range is an important parameter. In the Sudan it gives him an indication of the trend for the communal grazing areas, if the species association is linked to animal preferences. This means that key species may be unpalatable and yet they are strongly associated with palatable or preferred species. In case of the noxious shrubs and trees, manipulation of the associated species may help in their biological control.

Exclosures have been used extensively in the Sudan to study the natural succession, and as an indication of the potential of the range. Ecologically this is quite sound, but in many cases, the range surveyor has to derive this information due to the long time involved for progressive succession to occur. These exclosures may work as reference points to study the utilization and the variation in species composition due to climatic factors.

Animals

Animals are important factors in the range ecosystem. Through selective grazing and trampling, they can alter the species composition and the natural successional patterns of the range. The mechanical action of animals in loosening seed, in carrying burs, awned seeds, in distribution of hard coated seeds through the feces, and in loosening bulbs, corms and bits of rhizome that they may be transported elsewhere is probably of unsuspected importance (Stoddart and Smith, 1955).

In the annual range type, plant species preferred by a herbivore will be endangered by grazing if the species is not endowed by the power of regeneration. Such species should be allowed to set their seeds before they are grazed. The terms "increasers," "decreasers" and "invaders" do not necessarily apply in the annual range type if we consider that the climax is considered a perennial bunch grass (Heady, 1956). Then surely we will consider the present flora as dominated by invaders. Ecologically, this may be sound but to the range surveyor the annual plant species should still be classified as increasers, decreasers and invaders. It is true that no one is able to draw definite boundaries between decreasers on one side and increasers and invaders on the other unless he has a long and continuous experience with that particular vegetation type. During drouths, in arid and semi-arid areas, animals under hungar stress appear to exhibit less definite forage preferences and they consume practically all available herbage. The term "alternative species" may adequately describe the species that are low in palatability. Then it is the responsibility of the range surveyor to report species composition ranked according to their preferences to a certain animal species, being careful not to describe a certain species as unpalatable unless he has concrete evidence that it is. He should be concerned about the degree of association between the readily palatable, the alternative species and the completely unpalatable ones.

The range surveyor should consider animal species' preferences through time and its relation to plant association, phenology, abundance and distance from water. Under the nomadic conditions, the frequency of watering of the animals has a direct effect on forage preferences as it is suspected by range managers in the Sudan (Salih, 1969). Each area surveyed, then, should have an indication of how far it is from the nearest water point and at what season or part of the season it is grazed and by what animal type. The grazing of rodents has never been estimated in the Sudan. Skerman (1965) found that the carrying capacity outside an exclosure was higher than that inside and he offered no explanation. In my opinion, the grazing of rodents was not investigated thoroughly enough to provide a possible explanation to this variation in productivity. Range surveyors should differentiate between forage production and herbage production of a range but they should report both as separate entities.

Wildlife immigration patterns should be a supplementary information source for the range surveyor.

Man

As a single factor, man under the nomadic conditions is the most influential on the range ecosystem. By his beliefs, traditions, biases, social and economic structure, and his practices and activities, man determines the fate of every rangeland. As basic information, the range surveyor should report man's activities and his potential behavior in the area he is surveying. Management can never reach its goal unless the human factors are accounted for. The psychology of the nomads and their philosophies are landmarks in range extension and management work. Areas preferred by nomads for gatherings, feasts and celebrations should be marked on the map as the least liable for proper management. Patterns of migration, alternative animal routes and water points are to be investigated by a direct questionnaire with the nomads. Their suspicions should be overcome by the proper approach to get reliable data useable in the range inventory.

A PROPOSED SYSTEM OF RANGE INVENTORY

The second Australian Arid Zone Research Conference in 1965 concluded that the use of American methods of evaluating range condition and trends were reported to be of limited use in Australia for the following reasons:

1. Australian ranges and the stock industries are much less productive per unit area of land than American ranges, thus, the methods may be too expensive in relation to income.
2. Australian ranges are grazed year-long, whereas many American ranges are used for seasonal grazing and condition is determined prior to the grazing season.
3. With few exceptions, American methods are concerned with perennial plants, whereas on Australian ranges much of the production is from annual plants.
4. American range managers can draw considerable background knowledge of individual sites and plant species which is not available for Australian ranges.

This is a similar situation to that of the Sudan, the only exception being that we do not have year-long grazing on the arid and semi-arid rangelands. Yet the result is more or less the same since the current production of the range is totally consumed by the end of the grazing season.

It is important to determine range productivity per species per season, before allowing grazing to take place. This is a problem in the annual range type where the forage production is the least predictable parameter due to fluctuations in species composition and climatic influences as has been discussed before. Early in the rainy season, the species composition is not a reliable indication of any of the other range parameters. Heady (1958) stated that positive identification of all the grass species is impractical and suggested that we should study the relation of weather to seed germination and the relation of weather to seedling survival and establishment.

The approach to this problem will be through two methods that can be used jointly or separately in the annual range types of the Sudan.

The types of determinations and information needed to apply these methods are listed as follows:

1. Soil type, depth, field capacity and permanent wilting percentage as the upper and lower limits of soil moisture. Determination of the moisture depletion and recharging patterns should also be conducted.
2. Average annual rainfall in the area concerned and a rough estimate of the time lapse between showers should be determined.
3. Knowledge of the vegetative type and the plant species that can grow on the site must be obtained. Reconnaissance surveys may help in this respect.
4. The viability of seeds of major species must be known and any potential dormancy or failure to germinate should be established.
5. Water requirements for major species and the degree of drouth tolerance expressed as the number of days that moisture in the upper foot of soil is at or below the wilting point and endured by the species at the grand period of growth (Campbell and Rich, 1961) must be determined.

6. Determination must be made of the maximum possible density under field conditions as an indication of the potential competition between species at the seedling stage. Harris (1967) stated that the initial difference between perennial and annual species is negligible inasmuch as both types compete as seedlings.

Proposed field procedures

Rauzi (1960) used the infiltrometer to determine the effect of different kinds and amounts of grass cover on the ability of the soil to absorb water and to obtain a relative water-intake rating for major soil types under varying vegetation cover. Using the infiltrometer, a range surveyor can determine infiltration rate, moisture penetration depth and runoff under different rain intensities. From weather records, he can also calculate the intervals between showers and the amount of precipitation for every shower. This can be illustrated by the following example:

Suppose the area which the range surveyor is studying has an average annual rainfall of 360 mm and the rainy season is 6 months in length. Further, suppose that the time required for soil moisture in this particular soil type to drop from field capacity to permanent wilting percentage is 10 days. The range surveyor can estimate the amount of precipitation required to keep the soil moisture content within the range of available moisture, by the following equation:

$$\frac{10 \text{ days}}{180 \text{ days}} \times 360 \text{ mm} = 20 \text{ mm every 10 days.}$$

This means that the required amount of precipitation is 20 mm every 10 days. Knowing the average intensity of rain for the area, he can determine the time of application, after correcting his values to E_W

(evaporation from free surface water in standard tank). The information he has now is the:

1. Amount, intensity and duration of each shower
2. Number of showers per season
3. Infiltration rate and runoff
4. Field capacity and permanent wilting percentage and the time it takes the moisture to drop from the upper limit to the lower.
5. Moisture depletion and recharge patterns.

After applying moisture to the soil, seeds of the different species will germinate and the potential density can be determined. It is difficult to determine frequency or cover at this stage because grass species cannot be identified and the plants did not reach their maximum projection. Frequent readings of the density will offer a type of correlation that can be used as an index for that particular vegetation and soil type. Changes in the density due to competition between the plants can be plotted against time and soil moisture. This will represent the potential condition for that range and can be used regarding density only. From density and height, the herbage production or the usable part of the herbage can be determined only if the problem of identifying the plant species at the seedling stage is solved. To overcome this problem, a second step can be applied.

Alternative laboratory method for species identification

It is known that plant species particularly grasses can be identified much easier through examining their seeds than examining their seedlings. If a soil core is taken from the field, separation of the seeds can easily be done by immersing the soil core in a suitable liquid. The viscosity of the liquid should allow soil particles to settle and seeds to float to the surface. The cross-sectional area of the core is then related to an area in the natural range. Density and frequency can be calculated after correction to the actual germination percentage of every species. Changes in the density, frequency and composition during the growth period can be determined in the field or in the laboratory.

These two methods offer the potential for determining density, frequency and composition which can all be related to productivity by indices or regression equations (Hughes, 1962). Range surveyors can then predict the productivity of a range once they have enough information about some of the climatic factors such as data on first rain, time lapse between showers and the average intensity and amount of these showers, temperature, evaporation and soil moisture behavior under these conditions. This can be applied for every stand and for every soil type. Perennial plant species do not represent a problem as that of the annual species and these can be measured by the regular parameters and methods.

Once the potential productivity is estimated, the condition of the annual range can be determined before grazing starts.

The sample location of the soil cores or plots used with the infiltrometer should be selected along a transect long enough to detect change in composition or soil, yet avoiding crossing the boundaries between two different stands in the association. The trend can be determined by comparing year to year data and weighing the averages to eliminate climatic influences. Weighting the averages can be corrected by the aridity index quoted by Skerman (1965):

Aridity index = $\frac{P}{T + 10}$, where P is precipitation and T is temperature.

When the rainy season begins and germination of all the viable seeds starts, the density of the stand should be determined and compared to the potential. This will give an indication of the behavior of the plant species and the expected competition. Therefore, when the grass species reach the "boot" stage and can be identified, frequency, cover, height, density and productivity can be estimated. The degree of deviation of the actual productivity from the potential offers a condition class whether excellent, good, fair or poor.

To complete the inventory, the range surveyor should offer a measure of the available forage through time using the height as related to productivity.

SUMMARY AND CONCLUSIONS

When dealing with an annual range type, range surveyors face several problems not encountered on perennial range types. These problems arise from the dynamic nature of the different plant species and their interactions with the climate and soil.

Due to the short time involved between the germination of the annual plant species and the readiness of the range for grazing, range surveyors are required to possess the means of predicting productivity, condition and trend within a time period of approximately one month. The information on these parameters can be collected by the use of different indices established through research. The potential productivity of the annual range should be corrected and adjusted year after year to allow for a more precise evaluation of condition and trend as the communities change.

Climate and soil are the two major factors affecting cover, density, species composition and plant distribution in arid and semi-arid regions of the country. The responsiveness of all plant species to the slightest moisture change makes soil moisture one of the most important parameters to be measured in a single ecotype.

Information on the past human and animal activities in the area should be reported to complete any range inventory and to make it useful to range managers.

A proposed method of range inventory is introduced to allow range surveyors to estimate species composition, density and frequency. An alternative method is also introduced when identification of plant species at the seedling stage is rather difficult or impossible.

The burden placed on range researchers is great as they have to establish most of the discussed relationships and derive equations, graphs and indices used in predicting productivity and vegetational changes in an annual range type.

Under the nomadic grazing systems, the early prediction of productivity will allow range managers to plan and execute their management programs using watering points as a tool. Assessment of stocking rates would become an easier task once the information supplied by range surveyors is adequate and within a reasonable margin of sampling error.

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