A Tentative Outline for Thesis.

PLANT SUCCESSIONS ON GRAZING RANGES IN SOUTHERN ARIZONA.

PART ONE. THE ORIGINAL VEGETATION.

I. Evidences.
   1. Relicts.
   2. Reversion under protection.
   3. Early records, reports of explorations, etc.
   4. Statements of early settlers.

II. Reconstruction of the original range (a picture of conditions in early times).
   1. Distribution of grassland and rainfall.
   2. Conditions which maintained the dominence of grasses (fires, rainfall, soil character, etc.).
   3. Original fauna, and the maintenance of a natural balance between grazing and predatory animals.
   4. Differences of former and present grazing conditions.

PART TWO. THE PRESENT VEGETATION.

I. The Destruction of the Original Range.
   1. The destruction of the original grazing animals.
   2. The upsetting of the natural balance among grazing and carniverous animals.
   3. Introduction of cattle and their effect.

II. The present range.

   1. Conditions on the range.
   2. Principles of succession under grazing conditions.
   3. Introduction of alien plants.
   4. Conditions of control which are largely responsible for the present state of the range.

PART THREE. RANGE IMPROVEMENT.

I. Experimental Studies.
   1. The effect of total protection.
   2. The effect of rodent grazing when protected against cattle grazing.
   3. The effect of cattle grazing with partial removal of rodents
   4. Effect of deferred grazing.
   5. Rotation and the handling of grass types.
   6. The effect of burning.
   7. The introduction of alien browse plants, herbs, and grasses.
   8. Reseeding the range: (a) with alien, (b) original grasses.

II. Practical Handling of the Range.
   1. Fencing for grass types and for control of the range.
   2. Water development.
   3. Salting methods.
   4. Rodent control.
   5. Handling of grass types.
   6. Measuring range utilisation.
   7. Overgrazing indicators.
   8. Rainfall cycles.
   9. Reserve and emergency feeds.
   10. Expansion and contraction of herds.

PUBLICATIONS BY HERBERT C. HANSON.

1. Leaf-Structure as related to environment. Am. Journ. Bot.4:533-560. 1917.
2. The invasion of a Missouri River alluvial flood plain. Am. Midl.Naturalist 1918.
3. The malvaceous plants of Texas. Texas Agric. Exp. Sta. Circ. 22:1-18. 1920.
4. Distribution of the Malvaceae in southern and western Texas. Am. Journ. Bot. 8:192-206. 1921.
5. Prairie inclusions in the deciduous forest climax. To be published in the Am. Journ. Bot. for October, 1922.
6. Distribution of Arizona Wild Cotton (Thurberia thespesioides) To be published by the Experiment Station of the University of Arizona.

PROJECTS AND INVESTIGATIONS IN PREPARATION.

1. Ecology of the Boulder Region, Colorado. Investigations covering a radius of about twenty miles with Boulder as a center have been under way for two seasons.
2. Leaf-structure under controlled, measured, environmental conditions. A large amount of data has been collected on this study in a little over a years time. Drawings of leaf sections and assembling of data, and probably a few more greenhouse experiments, remain to be done.
3. Plant ecology of northern Arizona with especial reference to grazing problems. Work on this is to begin in June, 1922. It is planned to make extensive surveys as well as intensive studies of special areas by means of instruments and quadrats. Comparison of vegetation and factor data with southern Arizona will be kept constantly in mind. Immediate utility of all facts collected to farming, grazing and forestry will be emphasized.
4. Methods and principles in the eradication of poisonous and other objectional plants. Data is being accumulated from a great variety of sources; from personal experience with the eradication of cotton in southern Texas; from reports and experiences of state departments of agriculture; from reports and experiences of the U. S. Department of Agriculture on the barberry, currants and gooseberries; from experiment station reports; etc.

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Gorm Loftfield

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QUANTITATIVE STUDIES ON THE VEGETATION OF THE GRAZING RANGES OF NORTHERN ARIZONA

BY

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THESIS OFFERED IN PART REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY AT THE UNIVERSITY OF ARIZONA

Preface

Certain principles concerning the distribution of plants, while now well known to ecologists, are not in a form available to the average student. A brief discussion of them is therefore not out of place. A study of plant communities has revealed two principles of fundamental importance. The first is that of climax associations, that the widespread groups of plants forming the characteristic vegetation are the dominating plants controlling the growth of all less important plants associated with them, and able to compete with, and replace all other major plants after a time, upon their domain. The second is the principle of succession.

That a plant will not grow in a habitat or environment for which it is unsuited, is self-evident. However, it often happens that a plant can not survive in a habitat to which it otherwise is fitted because of inability to compete with the existing plants. The dominant plants on an area are consequently those not only adapted to grow under existing conditions, but able to hold the ground against all other plants present. When they are also able to hold their dominance permanently they are members of the climax association. If, however, they can retain their dominance only for a time and are replaced by others able to become established under the conditions created by them, they are called succes-

sional dominants. The new invaders of the area may also be successional in which case these will in turn so modify the environment that another group of dominants can establish themselves and take over the ground. This continues until the climax dominants are reached which are able to so control the area that no other group of plants can invade it in competition with them. A corollary to the principle of succession, therefore, is to the effect that plants tend to modify the conditions under which they grow, and in so doing, they very often simply prepare the ground for the invaders which are destined to drive them out.

This is best realized by considering some specific habitat. A bare rock surface in a montane forest is wholly unsuited as a substrate for the plants of the climax vegetation. The only plants normally able to colonize and exist upon it are crustose lichens. When sufficient numbers of these have colonized the surface, enough water is retained to permit the growth of foliose lichens which then invade the habitat. These in turn retain a larger supply which permits of invasion by mosses. By this time a slight amount of soil is built up by the decay of plant parts, catching of dust, and by keeping a certain amount of water present at nearly all times, frost action may cause the rock to disintegrate. Herbs will then colonize the surface and build up the soil still more, permitting shrubs and finally trees to invade the area. In this manner each group of plants prepares the ground for the next until the climax vegetation is reached.

Successions fall naturally into two types, primary and secondary. A primary succession commences usually with a bare rock or a water surface, and is thus named since the plants themselves control conditions throughout the history of succession, furnishing or causing the accumulation of soil and preparing the way for the next stage. A secondary succession is initiated by some denuding agency which removes the vegetation present at the time either in whole or in part, but does not wholly remove the soil to form a bare rock or free water surface. In such successions, speed of invasion and various other factors enter in. Hence the action of secondary succession dominants is not necessarily a modification of the habitat which enables the succeeding vegetation to become established. To illustrate, again using the montane forest as an example, fire in removing Douglas fir is followed in most cases by an aspen cover. Seedlings of Douglas fir gradually establish themselves under this cover and the aspen is replaced by them as they grow. The climax vegetation occupies the ground, therefore, with but one intervening stage. But in some cases, a burn may be colonized directly by Douglas, showing that aspen is not a necessary step. Aspen produces large amounts of viable seeds easily carried great distances by the wind and is thus able to plant a burn much more quickly that Douglas fir as a rule. Fire merely served to remove the competition of the climax dominants for the time.

A secondary succession may run its own course to the

climax stage or may run into some stage of the primary succession. Repeated burns in the Douglas fir consciation may remove aspen to form a cover of bracken or fireweed which in turn will be replaced usually by grasses and herbs of the herb stage in the primary succession. Many grassparks in the forest have this origin. From this point on, the succession will be essentially like that of the primary succession, although the greater amount of soil may cause some of the stages to be abbreviated or even to drop out.

The climax vegetation is the stable vegetation of the region, but this stability is dynamic and especially towards the edge of the formation, is easily upset. When a tree dies or is killed, a succession is often initiated upon the small area once occupied, In the mature formation this goes on constantly. A swing in the climatic cycle may cause one formation to encroach upon another in the contact between the two while a few years later the progression may go the other way. This is one explanation of ecotones or transition zones between formations. Sometimes an area is at the meeting point of more than two formations and all are intermingled. Around Cabazon, California, from Banning to Whitewater, are found representatives of four climax formations, closely associated. The dominants of one formation will at times penetrate the entire adjacent formation. Thus in northern Arizona the grassland dominants are usually found between the trees of Juniper-Pinyon association and extending sometimes into the lower edge of the yellow pine.

The principles of plant succession as now understood were proposed by Clements (1916) in "Plant Succession" and the climax formations of western United States in "Plant Indicators" (Clements, 1920). Future work must now consist of investigations of unit successions or ~~rare areas~~ series and of the factors involved. This must be done by the use of the quadrat method and of factor stations. Certain pioneers have already achieved valuable results from such studies. Shantz (1911;1917), Weaver (1914;1917), Weaver and Thiel (1917), Bergman and Stallard (1917), Stallard (1917ms.), have used these methods successfully. The United States Forest Service has employed them in grazing studies largely with excellent results. While these methods are in widespread use, not many results have as yet been published. A series of quadrats must be maintained and charted over a period of many years before the data obtained can have very considerable value in regard to successions, although one year's work will throw much light upon the present composition of vegetation. This is clear when it is realized that a quadrat placed in some early stage of a primary succession may require much more than one man's lifetime to pass into the climax or ultimate vegetation stage. But when a quadrat or a number of them are placed in each stage of such a succession, a picture of the whole course may be obtained in the time required for each stage to pass on to the next, and the time of investigation shortened considerably. Even then to complete the necessary data requires a

number of years. However, usuable results are obtained with the first charting and grow in value each succeeding year as long as the investigation continues.

This investigation covers a period of six years at the most. Many of the quadrats, however, were added in 1922 and hence have not as yet great value in successional studies except by comparison with one another. Thus where some are in places where the grasses have been protected for some years and others of the same type are subjected to heavy grazing, it is permissible to draw conclusions from these in regard to grazing effects. On the other hand, certain quadrats were installed in areas which were heavily or partially grazed until 1918 and the areas fenced for complete protection. Such quadrats have therefore shown considerable change during the six years of the investigation and are of the greatest value in interpreting the data from the more recent quadrats.

Acknowledgment

The project was made possible by the cooperation of several organizations. The U. S. Forest Service paid the cost of the fenced plots at Williams and Coconino, Arizona, and these are placed on the Tusayan National Forest. Mr. Reid met the expense of fencing the plots on the Double O Ranch (Reid and Cashion) south of Seligman. Mr. D. A. Gilchrist of the U. S. Biological Survey and his assistant constructed the fences. The University of Arizona has cooperated with the investigation from its incep-

tion. Dr. C. T. Vorhies of the University carried on the charting of the quadrats for the season of 1918 while the writer was in the military service. Dr. W. P. Taylor of the the U. S. Biological Survey has inspected the areas with the writer each year, and Mr. D. A. Gilchrist has arranged whenever possible to keep the proper areas colonized with prairie-dogs. Other members of the Biological Survey have shown a keen interest in the project, notably Major E. A. Goldman and Dr. E. W. Nelson. The Forest Service through the Supervisor of the Tusayan National Forest (at present Mr. Kimball) has carried on inspections of the areas reporting several times during the season on the condition of the plots. And lastly, acknowledgement is given Dr. F. E. Clements of the Carnegie Institution of Washington who organized the research and made it possible to carry it through.

QUANTITATIVE STUDIES ON THE VEGETATION OF THE GRAZING RANGES OF NORTHERN ARIZONA

INTRODUCTION

REGION COVERED. The region covered in this study consists of a strip of the State extending from the California boundary along the Santa Fe Railway to Flagstaff. From Seligman it stretches south by way of Prescott to Phoenix, and from Flagstaff by way of Mormon Lake to Pine and Payson. From Williams and Flagstaff it extends north to Grand Canyon. This strip is typical in its vegetation of the entire northern part of the State with the exception of parts of the Painted Desert, and of certain other successional areas chiefly characterized by the presence of Atriplex species. Other locations occur, as for instance, at Adamana, Winslow, and much of the surrounding area, the short-grass plains contain scattered small shrubs of Artemisia bigelovii which at this place are a natural constituent of the climax formation.

This region is of great interest, for in it are contained samples of all the climax formations to be found in the State. In the eastern portion are the San Francisco Mountains which, with the White Mountains, are the only ones in the State high enough to have a true alpine flora,

constituting the alpine meadow formation. Below it successively down the mountain side are found two formations, the sub-alpine forest climax composed largely of Englemann spruce in this region, and the montane forest climax, represented by two consociations, Douglas fir and yellow pine. Extending west, north, and east from the mountains proper is found the pinyon-juniper formation, and below and beyond this, the southwest faciation of mixed prairie, which is a part of the great grassland climax. From Kingman westward, this is replaced by the desert chaparral climax of Larrea-Franseria formation. This extends across the western part of California to Cajon Pass. The accompanying map, while not strictly a formation map, since that part of the grassland which forms savannah with the adjacent formations, have been mapped with those formations, nevertheless is an accurate record of the vegetation as it now exists.

METHODS. An attempt has been made to make this study extensive as well as intensive. A quantitative investigation of the composition and movements of the vegetation upon a restricted area is of greatest value when an extensive survey of the surrounding region has been made in order to determine the relation of the area to the whole of the formation. The area studied intensively can be but a few acres at the most, and yet the results obtained are representative of a considerable region. Unless a considerable part of the formation is examined, it can not be known how much of it is typified by the area, nor to how great an extent the whole

formation is represented. Therefore repeated trips over the states west of the Mississippi and an examination of as much as possible of the vegetation of these states has been of great value in determining the relation of the vegetation of the region studied to each formation as a whole. Repeated surveys of the region have in addition permitted of placing stations for detailed studies in the most significant places, as well as furnishing the data for the accompanying map.

The basis for this as for all other quantitative studies of vegetation was the standard quadrat and its modifications. A standard quadrat is a square meter of ground staked permanently so that the plants upon it can be charted each year or after each growing season. A transect is a strip usually one or two meters wide and long enough to include the desired plants. Community maps are charts made of larger areas rarely less than an acre in size, in which the plants are mapped by communities as the name indicates. Bisects are made by excavating a trench and mapping the plants growing along one edge vertically, thus showing graphically the height, growth, spread, and inter-relationship of the roots of the plants found, as well as their relation to the soil. Tristatis are made by driving three stakes into the ground for a camera tripod to stand upon. By using the same camera and tripod each year, it is possible to photograph the same position, and the successive photographs are measured for changes. In addition, the clipping of quadrats for

the measuring of height, growth, and vegetation counts were employed to gain a quantitative measure of the composition and movements of the vegetation, and the effect upon it of rodent and cattle grazing. Fencing, burning, and other means were employed to vary the conditions under which the plants existed, and the reaction of vegetation to such conditions measured by the means indicated.

STATIONS. The quadrats, transects, and other areas were grouped in stations located at significant points in the region. Three stations were placed in the desert scrub or chaparral, one near Yucca, Arizona, another eight miles west of Kingman in the Sacramento Valley, and a third below Cave Creek in the edge of the Salt River Valley, making two in the western and one in the southern part of the region. Three stations were placed in mixed Bouteloua gracilis and B. eriopoda grassland, one two miles and one six miles east of Kingman in the western or lower edge of this faciation, and the third in the upper Chino Valley ten miles south of Seligman which is near the upper border of this form of the short-grass association. At Williams, a station was placed in Bouteloua gracilis mixed with Chrysothamnus and Gutierrezia in an open park in the Juniper-Pinyon-oak formation. North of Williams, two stations were placed in successional phases of this formation, one twenty miles south of the Grand Canyon in an area disturbed by prairie-dogs, and another thirty miles south in a Eurotia society. One station was placed in the chaparral, or oak-Ceanothus

formation eight miles northeast of Prescott, One station was placed near Coconino, twelve miles south of Grand Canyon in a wheatgrass park in the yellow pine forest. Additional stations of minor importance were located at various other places to help interpret the results from the other stations, and to add to the evidence obtained.

THE VEGETATION

THE FORMATIONS. The vegetation in the region falls into seven great climax formations. Over the greater part of the area belonging to each formation the climax dominants occupy the ground except where grazing, logging, or fire have removed the original cover. These formations in general tend to form zones at definite elevations, not because the elevation acts directly upon the plants but because rainfall usually increases with the elevation and the factors of evaporation, temperature especially, decrease. But since the northern slopes of a mountain are cooler and evaporation not so intense, these zones tend to run lower on this side of the mountains, and for opposite reasons tend to move higher on the south or southwest sides. Canyons are the courses of cold air drainage from the higher elevations as well as of water, and permit the higher formations to extend sometimes a thousand feet or more below their normal level on the mountain slopes. Dry, hot ridges with shallow, coarsely textured soil have the opposite effect. For these reasons the vegetation does not occur strictly in zones, and elevation has no effect save as it influences soil moisture and evaporation. As this influence is usually all-important save in the instances noted and certain other exceptional ones the zones may be ascribed to fairly definite elevations over the greater part of the region.

The alpine meadow association occurs on the higher peaks of the San Francisco Mountains above 11,500 feet (3500 meters). It is composed of certain low shrubs, mainly willows, and a great many species of low-growing herbs. The most important of these from the grazing standpoint are the various grasses and sedges. Poa rupicola and others, Festuca brachyphylla, Agropyron scribneri, Trisetum subspicatum, and Phleum alpinum are the commoner species of the grasses. They are outnumbered by the sedges which are the dominants, particularly Elyna bellardi, Carex rupestris and filifolia. These and the grasses, together with certain clovers and other herbs, form the main supply of forage. However, the small area covered by this formation, and the shortness of the growing season, reduces its value as range materially.

The subalpine forest occurs between 9,500 and 11,500 feet (2900 to 3500 meters) and is practically confined to the San Francisco Mountains in the region under discussion. It differs from that of the more northern states of the Rocky Mountains in that only one of the two chief dominants is present, namely, Engelman spruce. The other, Abies lasiocarpa, loses dominance in central Colorado. Lesser dominants in the region include foxtail pine (Pinus aristata), and limber pine (Pinus flexilis). The Engelmann spruce (Picea engelmanni) often forms dense forests, where the terrain permits, with little or no undergrowth. Occasional meadows and fire-made parks occur, however, which have high

grazing value as summer range. Characteristic grasses of the fire-made parks and the more open forest are Danthonia spicata, Calamagrostis purpurescens, and Muhlenbergia gracilis. The moister meadows contain Poa pratensis and others, Calamagrostis canadensis, Bromus richardsoni and others, and several grasses and sedges of minor importance. Like the alpine meadow formation, the small extent and rather limited seasons, reduce the value of the Engelmann forest to minor importance as range in comparison with the succeeding formations.

The montane forest also has two major dominants, both of which are present in this region. Douglas fir tends to form pure stands at the upper limit of the formation, and yellow pine does likewise at the lower edge. The greater part of the Mogollon Plateau forest is nearly pure yellow pine. Douglas fir is like Engelmann spruce in that it often forms dense stands with but little undergrowth. The yellow pine forest, however, is much more open as a rule and often has an appreciable stand of grasses and other herbs running through it. This formation occurs usually between 6,800 and 9,500 feet in elevation, (2000 to 2900 meters), but because of differences in rainfall in places will vary greatly. Near Prescott it drops as low as 5000 feet.

Pinyon-Juniper woodland is a very open formation and only occasionally at its upper edge occurs in sufficiently dense stands to shade the ground uniformly. It usually forms a savannah with the grassland dominants, and such areas are

not climax Pinyon-Juniper but a transition form of grassland, Pinyon pine is more common at the upper edge of the woodland formation than at the lower. Juniper, especially, tends to run considerable distances down into the grassland formation along rocky ridges and broken ground. Grass fires sweeping up into it also clears away the trees and causes tongues of grassland to run up into the woodland. For these reasons the lower limit of the formation is hard to define. In this region it seems to occur as a formation between 5,800 to 6,800 feet, although on broken ground or shallow soil particularly, it occurs as a subclimax to grassland and chaparral a full 2000 feet or more lower.

Oak-Ceanothus chaparral is also a formation with indefinite limits, It is placed by Clements (1914;1920) as the next formation below Pinyon-Juniper woodland. To the north and to the west of the San Francisco Mountains it is either patchy, narrow, or entirely wanting. To the south, however, the reverse is true. Below the edge of the Mogollon Rim above Pine and Payson, and at Prescott as well, this chaparral formation is of vast extent. The Junipers at these places occur usually as stragglers in the chaparral. The most typical dominants of this formation present at Prescott were Quercus undulata, Ceanothus fendleri and Schmaltzia.

The great plains grassland occurs from Kingman on the west to Ashfork. In general, it occurs from 3,500 to 5,800 feet elevation as a climax formation, but is found above this to 7,000 feet as a subclimax. This is the most important of the formations from the standpoint of grazing.

The southwest extension of the grassland which is found in this region differs from the faciation to the east in not having buffalo-grass (Bulbilis dactyloides) as a major associate with blue grama (Bouteloua gracilis). Instead, this latter dominant is usually associated with wooly-foot grama (Bouteloua eriopoda) which is also found in the desert plains formation. A certain amount of ring grass(Muhlenbergia gracillima) occurs particularly in certain overgrazed swales or flats. The dominants of lesser importance are Galleta (Hilaria jamesii and H. mutica) and western dropseed (Sporobolus cryptandrus and its subspecies).

The true desert is largely confined to California;— the Mohave and Colorado deserts. A narrow belt beginning near the Mexican border south of Ajo and extending north and westward along the Colorado River comprises its extent in Arizona. Narrow extensions to the east of this region occur on one hand, on the other, the grassland extends westward into the area. Along the Atchison, Topeka, and Sante Fe Railroad, this formation begins properly at Yucca. Between this town and Kingman, overgrazing has destroyed the original grasses which formed a savannah with Yucca bacata and Opuntia arborescens, thereby practically adding this to the desert.

The desert scrub formation as a whole consists of desert plains grassland and true desert. The dominants of the true desert consists of creosote bush (Larrea mexicana)

and desert scrub (Franseria dumosa). Those of the desert plains occur in two faciations, an eastern and a western. The eastern consists of creosote bush, mesquite (Prosopis juliflora) and Flourensia cernua associated with grasses, the western of creosote bush, mesquite, desert scrub (Franseria dumosa), Yucca baccata and Yucca elata. Dominants of lesser prominence but of considerable importance include desert buckwheat (Eriogonum poliofolium), Joshua trees (Yucca arborescens), ocotillo (Fouquiera splendens), catsclaw (Acacia greggii, A. contorta, etc.,), palo verde (Parkinsonia microphylla, P. torreyana), sahuaro or giant cactus (Carnegiea gigantea), prickly pears (Opuntia engelmanni, O. pheacantha, O. discata, etc.,), chollas (Opuntia bigelovii, O. spinosior, O. versicolor, O. fulgida, O. leptocaulis, O. arborescens, etc.), and many others. This formation tends to break up into associations perhaps more than any other in each of the regions in which it is found. In the regions with three inches or less of rainfall and high evaporation, creosote bush and desert scrub form the true desert, and this has very little grass outside of annuals such as six-weeks grama (Bouteloua barbata).

THE GRAZED FORMATIONS

The upper formations, the alpine meadow, and the sub-alpine forest are, as previously stated, of such small extent, that they have but little economic importance from the grazing standpoint. The associations considered, therefore, consist of yellow pine forest, woodland, chaparral, grassland, and desert scrub savannah. The most important is, of course, the grassland proper. The others, however, are so open that considerable grass is found associated with them and hence are very important as range land. A more detailed discussion of these five formations is necessary, in consequence, to gain a clear picture of the northern Arizona ranges.

The distribution of the formations in any given area is based upon the ratio between rainfall distribution and the evaporation factors. When a large region, however, is considered the size of the members of the ratio also becomes important. Thus if the ratio between soil water content M and evaporation E varies between (c) and (d) for example, the station is in true grassland, if the ratio $\frac{M}{E}$ varies between (e) and (f) it is in Pinyon-Juniper savannah phase of grassland. If it varies between (b) and (c) on the other hand, it is in the Yucca-Prosopis savannah or upper desert plains grassland. As the formation extends south, the evaporation factors increase and a higher water-

content is required to meet it and keep the ratio the same. But in the zone of the same ratio the plant must have a greater root system and increased means of water conduction to meet the increased evaporation. As the formation dominants show considerable ability to adjust and adapt themselves to new conditions, these are in large measure met, but there is an increasing tendency as the members of the ratio increase, to move into the next zone where the ratio is greater. The most striking effect, however, is to produce faciations, each of which differs from the others by being composed of different dominants in part; certain dominants, as a rule, being found in all.

YELLOW PINE. The yellow pine consociation, as already stated, forms pure stands at the lower edge of the montane forest, since it is the more xerophytic of the two dominants. Associated with it are thickets of Cowania mexicana, Quercus gambeli, and certain grasses and herbs, such as Muhlenbergia gracilis, Festuca ovina arizonica, Lycurus phleoides, Bouteloua curtipendula, Andropogon scoparius hirtiflorus, Agropyron smithii, and A. spicatum. The first two grasses are found under the trees where these are not too dense, the next three are common where ravines and broken ground keep the trees scattered, and all are commonly found in both the water-made and fire-made parks. The Grand Canyon forest, unlike the Mogollon, resembles the yellow pine forest of the desert ranges of California in that Artemisia tridentata occurs scattered through it as

well as in its parks.

The forest studied in greatest detail is that on the south rim of the Grand Canyon. The chief station is near Coconino in a water-made park. In it the grasses are chiefly Agropyron smithii and Sporobolus oryptandrus. On an adjacent area there are Lycurus phleoides and Bouteloua gracilis growing under the trees. In 1918 blue grama (Bouteloua gracilis) was invading the park as a result of heavy grazing, since this grass forms low-growing mats and cattle can get only the stems and taller leaves under such grazing. Western wheat grass (Agropyron smithii) was the chief grass, although grazed to the soil level. A number of plants of western dropseed (Sporobolus cryptandrus) were also present but had been grazed almost to extinction. Fencing of two three-quarter acre plots that spring, however, protected these grasses and permitted the dropseed to produce a large crop of seed which were scattered over the greater part of the park. The end of the growing season of 1919 found large numbers of dropseed plants everywhere, and this grass has since been a very important constituent of the park vegetation.

Other grasses, chiefly Koeleria cristata are also present. In the entire park but one plant of Stipa comata, or porcupine grass, occurred in 1918. This was included in one of the fenced plots and under protection from grazing is slowly spreading. A number of plants of a low annual grama (Bouteloua procumbens) has always been present, but

first became important in 1922 when it occupied all available space between the other grasses outside the plots. It was practically absent inside the plots, however, as it was not able to compete with the protected grasses. Its grazing value is very low because of its short life and small size.

A careful study of this park, with the grasses in it placed under conditions of cattle grazing, rodent (prairie-dog) grazing, and total protection, and of the more or less protected areas near Flagstaff, Riordan, and Bellemont, have given a clear picture of the original grass cover, and the results produced by rodent and cattle grazing. The rockiest areas near Flagstaff and Riordan have stands of Andropogon scoparius (hirtiflorus) and Bouteloua curtipendula . Where the ridges are not so rocky, and the soil somewhat deeper, Lycurus phleoides comes in and extends into the ravines and shallow depressions as well. The main cover under the trees over the greater part of the forest was undoubtedly Muhlenbergia gracilis and Festuca ovina arizonica (65 per cent and 25 per cent respectively) with lesser amounts of Stipa comata, Agropyron smithii, and Koeleria cristata. In the shallow soil of the ridges, in in the fire-made parks and other open places, a certain amount of Bouteloua gracilis was also present and still persists in such situations today. The grasses of the fire-made parks are much the same as those found under the trees but show much greater growth due to the removal of shade and the mulching effect of the pine needles.

In the water-made parks the plants were normally Agropyron smithii (35 per cent), Sporobolus cryptandrus (25 per cent), Stipa comata (20 per cent), Koeleria cristata, Artemisia tridentata, A. dracunculus, Chrysothamnus nauseosus, Malvastrum lobatum, and Sitanion (two forms, a glabrous and a woolly pubescent variety), of importance in the order named. The last two are chiefly found in places where disturbance has been caused by moles, ants, and various kinds of rodents, or by other denuding agencies.

Grazing by cattle and sheep has been peculiarly destructive to Stipa comata and Koeleria cristata, since both are early bunch grasses. From a very important constituent of the grass cover of the region, the former has been reduced to one of the rarest of grasses, and relicts of it are hard to find. Such relicts are widespread, however, and its very rapid recovery when given protection against overgrazing, show that it was at one time very important. The estimates of relative percentages were made from quadrats placed where some sort of stability seems to have been reached under total protection.

In the deeper soils of the water-made parks, Agropyron smithii has withstood the direct effect of grazing very well. However, removal of other grasses by such grazing has produced the opportunity for spreading by the shrubs, such as Artemisia tridentata (in Grand Canyon forest) Chrysothamnus nauseosus, and Gutierrezia sarathrae. These have the ability to crowd out wheatgrass, largely by shading, as well as by removal of moisture.

Cattle grazing alone will not destroy Sporobolus cryptandrus unless unusually severe. While a tall-grass when given the opportunity to grow normally, it possesses the power to form mats very similar to those of Bouteloua gracilis under like conditions. In such a form it does not produce much more forage than blue grama. Sheep, however, can readily graze it to the point of extinction, and prairie-dogs almost invariably destroy it by seeking it out in preference to the other grasses present and grazing it down to the roots. If protected before all seed plants are gone, it produces large amounts of viable seed which permit it to reestablish very rapidly upon the area. Thus, the small number of plants present in 1918 were permitted to produce a crop of seed that year. The following year (1919) found seedlings starting up all through the park, and at the end of this season this species covered 60.27 square decimeters of the clip quadrat as compared with 3.20 square decimeters of wheatgrass. The difference in forage produced, however, is not as great as this difference in area, as this quadrat yielded 100 grams of wheatgrass to 117 grams of dropseed. The following year the increase of the other grasses reduced the amount of Sporobolus considerably, and at present it constitutes about 25 per cent of the total cover.

The forage yield of such a park is very high, the average for five years being over 1800 pounds of hay per acre. Continuous grazing, however, reduces this very considerably, although the area held by the grasses is not so much dimin-

ished. Under conditions of deferred grazing the yield would be about the same as under total protection.. With the present system, it is much less, probable less than a half of this yield, although no data are available by which this may be estimated with any degree of accuracy. These figures are based upon the results obtained from clip quadrats inside the total protection area, and outside under present grazing conditions. With deferred grazing such a park will support a cow per three acres for three months, while under present conditions one cow per ten acres will result in overgrazed conditions.

Overgrazing in this type at first causes practical extinction of Sporobolus, reduction in the number of shoots of Agropyron and the coming in of blue grama. Weeds such as Malvastrum elatum and bushes of sagebrush (Gutierrezia sarathrae) come in next. The final stage is the killing out of the grasses leaving sagebrush, rabbitbrush (Chrysothamnus nauseosus, sub-species graveolens and consimilis) and snakeweed.

Parks containing Festuca ovina arizonica and Muhlenbergia gracilis as the major grasses do not have quite as much forage as the wheatgrass type but still have high grazing value. A clip quadrat near Bellemont west of Flagstaff showed a yield at the rate of 1450 pounds to the acre. The areas covered by blue grama(Bouteloua gracilis) and Texas timothy(Lycurus phleoides) are considerably less although exact data was not obtainable as the quadrats in this type were not protected from grazing. Yields from

both of these grasses in other formations, however, would indicate that this type has not more than a third higher grazing value than blue grama alone.

All of these grasses, but more particularly Muhlenbergia gracilis and Festuca ovina arizonica, are found as an undergrowth in the forest itself except where they have been killed out by overgrazing. In such cases they are often not replaced by other plants. Even such shrubs as oak (Quercus gambellii), cliff rose (Cowania mexicana) and the seedling yellow pines are often killed under these conditions.

The parks are destined ultimately to be added to the forest, In the Grand Canyon forest they are invaded by sagebrush, then by oak, and finally by yellow pine. The oak and Cowania thickets are therefore the subclimax stage which tends to persist after the climax is reached. The fire-made parks are often invaded directly by the yellow pine, but the water-made parks usually follow the course indicated. A fire in the upper part of the forest is nearly always followed by aspen. If seed trees still occur nearby and a good seed year is followed by a favorable season yellow pine follows directly,- otherwise the area gradually becomes grassland as the aspen dies out. In northern Arizona widespread seeding and establishment of yellow pine seems to be a rare event. The season of 1919 was the last year of such a crop, the previous one having occurred about thirty (30?) years before.

PINYON-JUNIPER. The dominants of this formation in northern Arizona are Juniperus occidentalis monosperma, J. californica utahensis, J. virginiana scopulorum, Pinus edulis monophylla, and in many places Cupressus quadelpensis. The major dominants are juniperus o. monosperma and Pinus edulis which are regularly associated. Towards the west juniperus o. utahensis and Pinus e. monophylla replace the other two. Juniperus V. scopulorum occurs throughout the formation, but seems to become important only as an associate of oak in chaparral in the southern part of the region investigated. Certain shrubs, particularly Berberis fremontii, are found associated with the trees.

The formation is normally an open woodland with considerable grass growing under and around the trees. Generally these grasses are the dominants from the grassland below but on the upper edge the same grasses also occur that are found in the yellow pine forest. On rocky ridges, side-oats grama (Bouteloua curtipendula), galleta grass (Hilaria jamesii), ~~and~~ little redstem (Andropogon scoparius), and Texas timothy (Lycurus phleoides), are often common. Because of the shading by the trees and bushes there is not as much grass as in the grassland proper, but estimates made from vegetation counts give one fifteenth to more than three-fourths as much grass by area as in the corresponding pure grassland types. Where badly overgrazed, these grasses are replaced by rabbitbrush (Chrysothamnus), snake-

weed (Gutierrezia), and Senecio douglasii, and in more open situations by ring-grass (Muhlenbergia gracillima).

Burns in this formation, if severe enough, simply clear away the trees and allow the grass to hold the ground. In the cases where the grasses are also killed, a chaparral of Fallugia paradoxa, Rhus trilobata (Schmaltzia), Cercocarpus parvifolius, and Berberis fremontii will often come in. The spaces between these are later occupied by grass and finally Pinyon (pine) and Junipers come up through the bushes. Such cases, however, are comparatively rare, and a grass fire sweeping into the formation is normally followed by a grass cover. Tongues of Juniper work their way into the grassland, particularly along broken ground and rocky ridges, and in such places, from a persistent subclimax to the grassland as long as such topography persists. The greater part of the area occupied by these trees is essentially grassland climax, since the area is controlled by grasses. The true Juniper-Pinyon formation is of very small extent.

In the contact between the grassland and this formation are a number of shrubs. To the north of the San Francisco forest and woodland are small patches of chaparral consisting largely of Berberis fremontii and Fallugia paradoxa. North and west of Williams and north of Maine postoffice the Juniper-Pinyon woodland comes into direct contact with the grassland. As the grassland is above the usual altitude in this strip between the San Francisco and Grand Canyon forest it seems probable that

it is the result of flooding and of fire and therefore a persistent subclimax to the woodland formation. Outliers of Juniper which have invaded these parks, but are now dead, have fire scars, showing the manner in which they were killed, (Plate IV). The grass fires in the flood parks have apparently swept up into the surrounding woodland without penetrating very deeply, and have, therefore, only killed the trees along their edges and on the ridges running into them. The shrubs do not seem to be killed as readily as the conifers, and hence many patches survive as a chaparral where the associated Junipers and Pinyon (pines) have been destroyed.

As stated, only a small part of the area occupied by the woodland dominants form the true woodland climax. The Pinyon-Juniper savannah is a part of the grassland climax. Where the woodland is sufficiently dense to shade more than half the ground below the trees, the area belongs to the woodland formation. Even where the trees form so dense a stand that their branches touch each other, the grasses formerly covered most of the ground beneath them. These grasses were much the same as those in the yellow pine forest, but the composition was not the same. Here porcupine grass (Stipa comata) and blue grama (Bouteloua gracilis) played a more important part than under the yellow pines, while Arizona fescue (Festuca ovina arizonica) was of lesser importance, and Muhlenbergia gracilis became neglible.

The chief station in this formation is five miles north of Williams. Although the fences have been installed at this place for the same length of time as at Coconino, the present total protection area has been kept as such for only two years. For this reason, no part of the area has become sufficiently stabilized to permit an accurate estimate of the composition of the original grassland. No porcupine grass (Stipa comata) is present although relict areas show it to have been the most important tall grass constituent of this formation. On October 17, 1923, a quadrat under total protection was planted with 100 seeds of this grass, and in this manner it is hoped to gain definite information regarding its position in this type of grassland within a few years.

Overgrazing in this forage type has practically destroyed all of the tall grass components. Only the short grasses remain and these have also been removed from considerable areas. Even ring-grass (Muhlenbergia gracilima), which is almost worthless from a grazing standpoint, is suffering. Although largely immune from grazing, it succumbs to the trampling of sheep and the competition of the ungrazed shrubs. Considerable areas contain nothing but rabbitbrush (Chrysothamnus nauseosus) and snakeweed (Gutierrezia sarothrae), which are not grazed by livestock except when they are starving, with occasional plants of saltbush (Atriplex canescens) and winterfat (Eurotia lanata) which have grazing value. Such areas are, therefore, the last stages of overgrazing and mark the final

destruction of the original range.

CHAPARRAL FORMATION. The two chief constituents of this formation are subspecies of Quercus undulata and Rhus trilobata the latter of which is represented in northern Arizona by species of Schmaltzia. Counts made at the Prescott station showed that scrub oak and sumac (Schmaltzia) formed 91 per cent of the brush. Barberry (Berberis fremontii), deerbrush (Ceanothus fendleri), mountain mohagany (Cercocarpus parvifolius) and one-seed Juniper (Juniperus monosperma) made up the other bush members of the association. Counts made at Mayer, Payson, and near Seligman all showed the same preponderance of scrub oak and hairy sumac, Quercus composing more than three-fourths of the bushes. Other shrubs occur occasionally but are of minor importance. The bushes grow from 3 to 12 feet in height, the average being about 5 feet.

Over considerable parts of the region in which this formation occurs, the stand of bushes is so dense as to make a continuous cover with but few open places. At the lower edge, however, the shrubs become more scattered and before their lower limit is reached have become an open savannah similar in many respects to that formed by Juniper. Where the stand is dense, there is not much grass, but where the cover is more open, there is considerable. The lower edge, which forms savannah, has practically a continuous grass cover where it has not been grazed out.

The grasses are very similar to those found associated with Juniper-Pinyon. Wooly-foot grama, however, occurs in considerable quantity in this formation but is less important in the woodland. The quadrats at Prescott contain blue grama (Bouteloua gracilis), side-oats grama (B. curtipendula), woolly-foot grama (B. eriopoda), and needle grass (Aristida longiseta) as the chief grasses of importance in the order named. Ring grass (Muhlenbergia gracillima) and stickseed grass (Aristida micrantha)were also present, and are the first stages of overgrazing. At Payson the formation, because of rougher topography, contained mostly grasses characteristic of rocky slopes, side-oats grama, hairy grama (Bouteloua hirsuta), little redstem (Andropogon scoparius hirtiflorus), Muhlenbergia emersleyi, mesquite grass (Hilaria cenchroides) being present in addition to blue grama. Relicts of porcupine grass (Stipa comata and Stipa neomexicana) are also to be found. No fenced areas have been installed in this formation as yet and hence no definite data are to be obtained regarding the original grass cover for northern Arizona. The results obtained from the installations at Colorado Springs, Colorado, are not strictly applicable to this region. The great importance of Stipa comata in the area under protection in Colorado, in view of the numerous relicts of this grass in northern Arizona, leads to the inference that it was originally a highly important constituent of the formation in the latter region also.

Overgrazing in this formation is not so destructive in some respects as in the other formations. The shrubs protect those grasses in part which grow up through them. When all the grasses between the shrubs have been killed, there are a few under them which have escaped and can produce seeds to reestablish the range should the opportunity ever be given. Long continued overgrazing, however, favors establishment of the shrubs, even though these are browsed, and their competition can reduce the area covered by grasses and the value of the range permanently. Here, also, snakeweed (Gutierrezia) spreads rapidly on the overgrazed range replacing the grasses.

GRASSLAND CLIMAX. The great dominant of the formation is blue grama (Bouteloua gracilis). It is the only major dominant left at present in northern Arizona, the other one of former presumable importance having been porcupine grass(Stipa comata). Grassland tends to form several faciations, the one found in this region being characterized by the presence of wooly-foot grama associated as a dominant with blue grama. Another faciation containing buffalo grass(Bulbilis dactyloides) instead of wooly-foot grama occurs in northwestern Texas, Oklahoma, and eastern Colorado. In the great plains region, where this formation covers the greatest area, and had its most characteristic development, it has a shortgrass phase to the west and south, a central region best known as "mixed prairie" (Clements 1920), and an eastern "true prairie".

The formation in northern Arizona has also three subdivisions. The upper zone of the grassland climax consists of Juniper-Pinyon savannah, a grassland which corresponds in composition with the mixed prairie of the great plains but has scattered Junipers in it. The middle zone consist of "true" grassland which corresponds in composition to the shortgrass plains. The lower boundary in a yucca-mesquite savannah which marks the grassland part of the transition into the desert plains formation.

The Juniper-Pinyon savannah, which has been discussed in connection with that formation, is a grassland with Stipa comata, Sporobolus cryptandrus, Hilaria jamesii, and possibly Poa eatoni as the tallgrass components, and with Bouteloua gracilis as the shortgrass component. The "true" grassland, has at present practically no tallgrasses mixed with the shortgrass, and the total protection areas in this part of the formation has not yet settled the question whether these grasses were of any great importance. Nevertheless, Stipa was at one time present, and a certain amount of dropseed (Sporobolus cryptandrus) and galleta(Hilaria jamesii) are present still, the latter grass being of chief importance on rocky slopes. The shortgrass of this association consists of two dominants, blue grama and wooly-foot grama. Blue grama (Bouteloua gracilis) is of major importance at the upper edge of the association, wooly-foot grama disappearing as it passes into Juniper-Pinyon savannah. At the

lower edge, wooly-foot grama(Bouteloua eriopoda) becomes of major importance, the blue grama disappearing when it passes into the yucca-mesquite savannah. The chief grasses of the latter savannah are wooly-foot grama, dropseed (Sporobolus cryptandrus), black mesquite grass(Muhlenbergia porteri) and galleta(Hilaria mutica).

Taken as a whole, the chief dominants at present are blue grama and wooly-foot grama, the tallgrass components having been grazed out in the places where they formerly existed. The lesser dominants are western dropseed(Sporobolus cryptandrus), galleta grass(Hilaria mutica and H. jamesii), and the needle grasses(Aristida purpurea, A. arizonica, A. divaricata). Ring grass(Muhlenbergia gracillima) and burro grass(Scleropogon brevifolius) also occur where overgrazing is heavy, the latter grass occupying usually the draws subject to flooding, while the former prefers somewhat higher ground. Ring grass is readily killed out in places where the soil is subject to washing or to erosion, such as occurs in the Williams area. Burro grass is probably the subclimax stage in the hydrarch succession or primary succession from a water stage.

The subclimax vegetation in the xerarch succession, i. e. primary succession originating from rock, consists of side-oats grama(Bouteloua curtipendula), Texas timothy (Lycurus phleoides), and little redstem(Andropogon scoparius). The first climax dominants to come in are Aristida divaricata, galleta grass and dropseed. Blue grama

comes in next and all these may be found mixed upon a rocky ridge. Wooly-foot grama usually does not come in until the climax stage has been rather definitely reached except on the extreme lower edge of the formation.

The composition of the grassland in the region may be characterized as follows. The yucca-mesquite savannah phase of the formation extends from Yucca to Kingman. The pure grassland begins one mile northeast of Kingman at the edge of the mesa overlying the town. At this place the dominants are wooly-foot grama, galleta grass, and western dropseed in the order named. This association is climax to forty miles east of Kingman, when upon climbing out of the canyon containing Crozier's ranch, blue grama begins. Because of the topography, there is no intermediate zone with the blue grama coming in gradually; it is immediately a major dominant. However, in passing down the Big Chino Valley southeastward there is found a broad zone of intermingling. The composition of the grassland west of Seligman is nearly pure blue grama, but becomes more and more intermixed with wooly-foot grama. By the time Jerome Junction is reached wooly-foot grama has become of greater importance than blue grama, and farther south has replaced it altogether.

The grassland extends eastward with many interruptions as far as Ashfork and north of Williams. Between the Grand Canyon and Williams it holds the ground above 6,400 feet in successful competition with Juniper as a result of flooding and fire. The ease with which Chrysothamnus, Atriplex

canescens, Senecio douglasii, and other shrubs penetrate and compete successfully against the grasses would indicate that the soil moisture is too great for the grasses to obtain all before it reaches to the deeper rooted plants. The shrubs and not the grass, therefore, are the subclimax stage. Winterfat (Eurotia lanata) forms pure societies of considerable extent in this region and is scattered more or less throughout the grassland at this place. The presence of Koeleria cristata, Festuca ovina arizonica, and Elymus ~~e~~itanion brevifolius also indicates greater moisture than is ordinarily found in the climax grassland.

The forty-mile strip south of Kingman is typical overgrazed yucca-mesquite grassland savannah. West of Kingman for some distance into the Sacramento Valley are found relicts of Bouteloua eriopoda associated with the desert scrub. Hilaria mutica is also present, and because it tends to become hard and woody toward the base of the plant, is not so destructively grazed as is wooly-foot. The presence of these plants, as well as the fact that the greater proportion of desert scrub dominants represented are the least xerophytic plants of this formation indicates that the original vegetation here was the transition from grassland to desert plains grassland. Evidence of overgrazing is everywhere at hand, and it must be concluded that this caused the destruction of the grasses, thus permitting the desert scrub completely to occupy the area. Additional

evidence of this is found by the presence of woolly-foot grama (one plant), Aristida purpurea micrantha, Hilaria mutica and Sporobolus cryptandrus in the railroad right-of-way one mile north of Yucca.

DESERT SCRUBS. The desert scrub formation is the most xerophytic of all those found in the United States. For this reason it contains many species of very peculiar structure and adapted more or less successfully to operate with little water under conditions of very high evaporation. The many varied means of accomplishing these result in plants with considerable difference in capabilities and causes them to group into many lociations. The most successful and adaptable and, therefore, the most widespread and characteristic dominant of the association is the creosote bush(Larrea mexicana). This and mesquite(Prosopis juliflora and its varieties) are the major dominants, although mesquite often plays a minor part in the association. The third major dominant of the western association of the formation, Franseria dumosa, becomes important from Yucca toward the west in the northern part and from Ajo westward in the southern part of the state. An extension of it runs eastward up the Gila River beyond Florence, and this and a southern extension along the Santa Cruz and San Pedro Rivers to the south form the most eastern extension observed in the State.

The associates found in the Sacramento Valley between Oatman and Kingman were Larrea mexicana, Franseria dumosa, Eurotia lanata, Eriogonum poliofolium, Psilotrophe cooperi,

Yucca bacata, Ephedra trifurcata, and a few grasses, the chief of which were Muhlenbergia porteri growing in the protection of the bushes, and Dasychloa pulchella, a small grass worthless for grazing and hence tending to replace other grasses where heavy overgrazing occurs. A few plants of an annual grama (Bouteloua barbata) were found as well. Here also Larrea mexicana and Franseria dumosa were the dominant vegetation. The plants found at Yucca, Arizona, were very similar. Associated with them were ocotillo (Fouquiera splendens), winterfat (Eurotia lanata), Mormon tea (Ephedra trifurcata), desert buckwheat (Eriogonum poliofolium), and Psilostrophe cooperi. The grasses were galleta grass (Hilaria mutica), needle grass (Aristida purpurea micrantha) six weeks' grama (Bouteloua barbata), black mesquite grass (Muhlenbergia porteri) which as usual grew up through the bushes only, and considerable mesa grass (Dasychloa pulchella). One mile south of Yucca are found the first Joshua trees (Yucca arborescens) which (are found) more typically in the Antelope Valley in the western edge of the Mohave Desert in California. Yucca radiosa and Y. bacata are also found, the latter forming characteristic societies in the formation. There are two characteristic chollas also found, Opuntia arborescens and pipestem cholla (Opuntia leptocaulis). In the canyons were found creosote bush (Larrea mexicana), mexican sage (Artemisia mexicana), Mormon tea (Ephedra antisyphilitica) and (E. trifurcata), ocotillo (Fouquiera splendens) and catsclaw (Acacia constricta). The grasses found on these slopes near Kingman, particularly those running up to the mesa

where the grassland proper starts, and occupied by these bushes, are side-oats grama(Bouteloua curtipendula), woolly-foot grama(Bouteloua eriopoda), six weeks' grama (Bouteloua barbata and B. aristidoides), needlegrass (Aristida purpurea), mesa grass (Dasychloa pulchella), galleta grass (Hilaria mutica), dropseed (Sporobolus cryptandrus) and black mesquite grass(Muhlenbergia porteri). Other grasses much less common since they were found on only one slope were Panicum barbipulvinatum and sprangle grass (Leptochloa filiformis).

Other communities occur further west and south in this formation more characteristic of the climax form. In the washes are found Dalea spinosa, commonly called the smoke tree because of its peculiar grayish appearance, Simmondsia californica, Parkinsonia torreyana, and Hymenoclea salsola. In the sandy areas, particularly where dunes occur, mesquite (Prosopis juliflora) grows up through them forming peculiar bushes covering the top. The trunk of the tree grows up through the sand and only the branches of the tree appear at the surface. Shrub societies occurring in these sandy areas contain beside the dominants such characteristic forms as Encelia suffrutescens and E. eriocephala. In the areas containing firmer soil, the washes and flood areas are surrounded by tall growing mesquite and creosote bushes, and are occupied by a peculiar shrub-by grass, Hilaria rigida, known as tobosa grass.

The formation as found in the south central part of the state or the southeastern part of the region described

here differs in that Franseria dumosa is not usually present. Mesquite is a far more important element of the association here than in the western part. Since this region receives more rainfall than the western boundary it shows a somewhat less xerophytic flora than that just described. The hillsides are commonly covered with ocotillo, palo verde, (Parkinsonia microphylla), brittle bush (Encelia farinosa), giant cactus(Cereus giganteus), and several chollas and prickly pears (Opuntia versicolor, O. bigelovii, O. engelmanni, O. pheacantha, and O. discata). Along the rivers and streams containing the permanent underground water flow fairly close to the surface are found the desert cottonwood (Populus wislizeni), sycamore (Platanus wrightii), hackberry (Celtis reticulata), and the valley floor is often covered with a dense forest of mesquite, with trunks up to four feet in thickness and reaching a height of forty feet or more. On the caliche tablelands or mesa, creosote bush forms nearly pure stands containing societies of chollas(Opuntia fulgida and O. fulgida mamalata). The only grasses remaining at the station in the Salt River Valley were Hilaria rigida and Hilaria mutica. Originally, however, this desert was a rather open savannah with the present dominant bushes far more scattered and the spaces between occupied by Rothrock's grama, (Bouteloua rothrockii). The valley floor usually had heavy stand of sacaton (Sporobolus wrightii). The hillsides contained side-oats grama and galleta grass.

At the present these grasses have been almost grazed out and the shrubs now completely dominate the ground, thus resembling in a measure the true desert such as is found in southeastern California.

THE RANGE

The chief characteristic of the Arizona ranges, and indeed of all in the western United States, is overgrazing. This has been carried on for so many years, that it is almost impossible to find an area that has more than a fraction of its former capacity. In many places, the original range has been totally destroyed, and cattle must depend for forage upon annual weeds and grasses which spring up after the rains. On the whole, this has not been carried to the extent in northern Arizona that it has in many other parts of the country, but conditions are nevertheless deplorable. Only a drastic change in the laws and regulations governing the public domain, permitting all of the range to pass intelligently under the control of the cattlemen, and widespread investigation and education as to means of reestablishing the range and keeping it up to its highest economic efficiency, can prevent the ultimate disappearance of one of Arizona's chief industries.

In northern Arizona, as elsewhere, such overgrazing has been in existence for a long time. Leiberg, et al (Forest Conditions in the San Francisco Mountains Forest Reserve 1904) writing twenty years ago stated "The areas of the northern Arizona plateau now comprised within the reserve limits originally produced a luxuriant growth of grass. It is yet abundant on tracts where,

owing to various causes, chiefly lack of watering places for stock, excessive pasturing has not prevailed ******* * * * * * The grazing capacity of the reserve is too heavily taxed. Most of the area south of the Atchison, Topeka, and Santa Fe Railroad is eaten or sheeped out, and like conditions prevail on most of the western half, as well as on most of the north and east tiers of townships in the area situated north of that railroad." They then go on to state that only a small area centering around San Francisco Peak remained in somewhat its original condition.

Since that time some attempt at control has been exercised by the Forest Reserve Service, but economic pressure has prevented it from being very effective. There are always too many requests for permits and Forest Service officials have been forced to consider the (needs) demands of the cattlemen and sheepmen to the detriment of the range. In consequence, many of the grasses reported by these writers to be common are now very rare. Large parts of the former open range have been or are being fenced. There is hope, therefore, that investigation and education in control of the range, will some day permit this region to again approach its former productiveness.

Many plans have been advanced for the regeneration of the range. Proposals have been made by many cattlemen and even by officials of the U. S. Department of Agriculture that the world be searched for plants which can be seeded to form a new and wonderful plant cover, one

which will develop a range immune against all overgrazing, and able to produce forage in competition with all weeds. It seems strange that the impracticability of this plan, in the majority of the cases proposed, should be apparent only to the trained ecologist. In the first place, the dominants of a region are always the plants most adapted to that form of climate. Plants introduced from a different type of region have no chance whatever to survive. Those brought in from a similar habitat have usually much greater ability to live in the region, but rarely have that close adjustment to the environmental factors that are found in the native plants. Overgrazing, however, is a factor that can be met by some plants better than others and in some cases, introduction of plants from other places related quite closely in climate to the region results in a cover which is far better enabled to withstand the introduced factor of heavy grazing. But there is no instance on record to show that any range has been improved by such means, and many occur to show that the result is disastrous. The Great Valley of California (The Sacramento and San Joaquin Valleys) was at one time covered with a stand of bunch grasses, Stipa setigera, Stipa eminens, and Poa fendleri being the dominants. They produced considerable forage and were of value as range throughout the greater part of the year. At present, this range has wholly disappeared, even relicts of the grasses are almost lacking. In their place is a cover of wild-

oats (*Avena fatua*) and several annual brome grasses (*Bromus rubens*, *Bromus maximus*, *Bromus hordeaceus* and others) which produce a crop of forage of high value for a few weeks during and after the winter rains, but almost or wholly valueless after that time. In the meantime, the cattlemen must carry their herds throughout the entire year. If it were possible to bring back the original range to replace the present one, the gain would be incalculable. However, from all data obtainable, it would seem that the damage in that region is now permanent. From this it seems that it should be self-evident that the best means of regenerating the range is by recovery of the original grasses, or at least those of their number best able to withstand grazing.

In each formation are found several "grazing types" or grass associations. The chief type is always, of course, the climax association of the grassland or those grasses which are typically associated with the climax dominants. The other grazing types are successional stages in the various formations. These types are therefore best considered in connection with the grazed formation. A complete investigation into a range must take up the types found today, the original cover as nearly as it can be ascertained, the stages by which destruction takes place and as far as possible the means by which it can be restored.

GRAZING TYPES IN THE YELLOW PINE FOREST. Nieberg (1904) lists the following species of grass as common in the yellow pine forest:

Agropyron pseudorepens (A. smithii)

Andropogon hirtiflorus (A. scoparius hirtiflorus)

Aristida arizonica

Aristida longiseta fendleriana

Eragrostis neomexicana

Festuca ovina arizonica

Koeleria cristata

Muhlenbergia porteri ? (He probably means M. gracilis. M. porteri is a desert plains grass and has never been found by the writer in the yellow pine forest while M. gracilis is a common and widespread grass in this type forest).

Poa eatoni

Sitanion breviflorum

Stipa comata

Stipa vaseyi

He goes on to say that Andropogon, S. hirtiflorus, Aristida arizonica, Festuca o. arizonica, Poa eatoni, and Stipa vaseyi "form 90 per cent of the entire cover, and supply the chief pasturage of the region". Epicampes rigens and Muhlenbergia (porteri?) "occur in abundance along the margins of the various runs and in the open parks where water stands in the early spring." Several grasses which occur rather commonly in this forest are not mentioned at all. Since the area even then

was badly overgrazed, and since the determinations of the grasses were not very accurate , a picture of the original vegetation can not be had from this description.

The only reliable information in regard to the original grass cover is that gained from fenced inclosures where remnants of the grasses have been permitted to recover and again hold the ground, or from areas otherwise protected from overgrazing. While the six years during which the fenced inclosures have been installed have not been long enough to (fully) bring the grasses into equilibrium, the light thrown upon their interactions by other areas partially protected for a longer time have served to give what is believed to be a fairly accurate picture of this original cover. Over the greater part of the forest the major grasses were undoubtedly Muhlenbergia gracilis, Festuca ovina arizonica, and Stipa comata. In the water-made parks and elsewhere where the soil was deeper and retained considerable moisture, Agropyron smithii, Sporobolus cryptandrus, and Stipa viridula(Stipa vaseyi) dominated. On the dryer ridges, Andropogon scoparius hirtiflorus, Lycurus phleoides, Muhlenbergia emersleyi, and others were to be found. Sitanion breviflorus and the various species of Aristida were of importance only on disturbed ground and hence their appearance on an area in number was the first evidence of overgrazing. In the lower edge of the forest, grasses belonging more properly to the grassland and Juniper-Pinyon savannah were to be

found, such as Bouteloua gracilis, B. curtipendula, and Hilaria jamesii, particularly in the more open and warmer places.

Of the grasses, Stipa comata was the most susceptible to overgrazing. While the fenced plot at Coconino shows it to be able to hold the ground in competition with the other grasses to the extent of 25 per cent of the total area occupied, it is nevertheless a very rare grass in the yellow pine forest. The fact that it is unable to form mats such as produced by Sporobolus, or spread by rhizomes in the manner of Agropyron smithii, and that it is palatable at all stages of its growth, has caused it to be grazed out completely. Stipa viridula being more robust , and its stems becoming woody is not so easily grazed out, and the much larger number of seeds produced, permit it to reestablish much more quickly, Stipa comata, however, is probably doomed except for occasional relicts, and will never again become an important constituent of yellow pine grassland.

Festuca ovina arizonica and Muhlenbergia gracilis have been able to withstand grazing much better, although they too have vanished over the greater part of the forest. Both produce a much larger crop of seed than does Stipa, and Muhlenbergia especially can survive by producing short leaves close to the ground. Both are normally of the "bunchgrass" type, however. It is largely upon these two grasses the cattlemen will have to depend if the range is to be brought back to its original condition

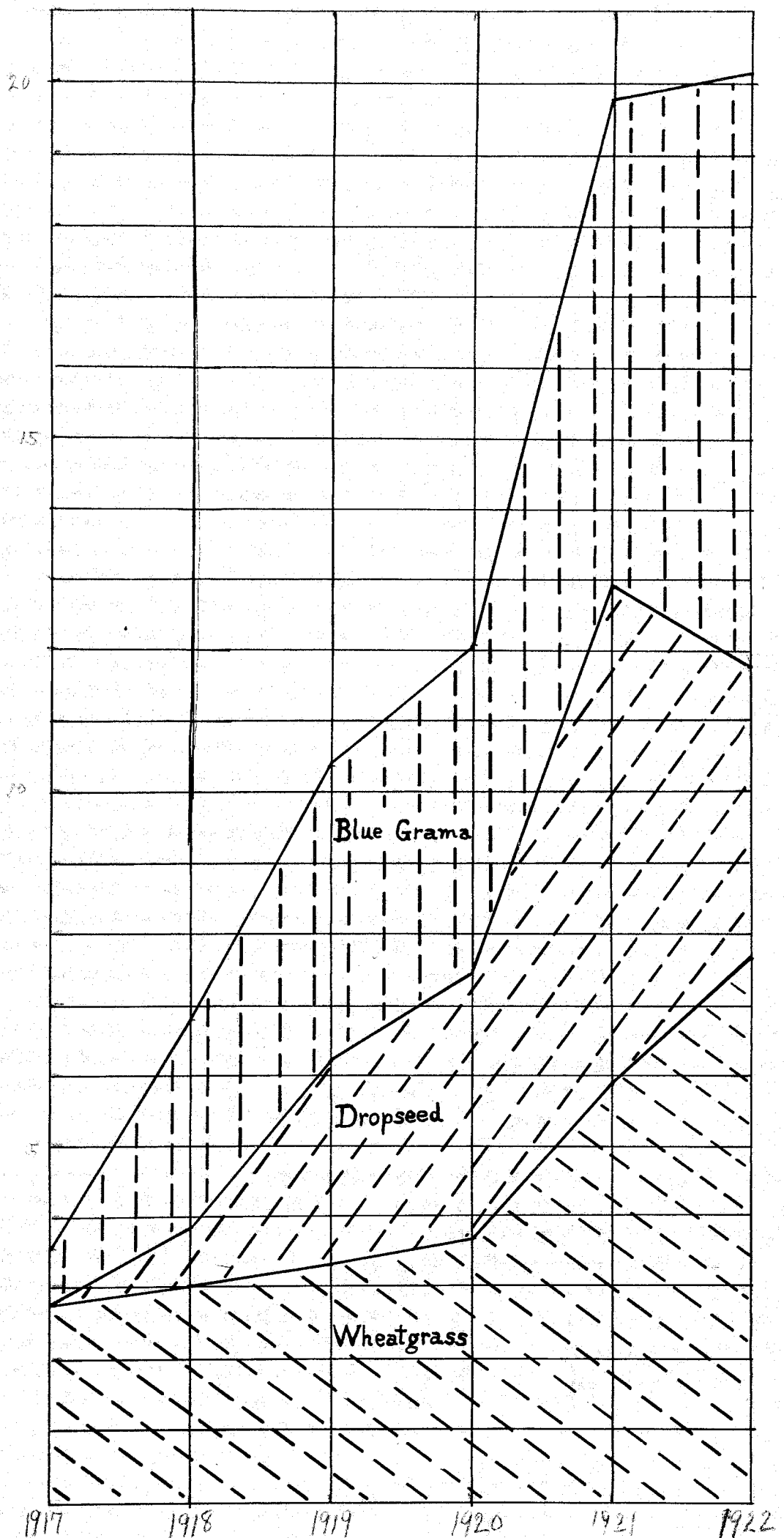
in the forest proper and in the fire-made parks and logged areas.

The grasses which have best withstood grazing have been Agropyron smithii, Sporobolus cryptandrus, Bouteloua gracilis and Lycurus phleoides. Agropyron spreading by rhizomes as well as seeds and storing food underground from the occasional shoots which always escape grazing has been able to hold its own in large measure in the situations where it is found. It is at present confined to the water-made parks, and the deep loose soil of the washes. Sporobolus cryptandrus being able to form mats and producing large amounts of seed when permitted, is of the semi-weed type, growing best in the washes and deeper soil of the parks, and is the first to reestablish under protection. Table 8 showing its growth in area upon a clip quadrat under total protection demonstrates this very clearly. Bouteloua gracilis and, to a lesser extent, Lycurus phleoides form mats normally and are not easily grazed out by cattle. They are not very tolerant of shade, however, and are largely found in parks and other open situations.

Figures 1, 2, and 3, ~~2, 3, and 4~~, show graphically the proportion of Agropyron smithii, Sporobolus cryptandrus, and Bouteloua gracilis growing in unclipped quadrats under conditions of total protection, rodent grazing alone, and of cattle grazing. The comparison is not a strict one since the quadrat under total protection has, in addition to these grasses, a shrub of sagebrush (Artemisia tridentata) which

Figure I. Area occupied by the grasses on a quadrat under total protection. The upper line shows the total amount of grass, and the shaded portions, the part of the total occupied by each. Divisions show the number of square decimeters occupied. Coconino, Arizona, A park in the yellow pine forest.

Increase in area under total protection



Increase in area of grass per square meter under prairie-dog grazing conditions

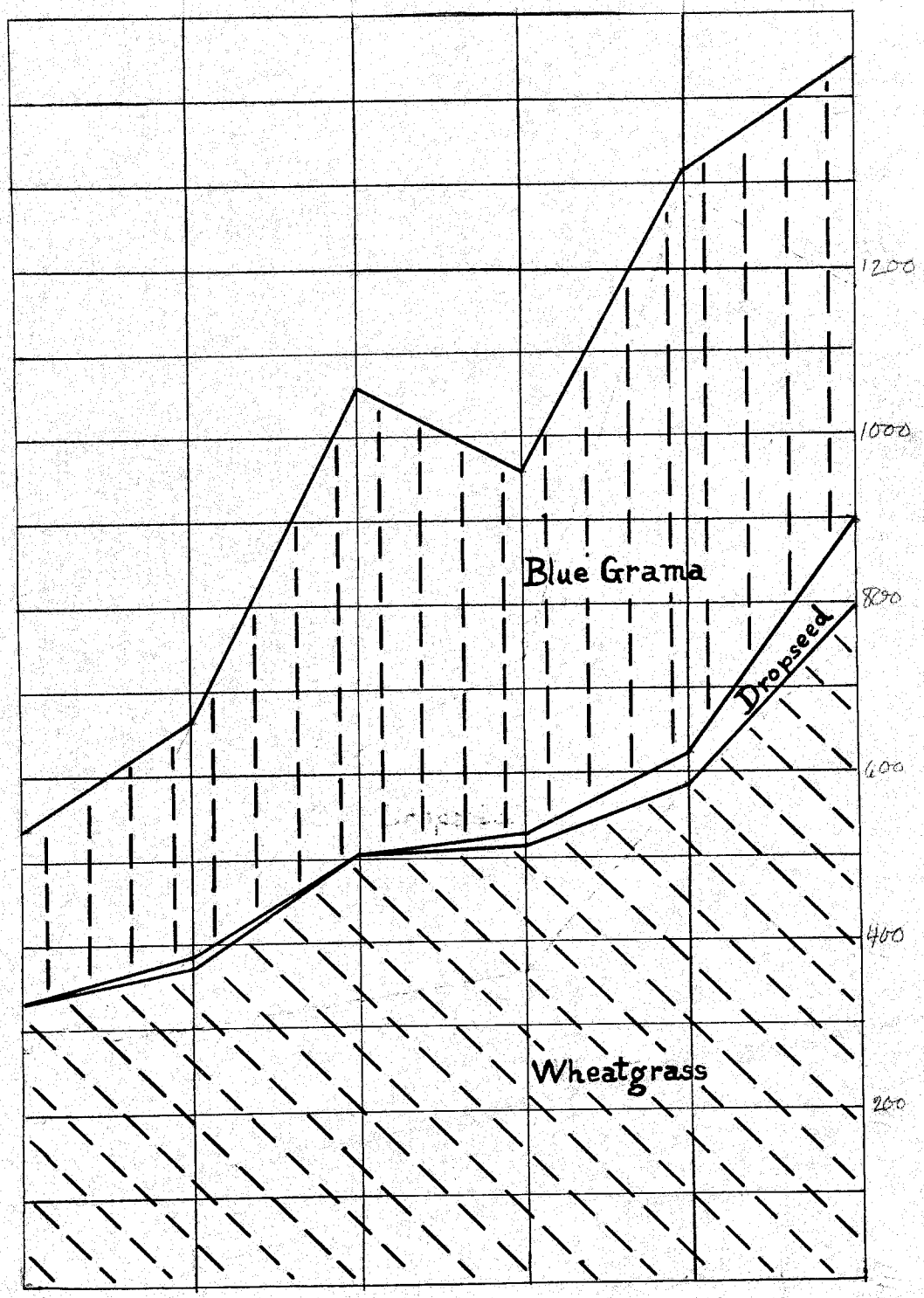


Figure 2. Area occupied by the grasses or a quadrat grazed by prairie-dogs only. The upper line shows the total amount of grass, and the shaded portions, the part of the total occupied by each. Divisions show the number of square decimeters occupied. Coconino, Arizona. A park in the yellow pine forest.

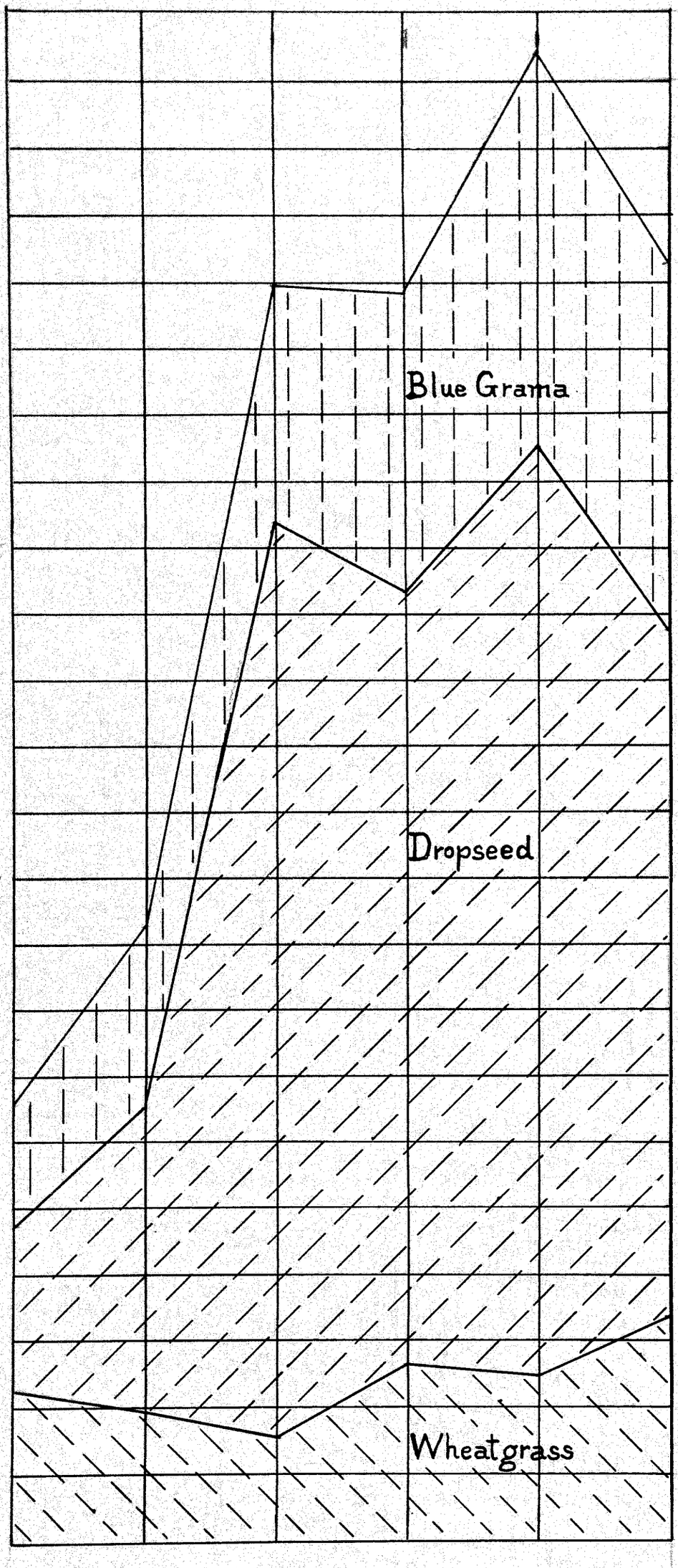

Blue Grama
Dropseed
Wheatgrass

Figure 3. Area occupied by the grasses of a quadrat grazed by cattle. The upper line shows the total amount of grass, and the shaded portions, the part of the total occupied by each. Divisions show the number of square decimeters occupied. Coconino, Arizona. A park in the yellow pine forest.

takes up and shades 11 square decimeters of the quadrat, reducing considerably the total amount of grass. The great increase of dropseed (Sporobolus) upon the cattle grazed quadrat is due to the extensive seeding of the entire park from the total protection plot. The small amount upon the quadrat in the prairie-dog plot is due to its palatability to these rodents and their habit of grazing it to the roots and utterly destroying it. Over the greater part of this plot, this grass is completely lacking. The first great increase in the amount of grass under total protection was shown by Sporobolus the maximum occurring at the end of 1919, the second year of protection. The first year permitted the plants already present to grow freely and produce a large crop of seed which apparently was spread widely over the entire park. The second year saw a vast increase in the number of plants (best shown in figure 5 and tables 1, 2, and 8.). Since this year, the increasing competition of Agropyron has reduced the amount of dropseed.

The potential yield of forage from the three quadrats is not represented by the total area occupied by the grasses, for the yield per unit area of one grass is not the same as that of another. The clip quadrats show that Agropyron produces an average of 25.8 grams of forage per square decimeter of the area occupied by it, Sporobolus 2.0 grams and Bouteloua 0.9 gram. The potential forage value of the quadrats is therefore largely dependent upon the amount of wheatgrass present. The actual yield

of the rodent and cattle grazed plots are considerably less than the potential yield, which represents the amount of forage the quadrat would yield under total protection. This is due to the weakening of the grass by grazing in the early spring before the food utilized to produce the shoots is replaced by photosynthesis and each succeeding shoot must again draw upon stored food. Exact data on the effect of such grazing is not at hand. The forage produced if cut as hay would average 1800 pounds or nearly a ton per acre each year. It is estimated that the present method of grazing reduces the amount utilized by the cattle to one-fourth of this, or approximately 450 pounds per acre. By deferred grazing, and reduction of the total number of cattle present, this could readily be increased by permitting the grass to get a start in the spring, and in large measure recover. The Muhlenbergia-Festuca forage type will produce at the rate of 1500 pounds of hay to the acre. This type has been so destructively overgrazed in this region that no estimate can be made regarding the amount actually obtained, but it can not be great.

The life histories of the grasses and the manner of their growth is of considerable importance to a knowledge of range control. The shortest lived of the dominant grasses is dropseed, yet the areas have not been studied for a sufficient length of time to find the maximum age even of this grass. It is hardly possible to discover this in the case of the others even in several lifetimes.

All the data at hand indicate no real limit to the length of time one of these plants may survive, and it is quite possible that some grass mats of blue grama are far older than the most ancient of the giant Sequoias.

The growth, average size for each year, and the ages of greatest mortality for dropseed (Sporobolus cryptandrus) when grown under total protection are shown in table 6. The study begins in each case with the seedlings which were able to establish themselves and survive to the end of the growing season. The greatest mortality probably occurs before seedlings reach this stage. If one reaches sufficient size to cover 2 to 5 square centimeters of ground it is usually able to survive until the next growing season. After a plant has been established three or four years and has attained an area of 20 square centimeters or more, it has become fairly well established, and if it does not meet with too much competition from the other grasses will probably continue indefinitely. Such competition, however, becomes serious during the years of drought when it plays havoc with this grass. Dropseed is therefore classed as a short-lived perennial and like the others of this class partakes in some measure of the qualities of a ruderal. The last column showing the number of plants and their area is significant in many respects, particularly after 1918 when some equilibrium was reached. It shows that distribution of rainfall is of greater importance than the total rainfall to the survival of the plants, while the total rainfall has a greater effect

upon the maximum area covered by the plants, or in other words, influences the growth of those that lived through the unfavorable part of the season.

There is no good reason to suppose that this grass does not start in the prairie-dog area fully as often as in the total protection plot and the cattle grazed plot. But when this area is fully colonized by rodents, it is rarely found present by the end of the growing season. The manner in which prairie-dogs graze this grass has been observed carefully. Their habit of grazing it to the roots, not leaving a single shoot to regenerate the tuft accounts for its destruction. That this grass is grazed by them in preference to all the others found in this grazing type, is shown by its early disappearance in this plot before any serious grazing of other grasses is found.

The number of seedlings starting up in a unit area is greater on the cattle grazed plot than in the total protection plot. This is accounted for in all probability by the trampling of the seeds into the ground. But on the other hand, the mortality among the plants subjected to cattle grazing is higher as well, and in places results in the death of all of the established plants. This happened upon one quadrat during 1923 because of the lateness of the rains. /When the rains finally came, a number of seedlings were able to establish themselves, and in large measure replaced the former tufts. This grass, therefore, depends upon its large seed production for survival, and because of this, resembles the annual or weed types of grasses. The large number of seeds

produced, and their small size permit them to scatter widely. Since practically all the seeds are viable, they establish this plant readily.

Wheatgrass (Agropyron repens) is a totally different type of perennial. It is very long-lived grass, growing from rhizomes, and while it produces a crop of seeds which are viable, it spreads chiefly by means of its underground stalks. Each node which can do so sends up one or two shoots and these are not distinguishable from seedlings. Hence it is impossible to follow its life-history in the same manner as with dropseed. The food is stored in the rhizomes and the loss of any shoot is not serious, food being pooled in the underground stalk, and a sufficient reserve being kept to grow another. It cannot be trampled to death, since the buds are underground, and in fact a certain amount of trampling is beneficial since it keeps the soil loose, and easier to push a shoot up through it. The deep roots and the rhizome habit confine this plant to some extent to the deep loose soils of the flood parks. Persistent, heavy, and close grazing will gradually weaken it by starving the rhizomes, and early spring grazing injures it particularly since the first shoots have not had an opportunity to replace the food which they used. Table 4 showing the number of shoots on quadrats under total protection, prairie-dog, and cattle grazed conditions and Tables 1 and 2 showing the yields under these conditions show this clearly. The number of shoots a square meter in the cattle grazed plot was but one-half the number on the corresponding quadrat under total protection.

in 1923, while the number on the rodent grazed quadrat which is much less grazed, was very nearly the same. But since the new shoots of this grass were closely grazed by the rodents in the spring as the grass started up and succulent food was still scarce, the succeeding shoots were not nearly as large as those protected from grazing, as indicated by the corresponding yields, and by the plates ( ) showing the height growth in the two respective plots. Complete starving out of the rhizomes is rare even under very heavy grazing. This is shown by the fact that although this park is badly overgrazed, clipping of the cattle grazed quadrat yielded from 2.5 to 22.6 grams by dry weight of shoots and leaves which had survived each year and were producing some food for storage in the rhizomes. This and its immunity from trampling and dessication which results from the rhizome habit, explains its survival under conditions of destructive overgrazing. Its growth habit would indicate that a deferred grazing system is the best plan for utilizing this type range.

Porcupine grass (Stipa comata) is one of the principal dominants of the grassland climax. Under severe and sustained grazing, however, it is doomed in Arizona. It is a bunchgrass, or a plant growing in tufts. When the shoots are grazed from earliest spring, it is unable to produce a crop of seed, and under the system used on the forest was grazed until the roots starved and it was finally destroyed. Its seeds are almost always viable, and hence when the plants are permitted to occasionally produce a crop, will be able

to restock the range. The seeds (fruits) are large and have long awns from 5 to 10 centimeters long which permit them to be carried, but a slight distance from the plant. Animals carry them at times to some distance as they are barbed and pointed. The awns are also hygroscopic, and changes of humidity will cause them to move pushing the seed over the ground. The seedlings attain the size of about 5 square centimeters the first year, and 20 square centimeters the second, after which the tufts increase more slowly in area. Plants covering a square decimeter or more are occasionally found but the usual size is not over 40 square centimeters. The yield per square decimeter of area occupied is about 25 grams (measurement made of one season's growth only) but only 354 square centimeters of the quadrat was occupied by this grass. Under grazing conditions, it shows some tendency to produce a mat, but this is not sufficient to carry it over years of overgrazing.

Not enough is known about Arizona fescue (Festuca ovina arizonica) as yet to give much information regarding its life history. It is also a bunchgrass and shows no tendency to form a mat under severe grazing. The large amount of seeds produced, however, probably helps it to survive. There has as yet not been the opportunity to follow the starting of any seedlings and their development into established plants. Muhlenbergia gracilis is a grass of the semi-bunch type, resembling dropseed in this respect. As with Arizona fescue, no seedlings of this grass have started up in the quadrats, and the course of development can not be given.

Little redstem (Andropogon scoparius hirtiflorus) is destinetly of the bunchgrass type. Seedlings of this grass are usually not more than 2 square centimeters in area the first year. At the end of the second season, they cover about 12 square centimeters and grow to about 40 square centimeters in four years. They usually produce no seeds the first two years or more. In the spring, when the shoots are succulent, this grass is grazed freely except when protected by the older stems, but later in the season, they become tough and woody, and then do not seem to be palatable. It can be grazed in the spring, however, and unlike porcupine grass, will then produce seed if protected in some manner. Sideoats grama (Bouteloua curtipendula) which is associated with this grass, can also be grazed under this system, hence the use of this type for early spring grazing would seem to be the best manner of handling such a range.

Whenever possible, therefore, the range should be fenced for forage types. Placing cattle upon the Andropogon-Bouteloua curtipendula type in the early spring, and moving them to the other types for the middle and later part of the season, would be the ideal method. This, however, can be done only when such types are segregated into areas of reasonable size, and even then the pastures would not be large. For this reason, it would hardly be a practicable system on the greater part of the forest range.

TABLE I. Grass yields from clip-quadrats at Coconino, Arizona, Wheatgrass forage type

End of growing season of		1919	1920	1921	1922	Averages.
Total protection plot	Wheatgrass	100.0	117.0	138.8	158.4	128.6
	Dropseed	164.6	32.8	81.8	38.7	79.5
	Both grasses	264.6	149.9	220.6	197.1	208.1
Rodent grazed plot	Wheatgrass	36.8	24.3	22.6	77.2	40.2
	Dropseed	Trace	None	None	3.7	1.0
	Both grasses	37.0	24.3	22.6	80.9	41.2
Cattle grazed plot	Wheatgrass	6.6	8.7	22.6	7.6	11.4
	Dropseed	4.6	None	None	6.1	2.7
	Blue grama	1.4	None	1.0	None	0.6
	Total grass	12.6	8.7	23.6	13.7	14.7

TABLE 2. Table 1 expressed in terms of pounds per acre.

End of growing season of:		1919	1920	1921	1922	Averages.
Total protection plot	Wheatgrass	893.3	1046.1	1239.9	1415.0	1148.8
	Dropseed	1470.4	293.0	730.7	345.8	710.2
	Both grasses	2363.7	1339.1	1970.6	1760.8	1859.0
Rodent grazed plot	Wheatgrass	328.7	217.1	203.9	689.6	359.1
	Dropseed	1.8	None	None	54.5	14.1
	Both grasses	330.5	217.1	203.9	722.6	368.0
Cattle grazed plot	Wheatgrass	59.0	77.7	191.9	69.0	201.8
	Dropseed	41.1	None	None	54.5	14.1
	Blue grama	12.5	None	8.9	None	5.6
	Total grass	112.6	77.7	200.8	123.5	221.3

TABLE 3. Forage consumed and grasses destroyed by prairie dogs and cattle in pounds per acre and in per cent of maximum yield as shown under total protection. Wheatgrass forage type at Coconino, Arizona.

Season of			1919	1920	1921	1922	Average
Grazed by prairie dogs only	Wheatgrass	lbs.	564.6	829.0	1036.0	725.4	789.7
		%	63%	72%	83%	51%	69%
	Dropseed	lbs.	1468.6	293.0	730.7	312.8	701.3
		%	100%	100%	100%	90%	99%
	Total grass	lbs.	2033.2	1122.0	1766.7	1038.2	1491.0
		%	86%	84%	90%	80%	59%
Grazed by cattle only	Wheatgrass	lbs.	834.3	968.4	1048.0	1346.0	947.0
		%	93%	93%	84%	95%	91%
	Dropseed	lbs.	1429.3	293.0	730.7	291.3	696.1
		%	97%	100%	100%	84%	97%
	Total grass	lbs.	2251.1	1261.4	1769.8	1637.3	1637.7
		%	95%	94%	89%	93%	93%

Note: Serious decrease in the number of prairie dogs on the area during 1922 decreased the damage for that year considerably.

TABLE 4. Changes in the amount of wheatgrass present at Coconino, Arizona, from the season of 1917 to 1922 inclusive under total protection, rodent, and cattle grazing.

Number of shoots present at end of season		1917	1918	1919	1920	1921	1922
Total protection plot	No. of shoots	279	302	335	336	581	756
	Increase over previous year		23	33	31	215	175
	Per cent of increase		8.2	10.9	9.3	58.7	30.1
Rodent grazed plot	No. of shoots	332	374	507	516	588	793
	Increase over previous year		42	135	9	72	205
	Per cent of increase		12.7	35.6	1.8	14.0	34.9
Cattle grazed plot	No. of shoots	227	194	159	265	249	337
	Increase over previous year		(33)	(35)	106	(16)	88
	Per cent of increase		(14.5)	(18.0)	66.7	(6.0)	35.3

The figures in brackets indicate decrease instead of increase over previous year.

TABLE 5. Changes in the amount of western dropseed present at Coconino, Arizona, from 1917 to 1922 inclusive, under total protection, prairie dog grazing, and cattle grazing.

Grass present at end of season of		1917	1918	1919	1920	1921	1922
Total protection plot	No. of plants	1	16	21	22	18	21
	Total area	4	81	294	369	707	421
	Increase (or decrease)		77	213	275	238	(286)
	Same in %		1975%	263%	25%	64%	(40%)
Rodent grazed plot	No. of plants	0	6	0	2	3	7
	Area	0	10	0	13	37	104
	Increase (or decrease)		10	(10)	13	24	67
	Same in %					185%	181%
Cattle grazed plot	No. of plants	15	53	40	50	36	56
	Area	247	458	1381	1168	1403	1037
	Increase (or decrease)		211	923	(213)	235	(366)
	Same in %		85%	202%	(15%)	20%	(26%)

Areas are expressed in square centimeters.

TABLE 6. Detailed report on the growth of western dropseed under total protection, Coconino, Arizona, (Tabulation sheet for quadrat Ac 1 showing manner of compiling quadrat data.)

Season when plants started	Before 1918	1918	1919	1920	1921	1922	Total at each charting.
1917							1917
No of plants	1						1
Total area	4						4
Aver. area	4.0						4.0
1918							1918
No of plants	1	15					16
Total area	26	55					81
Aver. area	26.0	3.7					5.1
1919							1919
No of plants	1	13	7				21
Total area	28	220	46				294
Aver. area	28.0	16.9	6.6				14.0
1920							1920
No of plants	1	12	3	6			22
Total area	30	284	25	30			369
Aver. area	30.0	23.7	8.3	5.0			16.8
1921							1921
No of plants	1	11	2	3	1		18
Total area	78	540	38	40	11		707
Aver. area	78.0	49.1	19.0	13.3	11.0		39.3
1922							1922
No of plants	1	11	1	2	0	6	21
Total area	60	296	15	18	0	32	421
Aver. area	60.0	26.9	15.0	9.0	0	5.3	20.0

This gives the life history summary of the grasses of each season. A series of comparison sheets are used to follow the life history of each plants, which are tabulated in this manner.

TABLE 7. Changes in the amount of blue grama present at Coconino, Arizona, from 1917, to 1922, both inclusive, under total protection, prairie dog grazing, and cattle grazing.

Grass present at the end of season		1917	1918	1919	1920	1921	1922
Total protection plot	Number of plants	1	1	1	1	1	1
	Total area	175	297	406	476	690	835
	Increase		122	109	70	214	145
	Increase in %		70%	37%	17%	45%	21%
Rodent grazed plot	Number of plants	1	1	1	1	1	1
	Total area	203	276	550	428	687	543
	Increase or decrease		73	274	(122)	259	(144)
	Same in %		36%	99%	(22%)	61%	(21%)
Cattle grazed plot	Number of plants	2	2	2	2	2	2
	Total area	180	271	357	450	587	554
	Increase or decrease		91	86	93	137	(33)
	Same in %		51%	32%	26%	30%	(6%)

TABLE 8. The total area of western dropseed upon a clip quadrat under total protection (in square decimeters), weight of forage produced (in grams) and weight of forage produced per square decimeter of tufts (unit yield)

Season	1918	1919	1920	1921	1922	1923
Total area	11.57	60.27	20.52	31.24	26.13	23.19
Total yield		164.6	32.8	81.8	38.7	30.2
Unit yield		2.7	1.6	2.6	1.5	1.2
Annual ppt.	19.9	21.0?	12.0?	15.8	10.0?	?

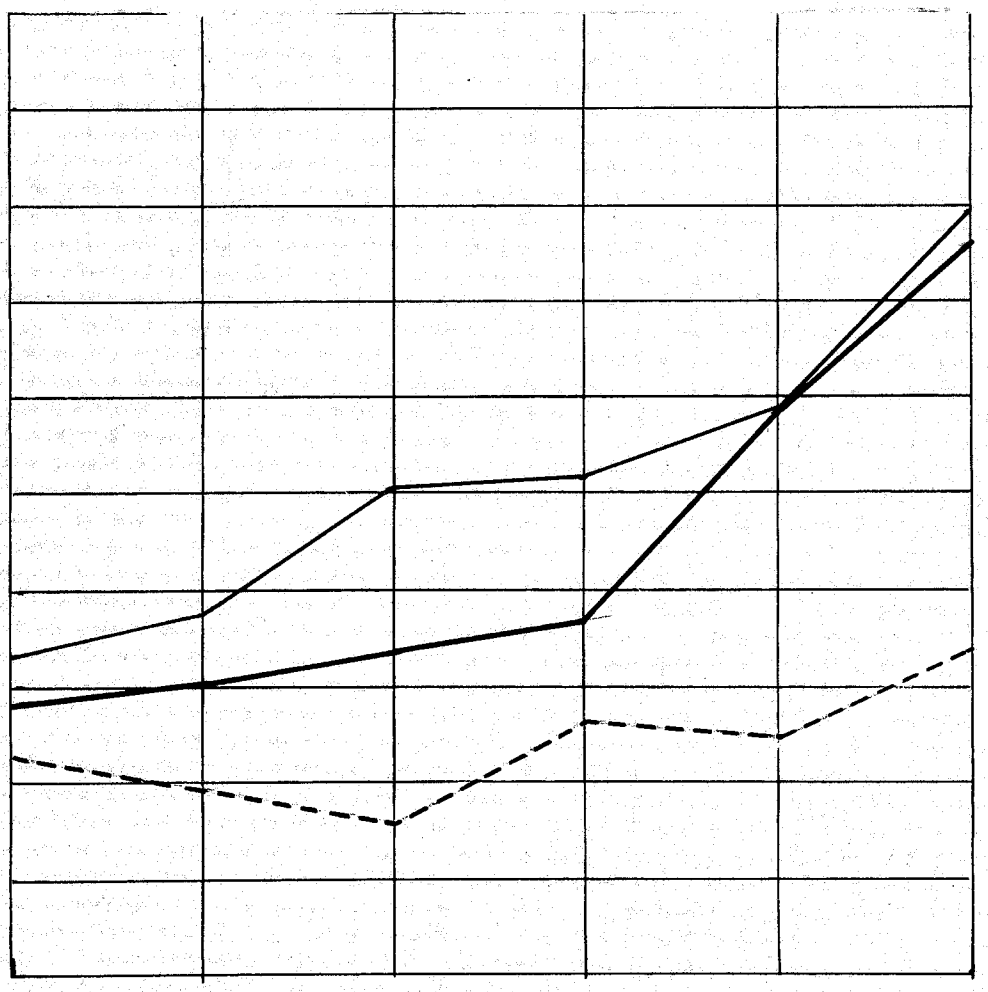
The rainfall data were often incomplete. When sufficient ?
were at hand to make a reasonable estimate, this was done the result being given with a question mark following it.

TABLE 9. The area in square decimeters occupied by western wheatgrass (Agropyron smithii) per square meter, the yield of dry forage in grams, and the yield per square decimeter of actual area occupied (yield per unit area). Clip quadrat under total protection, Coconino, Arizona.

Season of	1918	1919	1920	1921	1922	1923
Area occupied	3.02	3.35	3.66	5.81	7.56	6.83
Total yield		100.0	117.1	138.8	158 .4	151.0
Yield per unit area		29.9	32.0	24.0	21 .0	22.1

It is noticeable that, on the whole, the amount of forage produced per unit area is an inverse function of the total forage produced, the amount produced per square decimeter of area occupied decreasing as the total yield increases. This is due to increased competition for water by the greater number of shoots reducing the size of each individual shoot. The ratio is not a strict one since the competition of dropseed also enters into it (which explains the apparent reversal from 1919 to 1920) and rainfall distribution is a variable factor which changes the ratio.

Figure 4. Effect of total protection (A), prairie-dog (B), and cattle grazing (C) upon western wheatgrass (Agropyron smithii). The curves show the area occupied by each in square decimeters. Coconino, Arizona.



Wheatgrass

Figure 5. Effect of total protection (A), prairie-dog (B), and cattle grazing (C) upon western dropseed (*Sporobolus cryptandrus*). The curves show the area occupied by each in square decimeters. Coconino, Arizona.

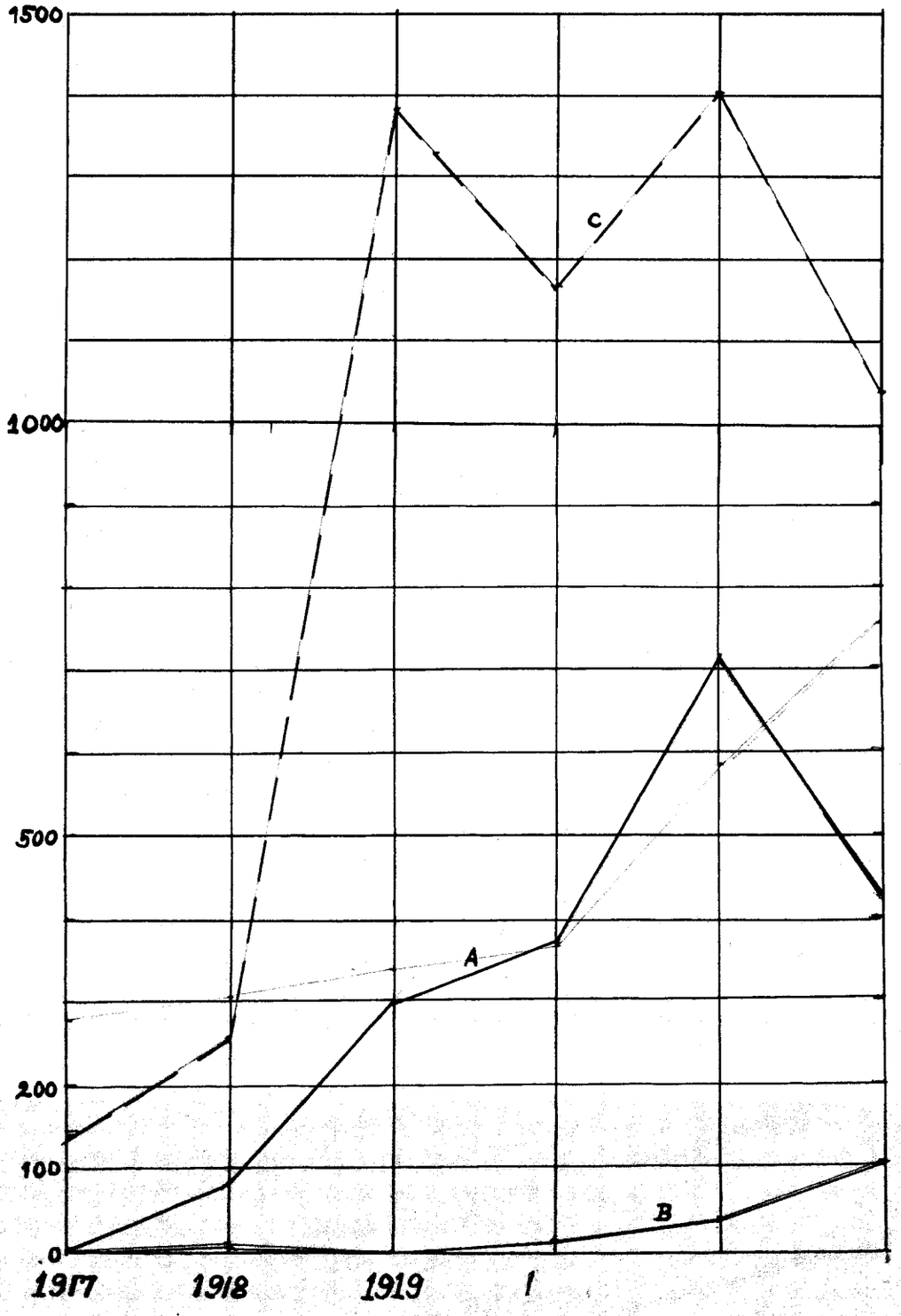
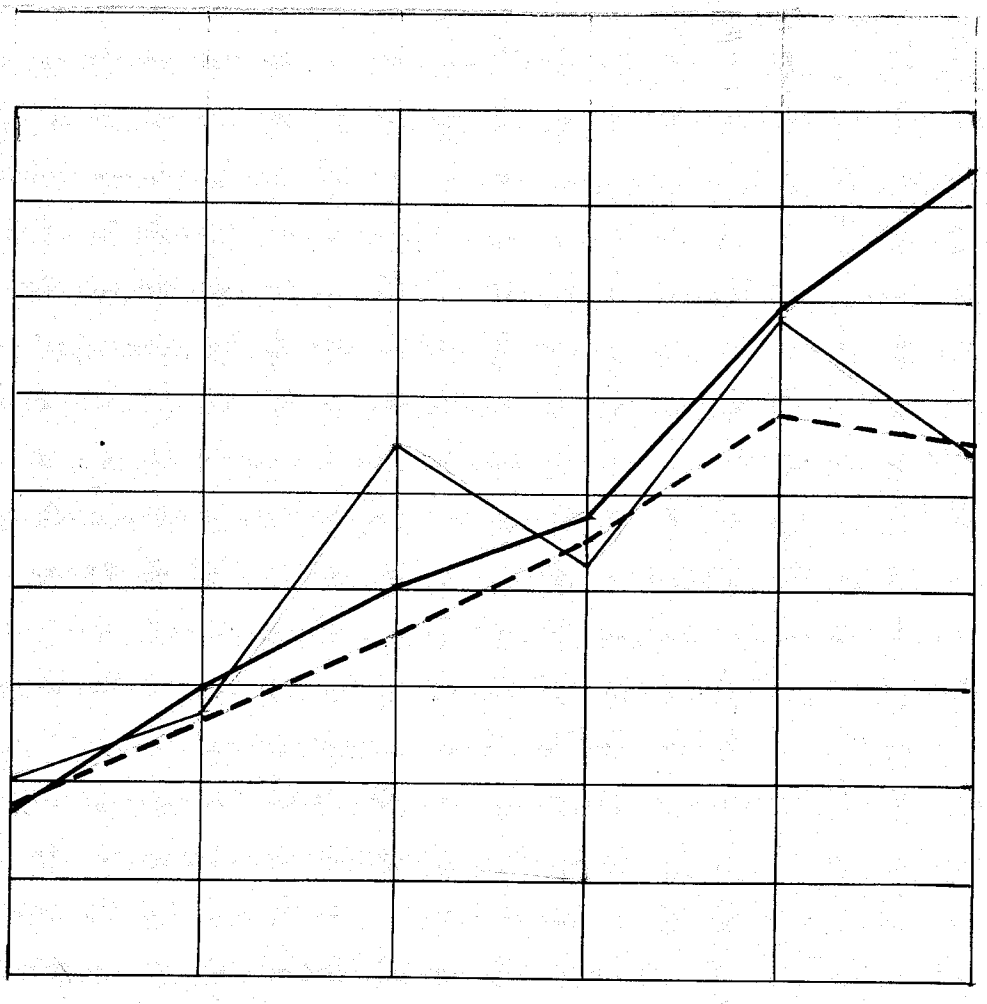


Figure 6. Effect of total protection (A), prairie-dog (B), and cattle grazing (C) upon blue grama (Bouteloua gracilis). The curves show the area occupied by each in square decimeters. Coconino, Arizona.



Blue grama

GRAZING TYPE OF THE WOODLAND FORMATION. The chief forage type of Juniper-Pinyon savannah was "mixed prairie", Stipa comata forming the tall component while blue grama formed the basal part. At present only blue grama remains. On the rocky ridges and hillsides, the grasses formed a type very much like that of the forest, little redstem, sideoats grama, and galleta making up the principle cover. This type passed through another, composed of Texas timothy, spreading three-awn (Aristida divaricata), and porcupine grass, into the chief forage type. These three were the principle grazing types of the woodland savannah. In the woodland proper was a transition into the chief forage type of the forest, and composed of grasses of both savannah and forest.

This type of range also shows almost everywhere the results of serious overgrazing. Porcupine grass has disappeared over the entire formation thereby reducing its forage value considerably. Even blue grama has been destroyed upon vast areas, partly as a result of prairie-dog work, and partly from sheep grazing. Cattle as a rule can not graze this grass closely enough to cause utter destruction. Snakeweed (Gutierrezia), from having formerly played an insignificant part in the association, has become the dominant plant upon such areas, vast tracts having no other vegetation. Goldbush, or rabbit brush (Chrysothamnus nauseosus) has also come into prominence particularly in the deeper moister soils of the valley, where originally the best stands

of grass stood. Both of these shrubs are practically immune to grazing, although all animals, cattle, sheep, and prairie-dogs alike will attempt it when all other forage is gone. Salt-brush also occurs to some extent, but this shrub has value, especially as sheep browse. Areas were found, particularly in the region between Grand Canyon and Williams, which were covered by a nearly pure stand of winterfat (Eurotia lanata) and which produce considerable browse. A quadrat placed in one of these and clipped produced at the rate of 1,028 pounds of forage in 1922 and 866 pounds in 1923. Clipping did not seem to have reduced the yield since there was no appreciable difference in size of plants clipped the year before, and those not clipped. The reduction found in 1923 must be attributed to decreased growth caused by delay in the summer rainfall. Where overgrazing by sheep has produced this type, the range can not be said to be destroyed, but such areas are exceptional.

The chief forage type which originally formed the grassland in the savannah was comparable in some measure to the relation that exists between open forest and grassland. Blue grama grows in mats practically never occupying more than 40 per cent of the area although shading as much as 70 per cent when only slightly grazed. Between the mats grew the taller porcupine grass, the leaves and stems of which did not seriously shade the blue grama. The two layers of grass had a similar relation underground. The root system of blue grama held the soil chiefly from the surface to a depth of 3 feet, while Stipa had most of its absorbing sys-

tem of roots between 3 and 8 feet. Blue grama, therefore, had the first use of any rainfall, and received nearly all of the water obtainable from the lighter rains, but porcupine grass, had a more uniform supply from which to draw, one that lasted longer and was not subject to the rapid drying out characteristic of that found in the more superficial layers. In some respect, however, the grasses did compete for water, for Stipa has a certain number of superficial roots, and blue grama roots penetrate in years of greater rainfall to a depth of 8 feet and possibly more. In greater part, however, the two grasses formed a mixture of two communities, growing closely associated in the same area, and entering as little into competition for space, light, or water, as was possible under those conditions.

At the present, Stipa is wholly grazed out. It was but natural that the tall-growing component of this forage type should be the first to go. Its place has been taken by the shrubs already mentioned which produce no forage, and hence the loss of this grass is a direct one from the economic standpoint. Had the loss of this grass resulted in an increase of blue grama it would not have been so serious, but the removal of porcupine grass, or of the weeds in the places where they are not too dense, does not seem to materially increase the amount of blue grama. No experimental evidence is at hand to indicate the manner in which Stipa may be brought back, nor means to utilize the range in such a manner that its loss be prevented and thus the maximum efficiency of this grazing type be kept unimpaired. Since this form

of grassland is of such great extent in northern Arizona, it would be of great economic benefit to inaugurate a comprehensive investigation of this phase of range control.

This forage type almost throughout its range is now a mixture of blue grama and shrubs, chiefly snakeweed. Experiments have been carried out to determine means of possible economic value to eradicate the shrubs, chiefly by means of burning and mowing. Clipping was done in the fall, and was not effective as table 10 shows. Whether clipping at any other time of the year would be of greater value, is not known, although if carried out just after spring growth is fairly under way may have some effect. It is very doubtful if anything short of complete eradication of the weeds would make this a possible method since the expense of mowing would be considerable. Burning is more effective although a stand of dry grass sufficient to carry fire is necessary. This also was tried out in the fall and did not result in anything like complete eradication, but may do this if carried out at some other time of the year. It has apparently a beneficial effect upon the grass (blue grama) for the increase in yield and of area occupied was greater in the burned quadrat than in the others. Grubbing is, of course, effective but is hardly an economic method. Moreover, seedlings of the shrubs are sure to start up in the disturbed ground which results in a renewal of the stand, and hence any such method would necessarily have to be carried out over a period of several years to produce a practically complete eradication. Burn-

ing, together with rotation grazing with reduction in the number of grazing animals, would appear the only economic means of destroying the weedy shrubs. Competition by grasses under total protection is not sufficient, no serious reduction having been caused by such means during the ~~six~~ 6 years the experiment has been in progress. Such protection, however, prevents any increase in their number. The yield of weedy shrubs under grazing is more than three times that found under total protection (Table 10)

The successional phases of this grassland are not so easily grazed out as the climax. The redstem-- sideoats grama type usually grow among rocks and in places where some survivors are almost always protected and ready to reseed the range if given the opportunity. Hence it is rare to find this type as completely destroyed as in the climax. All the grasses of this type are bunchgrasses; sideoats grama, however, tending to form mats when closely grazed. The transition from this type to the dominant type contains Texas timothy which definitely grows in mats although a taller grass than blue grama. The other grasses of this transition or subclimax are bunchgrasses.

Considerable data are at hand concerning the life-history of blue grama although the maximum length of life of this grass is not known nor will ever be known in all probability. Not all of its seeds are viable, although some viable ones are apparently produced each year, since seedlings are found every year. This, however, may be due to the holding-over of ungerminated seed from a good seed year, since our experi-

iments have shown that viability persists for several years. A strong seedling will cover 5 to 6 square centimeters at the end of the first season, and occasionally will produce a seed-bearing culm or two the first year. Most plants do not bear seed until the second year and a few not until the third. When the mat has attained a diameter of 8 centimeters or more in this forage type, the center tends to die out leaving a ring-shaped mat. This grows outward, and a certain portion on the inside usually dies each year, the part dying being negligible in a season of considerable and well distributed rainfall, and great in a season of deficient precipitation. The dying out of the older portion of the mat occurs always in the arid period of the season, and growth during the rains. This alternate period of growth and death is the means by which this grass responds to fluctuations of rainfall, a response to its environment so delicate and well-balanced that it has made blue grama the greatest dominant on the western and more arid part of the Great Plains grassland.

As the circle of mat grows larger, parts of it grow faster than the others. When an unfavorable season comes, segments of it die out completely, these usually being the slower growing ones where the dying-back of the segment has caught up and passed the growth period. When the rains come each segment grows out from the ends and parts of them will often grow completely around and back towards the former center. In favorable years many mats coalesce to form

fewer and larger ones, and often this interlacing of shoots of several plants is semi-permanent. When this is followed by a season of deficient rainfall, the mats tend to resolve again into its former elements. At times, however, parts of coalesced mats will remain united and any separation occurring simply cuts the interlaced parts from the parent mats. The more rapid growth of certain shoots at the edge of a mat usually causes arms or outshoots from that mat, and these by long-continued growth as well as by union with other mat segments produce very often large irregularly shaped mats which cover considerable area although rarely measuring more than 3 to 4 centimeters across any one part. One charted near Colorado Springs, Colorado, covered nearly a square meter of ground and the chart showing it resembled an attempt to sketch the plan of a maze.

Wide-spread seeding of blue grama rarely occurs. Seedlings start up practically every year in the areas which have already a cover of the grass, but on adjacent bare areas, even under total protection, it is only in occasional years that the grass advances into them by seeding. Seed collections made each year since 1919 and tested for viability show that this differs greatly from year to year. A small number of each years crop have germinated, usually much less than ~~one~~ per cent. The crop of 1921 showed a much higher rate of germination (3 per cent) and the following season (1922) showed a large number of plants started in the bare part of the protected areas at Seligman.

The life-history of porcupine grass (Stipa comata) differs somewhat in this formation from that which it undergoes in the yellow pine forest. Seeds collected from plants in the savannah grassland do not show the continuously high germination found in those collected in the forest. The rate of germination is therefore less, and the rate of growth is usually also less. As the seedlings usually start up in the more favorable seasons the size of surviving ones at the end of the first season are of the same size as those of the forest. The plants do not grow as rapidly after this year, however, and rarely reach great size, the maximum area usually being 25 square centimeters.

In the grazing type found upon the rocky ridges, little redstem (Andropogon scoparius hirtiflorus) has approximately the same life-history as in the forest. Sideoats grama (Bouteloua curtipendula) has not been described. It produces a large number of spikelets each of which falls as a unit and contains, as a rule, at least one viable seed. Crops from several years have shown as high as 85 per cent germination, 100 spikelets producing about 85 plants. This grass, therefore, shows the same ability to reproduce itself from seed as is found among the annuals. The tufts formed are individually small but often grow so closely that they form semi-mats. These tufts often die out except for one or more buds or shoots, each of which produces a new tuft. In this manner, a number of adjacent tufts may be formed from one parent, and while each is a distinct individual, they are

but segregated parts of one plant. This grass, therefore, like the other perennial gramas of this region increases by propagation as well as by seeding, but outstanding, however, among these grasses in the latter particular, and in this respect very much like dropseed. Like the latter grass, also, it is a short-lived perennial.

Very little is known about the life-history of galleta grass (Hilaria jamesii). In the years of the experiment no seedlings of it have been found. It tends to spread largely by means of stolons, but this is a very slow process, for it does this very slowly, and the stolons do not extend very far. No seedlings have ever been obtained from its seed, but this may be due to lack of knowledge concerning the factors necessary for germination. At all events, reproduction by seed is a rare process with this grass.

Except that woolly-foot grama is often present, the grassland found associated with chaparral is very similar to that of the Juniper-Pinyon savannah. For this reason, this grassland needs no particular mention.

The blue grama forage type produces from 130 to 410 pounds of hay to the acre, the average being about 385 pounds. Continuous grazing does not apparently reduce this very much. But quadrats at Colorado Springs where Stipa is present yield about the same amount of blue grama and an average of 550 pounds of porcupine grass to the acre. From this it would appear that the loss of the tallgrass component from this area has reduced the potential yield, which was also its former yield, to less than one-half. The

Table 10. Growth of blue grass (Boutelqua gracillis) under total protection, prairie-dog and cattle grazing at Williams, Arizona. Area f mats in square decimeters per quadrat.

Season	1918	1919	1920	1921	Rodent-grazed after 1921	1922	1923
Total protection.							
Total area of mats	16.91	34.28	27.40	16.06		16.02	21.98
Average area of mats	.104	.672	.361	.198		.229	.440
Number of mats	162	51	76	81		70	50
Prairie-dog grazed.					Total protection after 1921		
Total area of mats	17.35	31.24	32.32	17.73		21.94	28.29
Average area of mats	.141	.473	1.197	.157		.244	.566
Number of mats	123	66	27	111		90	50
Cattle & prairie-dog grazed.							
Total area of mats	14.78	28.53	21.70	24.03		24.04	
Average of mats	.085	.559	.209	.300		.364	
Number of mats	173	51	104	80		66	

It will be noticed that when the total aea if the mats increase, the number of individual decrease. This is due to the growing together of mats. In like manner a dry season, increases the number of mats, as a rule, by the death of intervening portions of larger mats.

TABLE II. Weight of weeds and forage produced per square meter under total protection, prairie-dog grazing, and combined cattle and prairie-dog grazing, together with the area occupied by the grass and the weight of grass per square decimeter of mat (yield per unit area). Blue grama forage type in Pinyon-Juniper savannah, Williams, Arizona.

Plot	Total protection		Rodent grazed		Cattle and rodent grazed	
					(Ac 6)	(Ac 7)
Season	1922	1923	1922	1923	1922	1923
Yield of weeds	51.1	18.8	22.0	20.4	60.4	62.5
Yield of forage	43.7	15.6	7.3	6.5	2.6	2.4
Total area	46.86	36.90	32.50	38.62	31.20	27.10
Yield per unit area	1.0	0.4	0.2	0.2	.08	.09
Forage in lbs. per acre	390.4	167.9	65.3	58.0	23.3	21.4
Total yield	94.8	34.4	29.3	26.9	65.0	64.9

The results are for one quadrat in each plot except the cattle grazed plot. The first clip quadrat (Ac 6) was destroyed during 1923 and was replaced in October that season by (Ac 7) which furnished the data for that season.

yield from the redstem-sideoats grama type in this savannah near Seligman was at the rate of 856 pounds to the acre. There is no good reason why a successional type should yield a greater amount per acre than the climax grassland. Means of reestablishing Stipa must be discovered, therefore, to raise the productiveness of this grassland to its maximum efficiency.

THE GRASSLAND GRAZING TYPES. The climax vegetation of the "true" grassland is mixed blue grama and wooly-foot. In forage yield, wooly-foot grama produces the greatest amount per unit area, but when closely grazed yields but a fraction of this amount. When closely clipped this grass takes three years or more to recover. The base of the stems are woody and tough and under a reasonable amount of grazing these are not touched. Under such conditions, considerable forage is produced by this grass each year.

The rocky slopes and ridges bear the same types as are found in the Pinyon-Juniper savannah. The subclimax grass in the playas is burrograss (Scleropogon brevifolius) and this is worthless for grazing purposes, being highly unpalatable. The stage preceding this grass is one composed of Helianthus ciliaris which is also worthless. On certain of plateaus overlying "rim rock" or basalt flows, when the soil is shallow and dries out readily, ring grass is a normal constituent. But since this grass also is grazed reluctantly and only when all other forage is lacking, it has spread greatly.

The maximum yield of forage in the dominant type of this grassland on the protected plot at Seligman was 895 pounds in 1922. The deficient rainfall for the season of 1923 caused a reduction in this rate to 85 pounds per acre. The variation in yield from a favorable to an unfavorable year is therefore very great and adds to the difficulty of utilizing this forage type in an efficient manner. It is naturally impossible to expand and contract herds of cattle or sheep on such range so as to always utilize it to its fullest capacity without overgrazing it in unfavorable years. This has aided in the destruction of this range over considerable areas, and must be taken into account in all measures undertaken to restore the range.

The transition phase of this grassland as it passes into the desert plains grassland differs in that blue grama has dropped out leaving only wooly-foot. This, however, is associated with dropseed and three-awn. Whether these are regular constituents of this phase or successional grasses could not be determined definitely, but the evidence at hand would indicate that they belong among the climax dominants, dropseed especially. In all protected places, such as the railroad right-of-way, this latter grass is always associated with wooly-foot grama. Three-awn (Aristida purpurea) was usually present as well.

Wooly-foot grama (Boutelcua eriopoda) spreads chiefly by stolons. Attempts at germinating seeds of this grass have been uniformly unsuccessful, but seedlings are occa-

sionally found in nature. Viable seed appear to be produced in quantity only at intervals of several years, only one such crop having been observed (season of 1919 on the Santa Rita Range Reserve). A seedling forms a fairly large plant under protection in two years. The outer culms bend toward the ground, root at the nodes and a number of smaller plants surrounding the parent. Two years after a node has rooted in this fashion, it also produces stolons and this process continues indefinitely. This grass forms tufts rather than distinct mats and therefore is of the semi-bunch type of grass.

The first growth of this grass in the spring is by elongation of existing culms or stems near the base. The new length of internode appearing is green (with a white wooly pubescence) and this seems to take the place of leaves for the time being. When the summer rains come, leaves also appear. This habit of using green stems protected by hairs or other means for carrying on photosynthesis, is a common method among desert and semi-desert plants to carry them through the arid parts of the growing season. Among grasses, however, it is unusual. This serves to explain the ability of this grass to become more dominant than blue grama toward the desert edge of the grassland.

GRAZING TYPES OF THE DESERT PLAINS GRASSLAND. The desert plains differ from the true desert in having an appreciable stand of perennial grasses. The dominant grass is Rothrock grama (Bouteloua rothrockii). Lesser associates are dropseed, black mesquite grass (Muhlenbergia porteri),

galleta grass (Hilaria mutica) and several species of Aristida, namely A. divaricata, A. californica, and A. purpurea. The grasses of the true desert are chiefly annuals, annual three-awn (Aristida bromoides), and two species of six weeks grama (Bouteloua barbata, and B. aristidoides). The true desert has an average of 3 inches or less of rainfall and the majority of perennial grasses can not survive the long periods between rains. A few are exceptions. Tobosa grass (Hilaria rigida) a shrubby deep-rooted perennial grows along the washes where it can reach the water which flows underground for some time after the rains. Mesa grass (Dasychloa pulchella) is an insignificant perennial of no grazing value found on the firmer ground of the caliche mesas or table-lands. The principle grasses of the true desert, however, are annual three-awn, and the six weeks gramas.

In this region the desert plains grasses have been almost wholly grazed out. Those normally growing under the protection of the shrubs have survived in some measure. These are desert three-awn (Aristida californica) common three-awn (Aristida purpurea) and black mesquite grass (Muhlenbergia porteri). Only galleta grass has survived to any extent among those that grow in the open. The bases of the stems of this grass are very woody and hence it can not be grazed ordinarily to the basal buds and destroyed. On the whole, the grazing value of this formation has largely disappeared and is of value only after the rains have produced a crop of annual herbs and grasses.

Table 12. Present composition of the least injured portions of the range at the principal stations, showing the average area of the quadrats covered by all and by the chief grasses at the end of the growing season of 1922. Areas given in square decimetes and also represent the per cent of the area covered.

Station	Riorsan	Coconino	Williams	Seligman	Lower 2station	Chino valley	Prescott	Kingman	Yucca	Cave Creek
Number of quadrats averaged	3	2	2	6	3	3	6	2	2	
Muhlenbergia gracillis	22.55									
Festuca arizonica	8.91									
Agropyron smithii		2.39								
Sporobolus cryptandrus		7.49		.96			.23			
Bouteloua gracillis		1.89	23.21	18.89	5.46	6.29				
Aristida (various species)	.31	.21		.66	.96	2.27	1.11	.09	.11	
Bouteloua curtipendula				.01		4.33				
Hilaria mutica & H. jamesii				.21			1.94	.22	3.81	
Muhlenbergia porteri							.72	.61		
Other grasses	3.91	.04	.11	.08	4.32	1.41	.11	.31		
Total grass	34.78	11.93	23.32	31.67	22.22	18.34	5.37	1.25	3.92	

RANGE DAMAGE. The most important range damage in this region is due to two causes, overgrazing and rodent destruction. The rodents are chiefly prairie dogs, (Cynomys gunnisoni zuniensis). Minor causes at times produce damage to the range, but usually are too infrequent or too insignificant to require more than passing mention. Destruction by trampling is almost certain to occur around water holes. Areas subject to flooding may have the vegetation completely killed at intervals during the history of the formation. Fires may be destructive to the range particularly if they occur near the end of a very dry season by consuming the entire plant, including the basal buds. In some areas, also, ants may reduce the range considerably when in great numbers by clearing the ground around their burrows. These factors pale into insignificance by the almost universal overgrazing and the vast colonies of prairie dogs to be found in the best parts of the grassland.

OVERGRAZING. The cause of overgrazing dates back many years. The open range was free to any man who had the cattle and could control one or more water holes. At first there were not sufficient cattle to stock the country but as the herds increased and the cattlemen became more numerous each cattleman deliberately overgrazed his range to prevent or discourage some other cattleman from encroaching upon his range. As the competition for range increased these practices became worse, neighboring cattlemen often placing excessive numbers of cattle upon the disputed areas to obtain

as much grass as possible from this range before it was utilized by his neighbor. Such practice finally became habit and almost universally over the west cattlemen are stocking their ranges to more than their maximum capacity in order to produce as many cattle as possible. Many of them only now are beginning to realize the shortsightedness of this policy. Very few ranges exist that have even a fraction of their former carrying capacity. Only when the range can be legally occupied by each cattleman, the government giving him a clear title or long term lease to his range, can this condition be remedied. Even then a long campaign of education must be carried into effect to educate the less progressive cattleman in regard to the best means of range continuation.

Perhaps the greatest single factor in the continuation of range destruction is the alternate succession of favorable and unfavorable seasons. During a period of years of high rainfall the average cattleman expands his herds to utilize all the grass present. When the unfavorable years come the range can not carry the cattle with which he has stocked it and in an endeavor to maintain their existence the cattle will eat the grass clear to the roots and keep it in this state until it is finally starved out.

During the dry years when the grasses are destroyed very few plants come in to colonize the denuded area, but when a more favorable year comes along the ungrazed plants are permitted to produce a heavy crop of seed while the grazed plants usually are not, hence such areas are nearly always colonized by unpalatable species. In the short-grass plains the

chief of these plants is Gutierrezia. Hence the coming in of this plant is the first indication to the cattleman that his range is overgrazed. In many areas the grass has been totally destroyed and completely replaced by this low shrub. Such a condition is found surrounding the town of Seligman. No method is as yet known by which such a range may be re-established under present conditions.

In wheatgrass forage type overgrazing, if not too intense, destroys dropseed and causes the spread of blue grama. If this is continued wheatgrass also disappears and the park becomes a grama flat often with Texas timothy associated with the blue grama. One quadrat in this type park showed ~~forty three~~ 43 per cent Texas timothy, ~~fifty two~~ 52 per cent blue grama and ~~five~~ 5 per cent Gutierrezia. Under more intense grazing Chrysothamnus and Gutierrezia come in directly without the blue grama appearing at all. In the Grand Canyon forest sage brush also comes in and many such overgrazed parks consist of Chrysothamnus and sage brush with only occasional grasses growing in the protection of the shrubs.

In the shortgrass plain the grasses under more moderate grazing may be replaced by ring-grass or a mixture of ring-grass and Gutierrezia. This? is the least palatable of the species of grass occurring in this formation and is therefore permitted to produce a crop of seed. In the swales and flood areas, burro grass (Scleropogon brevifolius) being also unpalatable will often occupy these areas if not too heavily overgrazed. Gutierrezia, however, is the most common and universal indicator of cattle overgrazing.

Special conditions also occur; if a dry year or a series of dry years is followed by a very favorable one, Russian thistle may come into the bare area and completely dominate it in the absence of the grasses. This, however, is not an unmixed evil, for it is readily grazed by cattle in its succulent stages.

At the southern edge of the grassland formation or wherever it comes in contact with the desert shrub, the effect of overgrazing is to favor the latter formation. Judging from the finding of relict grasses in the region west and south of Kingman, this has already occurred in this area. Such a replacement of grassland is a widespread occurrence in southern Arizona. It is still continuing on the western edge of the grassland formation in the region here covered. Twelve miles east of Kingman is an area where the grasses have been wholly destroyed, which is now occupied by Yucca baccata and Opuntia arborescens, but is totally surrounded on all sides by grassland.

The first step in range recovery must be the acquiring of a title or long term lease to the range occupied, and, then fencing into pastures to segregate the various forage types. In this manner, if the types are sufficiently diversified, deferred grazing can be easily arranged to permit each grass type to bear a sufficient crop of seed each year to permit recovery of partially denuded range. If the forage is all of one type, rotation grazing must be practiced in which part of the range each year is allowed to produce

a crop of seed and so permit recovery. This is done by resting the pasture for a year in whole or in greater part. Such practice also gives a certain amount of reserve range for use during unfavorable years. No experiments have been carried out to develop an economically possible method of restoring a completely destroyed range. Experiments are now being started with respect to reseeding such ranges with original grasses. Our experiments have already shown that it is hopeless to try to establish grasses which do not naturally belong to the formation.

Certain ranges have been badly damaged near the water holes while practically untouched some distance away. This can be remedied in part by salting cattle in the untouched part of the range, but the best method of remedying this condition is increase and distribution of the water holes or tanks. When the range can be fenced it is best to have pastures not larger than ~~four~~ 4 miles in extent in any direction and to have the water supply in the center of such a pasture. It is common experience that range much over ~~two~~ 2 miles away from the watering hole is not utilized to its fullest capacity.

RODENT DESTRUCTION. Rodent damage to the range is very distinctive and in many respects very different from that produced by overgrazing. Such damage is always intensified by grazing and over the greater part of the grassland formation in this region has become critical. This is due to two major causes, both of which are introduced by the cat-

tleman. Because the range is grazed to the limit of its carrying capacity prairie dogs must take what is left and as they are able to graze the vegetation to the roots they tend to clear the ground completely in a very short time. The destruction of predatory animals by the cattlemen to protect his herd and flocks has upset the original balance in nature and permitted the prairie dogs to increase greatly beyond their former numbers. The killing of predatory animals is of course justified, but to compensate for the removal of this check upon the increase of the prairie dog, similar campaigns for the eradication of the rodents must be waged.

Prairie dogs tend to congregate in towns in the very best portions of the range, and in competition with cattle for the grasses graze off the grass mats completely, leaving only the roots with not even a bud to start the plant again the following year. The rodents remain in their burrows until the distance to pasture becomes too great for safety when they move. Before this is done, however, the ground is combed again and again by them in search of food, so that no remnant of grass remains to reseed the area after they have moved. The result is a dead area or one occupied by weeds behind the colony with the prairie dogs gradually advancing into the untouched grassland, leaving total destruction behind. As this goes on, in favorable as well as unfavorable years, and as the damage is not a gradual decrease in the amount as under overgrazing, the plants associated with such damage are usually of a quite different type than

that found with overgrazing alone.

The succession upon the dead area behind a prairie dog colony usually begins with the coming in of Verbesina encelioides. This is gradually replaced by Gutierrezia or, if not too heavily grazed by cattle, by Aristidas, because these by the nature of their fruits can invade the area at some distance from the seedling plants. The prairie dogs, however, do not, as a rule, colonize rocky spurs or ridges with very shallow soil since burrows cannot be dug in such places, and often advance past such areas which then serve as points from which the range may be reestablished. Along many such ridges, however, parts of the colony establish themselves permanently and destroy any plants which may appear by reseeding from such spurs, and in such cases the damage continues until the rodents are destroyed. The area at Seligman is located on the edge of such a rocky ridge. In the five years of the experiment the prairie dogs have not advanced toward the ridge to any measurable extent. Excavations made in the grassland at this place show that the soil is residual except for the top three inches, being composed largely of angular ortho-clase fragments still in the same place as they were in the granite rock from which they were derived. The soil is not over ~~two~~ feet deep and passes gradually into the solid rock. The roots of the grasses penetrate to a depth of ~~twenty-eight~~ inches, but along the last ~~fifteen~~ inches only along the former cleavage and crystal planes of the original rock. The rock fragments are in

part cemented by caliche so as to make very hard digging and apparently this has discouraged the prairie dogs from attempting to establish burrows in such ground. Behind the prairie dog town the grasses have been totally destroyed and in 1918 were colonized by Verbesina encelioides. In 1920 a few plants of Russian thistle (Salsola ~~kali~~ pestifera) appeared and in 1921 this had in part replaced the Verbesina. In 1922 the entire area was occupied by Russian thistle and apparently no Verbesina remained. In 1923, the late appearance of the rains prevented the growth of Russian thistle during that season. In the meantime, ring-grass has appeared and is gradually colonizing the area in places.

The amount grazed by prairie dogs in the areas where they are not destroying the vegetation completely is surprisingly great. The forage eaten by cattle at Seligman was only 41.2 per cent, while that eaten by prairie dogs was 40.9 per cent, the difference of only three-tenths of one per cent. In the wheatgrass type at Coconino the amount destroyed by prairie dogs alone was 80 per cent of the total forage produced. The wheatgrass, however, is reduced 60 per cent while the dropseed is reduced 99 per cent. Hence the dropseed is subject to greater damage by prairie dogs than any other grass. At Williams 83 per cent of the available blue grama forage was destroyed by prairie dogs. This shows that prairie dogs, even in the places where they are apparently not doing any damage, nevertheless reduce the amount of forage present to an almost negligible frac-

tion of what it should be. The stockman realizes the damage done very readily where the range is entirely destroyed, but has no inkling of the terrific toll taken by them where they are doing no apparent damage.

"According to the evidence here presented prairie dogs and cattle feed on the same grasses and prefer them in the same order. Prairie dogs do not, from all the evidence obtained from four years observation, eat anything that cattle do not. Thus they are thrown into direct, and in times of drought, deadly competition. So far as these experiments go, prairie dogs cannot be shown to have a single beneficial food habit. In some overgrazed areas, apparently, the total eradication of prairie dogs as well as the reduction of cattle per unit area, will be necessary if the forage is to continue to exist." (Taylor and Loftfield, 1924).

Overgrazing is a gradual destruction process on the range in which the grasses are slowly replaced by non-palatable plants. It usually does not continue until the range is totally destroyed because the cattleman after a time realizes that his range is disappearing and checks the process. Moreover, the incoming unpalatable species serve to give protection from grazing to all grasses growing up through them. Rodent damage, however, causes complete destruction, which spreads as the colony advances into the undamaged grassland, and in such cases the range cannot be reestablished by any economic process now known. This constitutes the chief difference between the two types of

range damage and also explains the differences in the succession initiated by such damage.

Other rodents reduce the carrying capacity materially. Jackrabbits compete with the cattle for forage but do not have the destructive effect upon the range that prairie dogs do. The toll taken by these animals has been measured quantitatively on the Santa Rita reserve in Southern Arizona, but no data are available concerning their effect in the northern part of the state. Here, however, they are not nearly as numerous as in southern Arizona. The pocket mice, species of Perognathus, also cause some damage by destroying seed. As a rule this damage is not serious, for the animals occur chiefly in places where the grasses are permitted to produce considerable seed, and they get by no means all of it, especially in favorable years. Ants also consume a considerable amount of seed and in many cases obtain nearly all of it. Certain of them form clearings and when these are numerous reduce the range appreciably. In one area studied four miles south of Seligman the clearings occupied 7.2 per cent of the total area, but as these clearings were in an area occupied otherwise by Gutierrezia, they can hardly be said to reduce the range forage. They also occur in grassland, although they have never been found quite as abundant as in this area.

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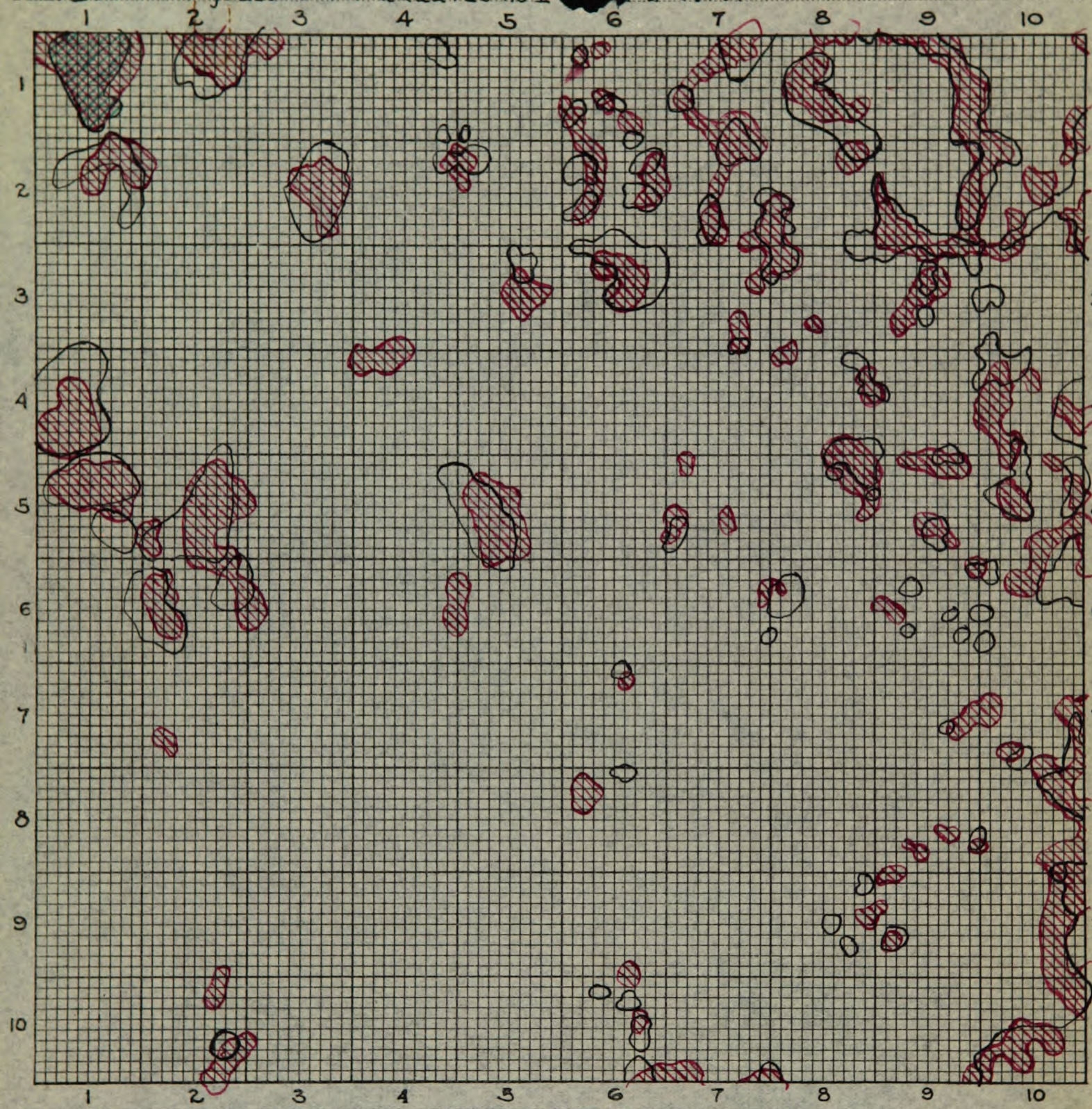
GROWTH RECO[illegible] SHEET

Plant *Bouteloua gracilis* in Quadrat As 1 [illegible] of 1918.



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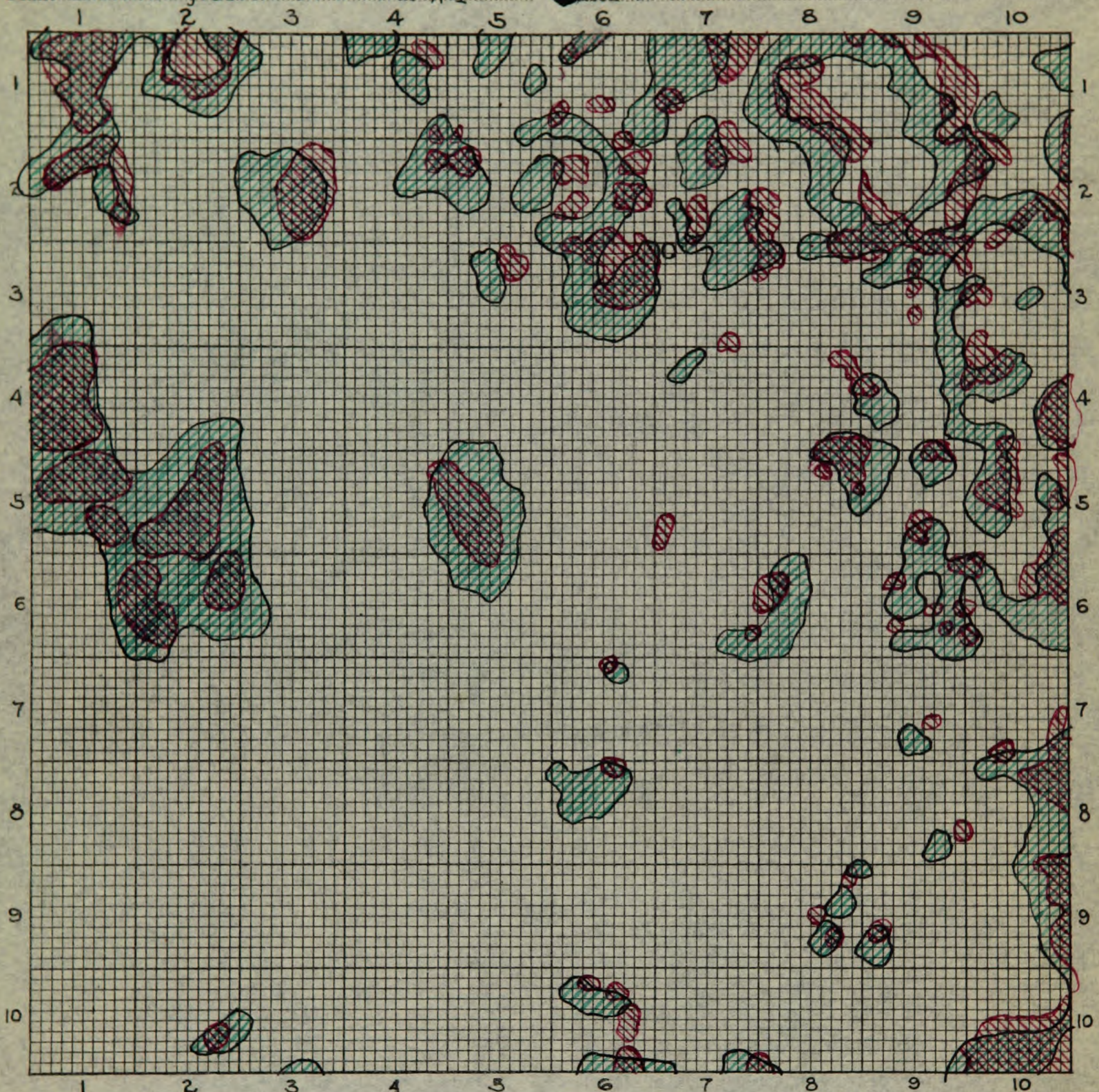

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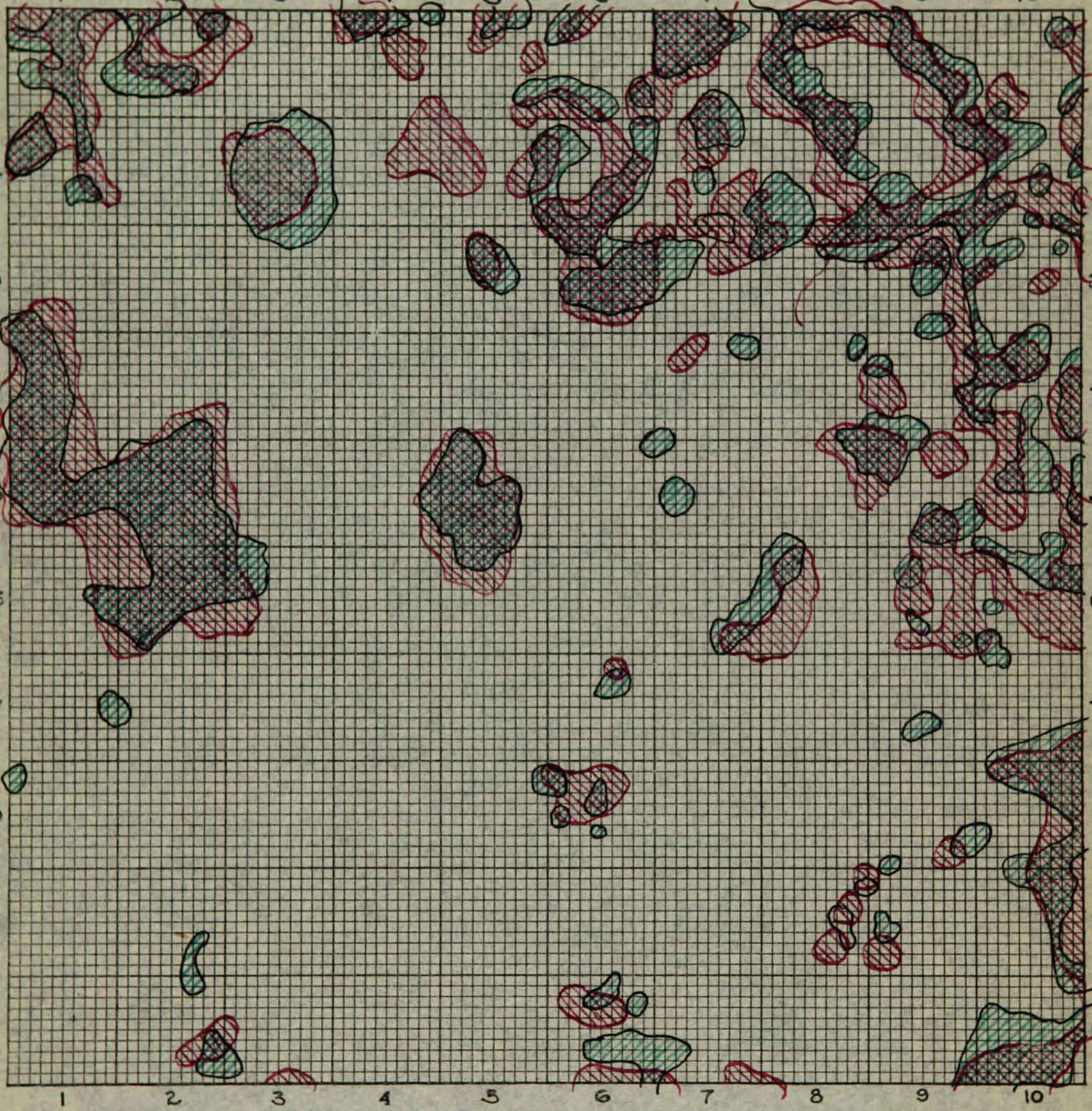

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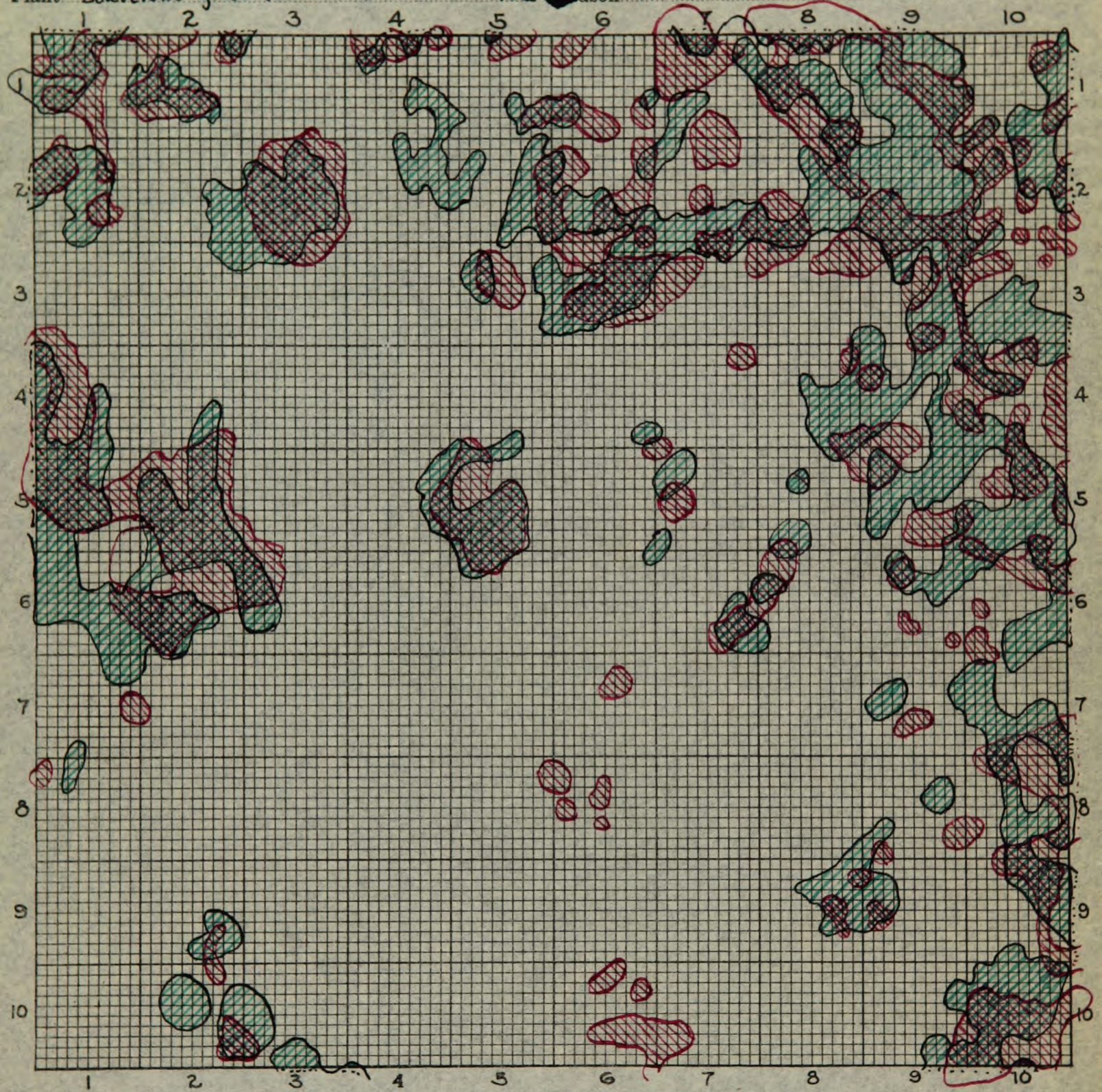

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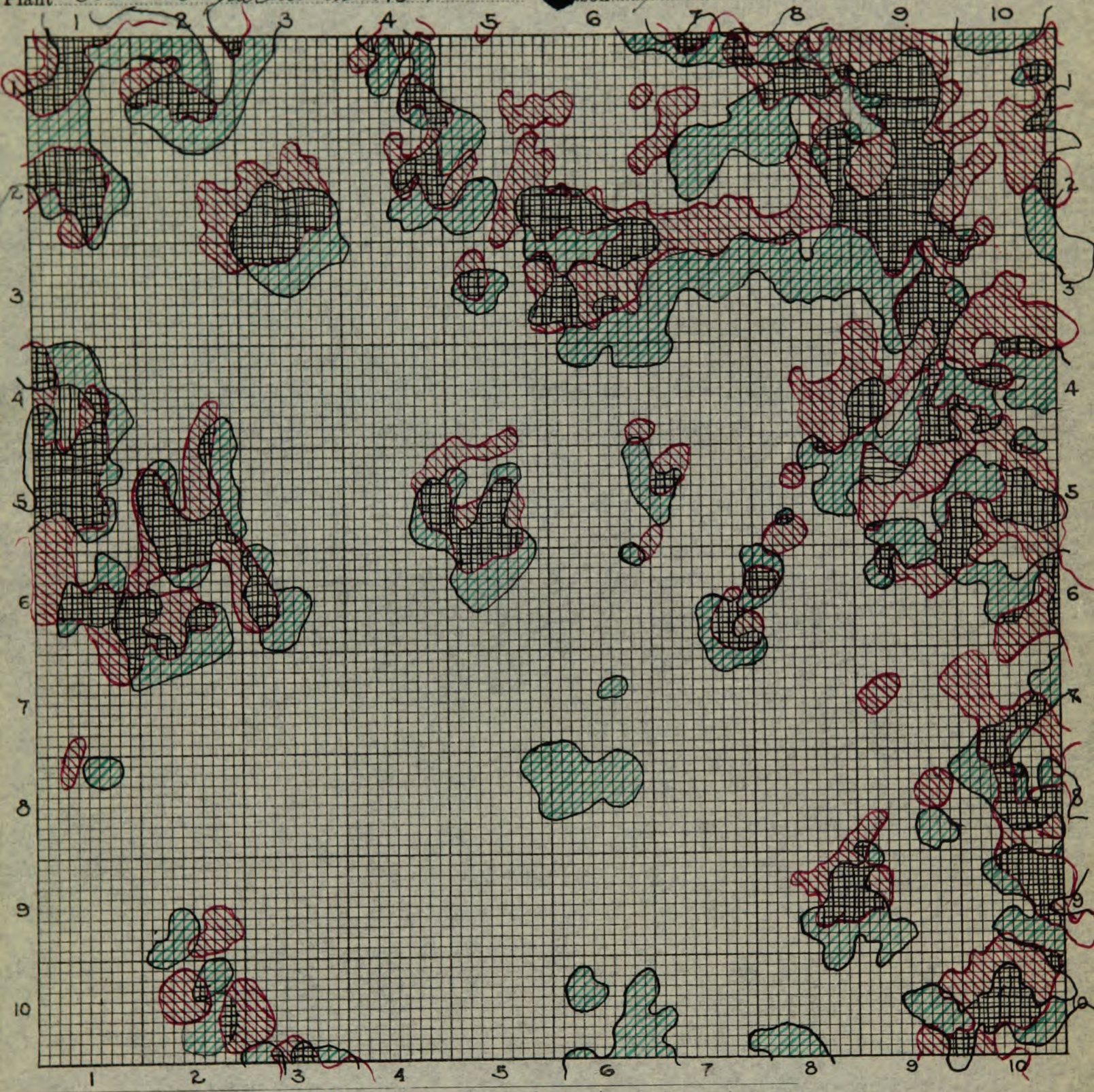

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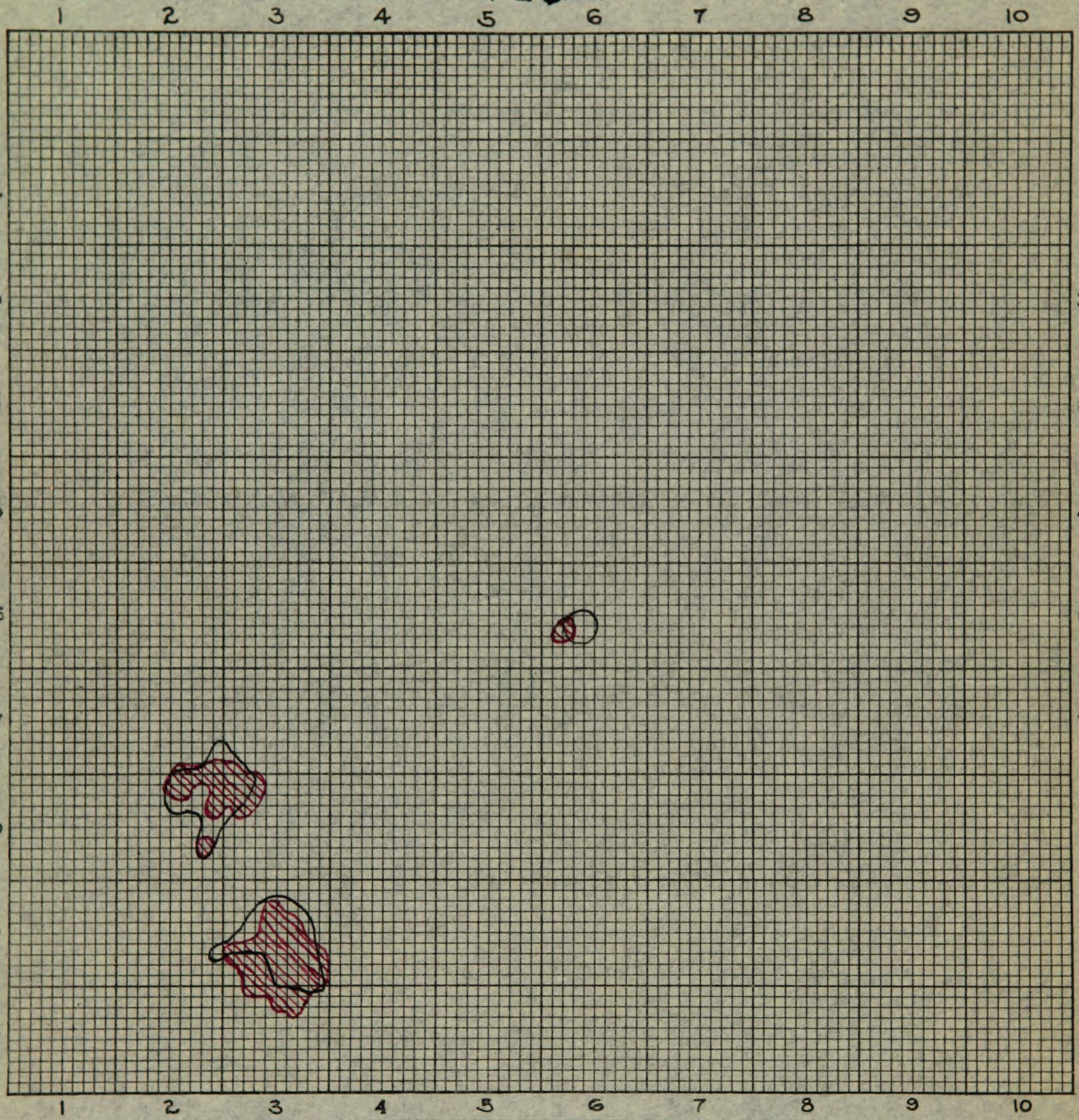

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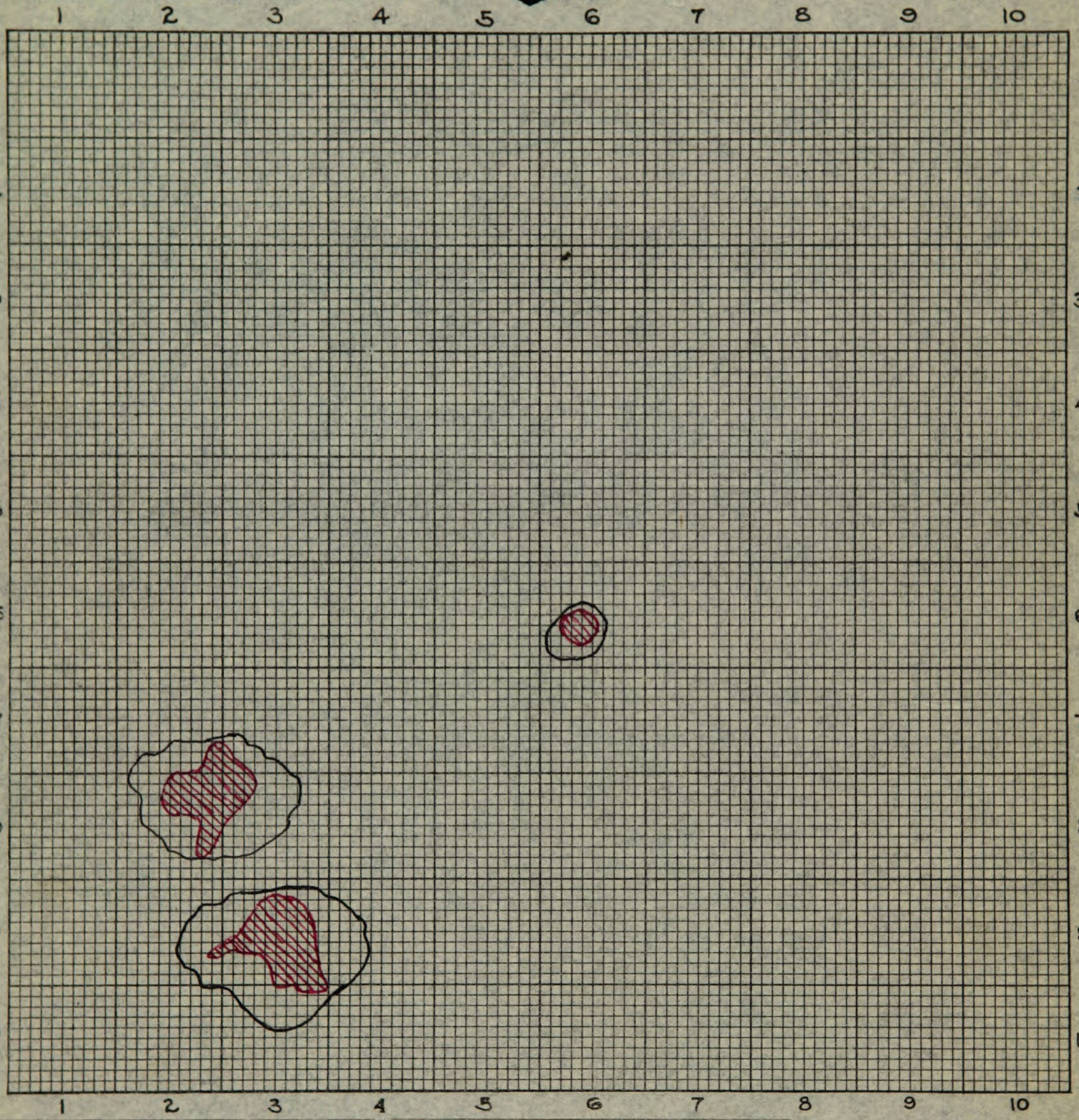

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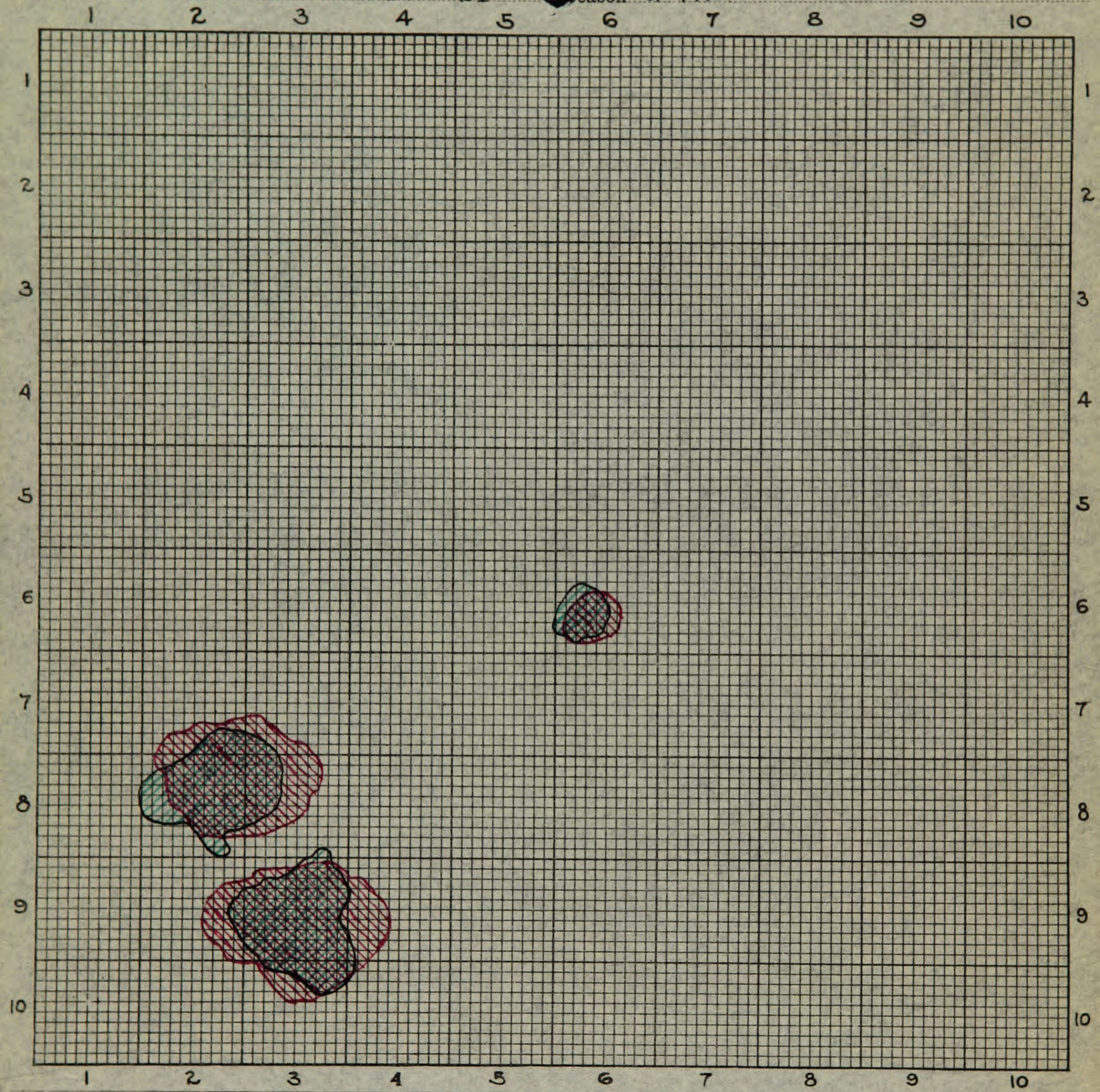

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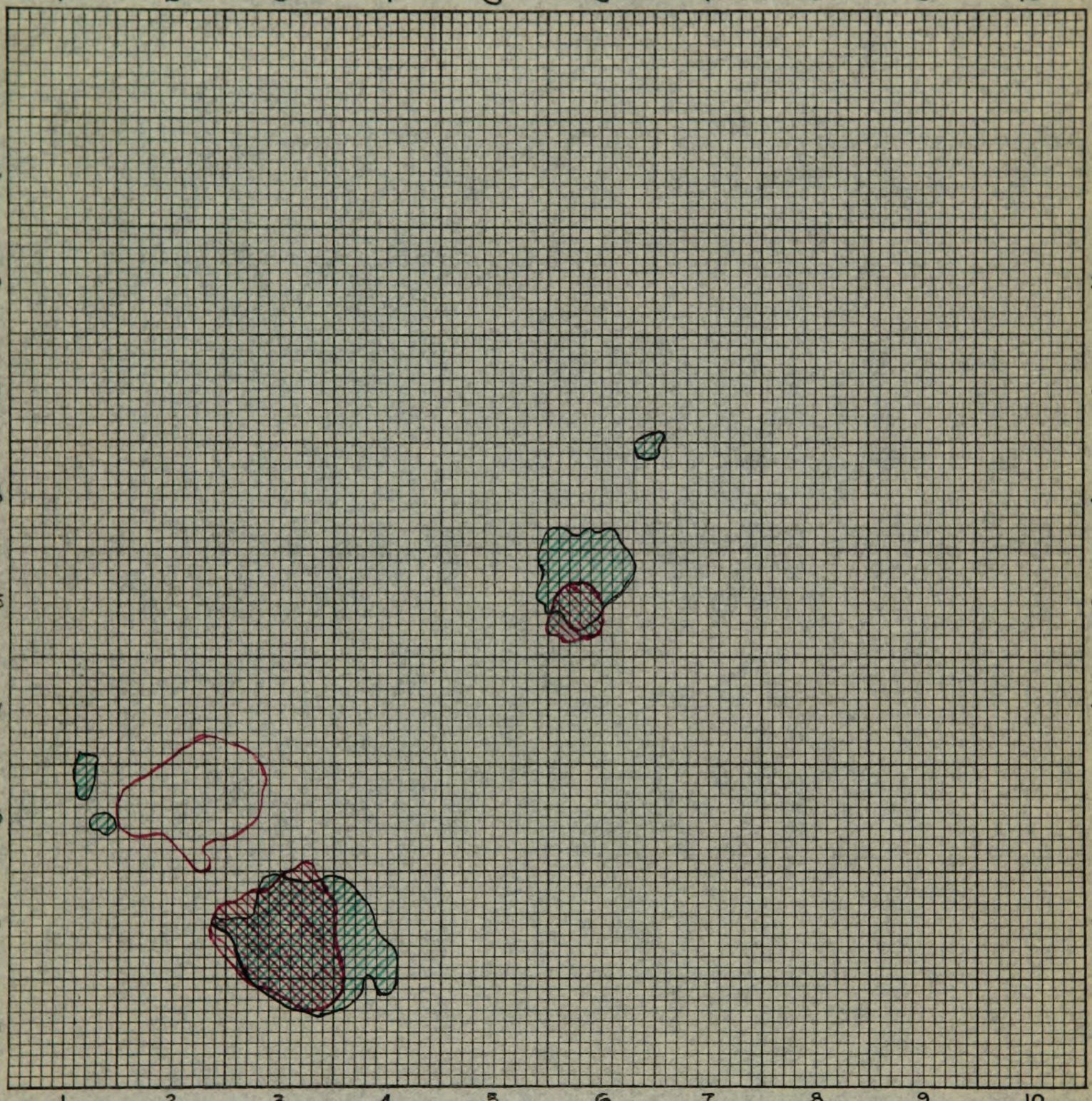

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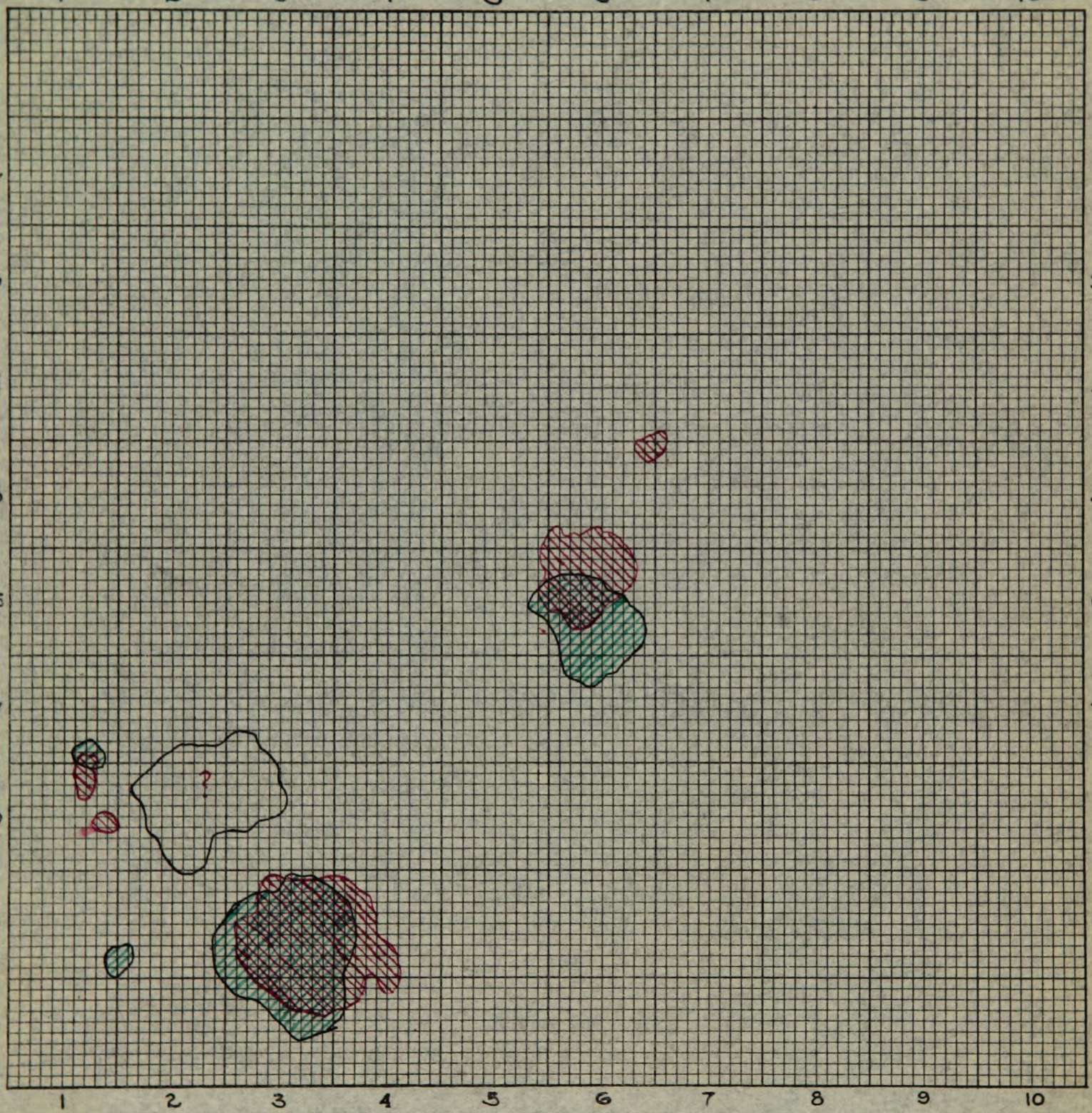


Wheatgrass Park in the Grand Canyon Forest. Yellow Pine intthe Background With Oak (Quercus gambeli) occupying the Slopes.

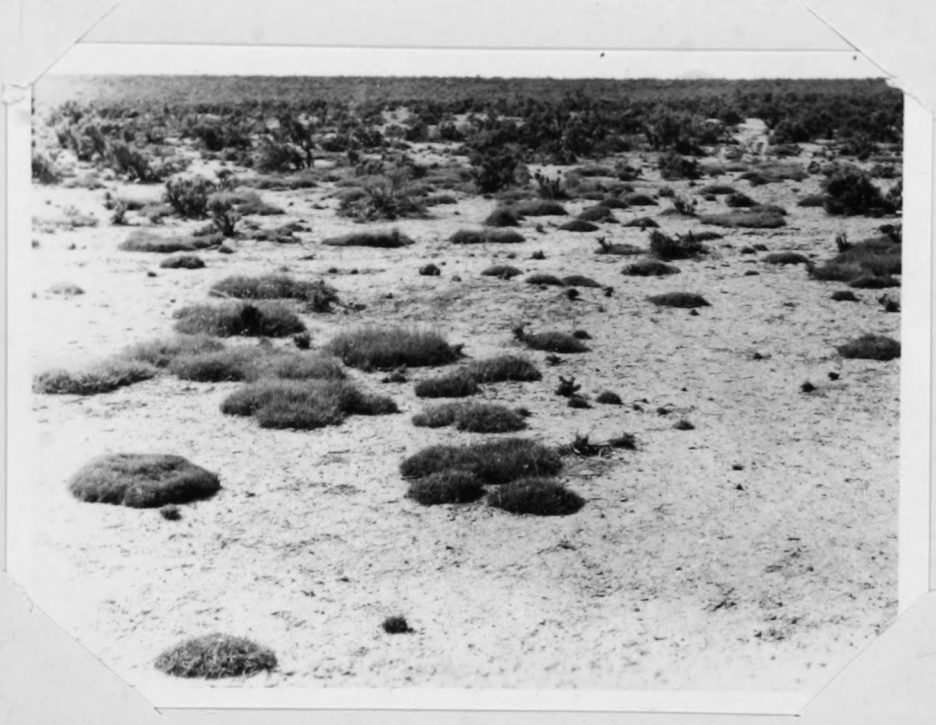
Fenced Areas of the Coconino Experimental Plot. Wheatgrass and Blue Grama in the Foreground grazed to the ground, Wheatgrass and Western Dropseed Knee-high within the Fence.

Plate II

Sagebrush and Chrysothamnus Park in the Grand Canyon Yellow Pine Forest.

Blue Grama and Texas Timothy as Grass Cover Under Yellow Pine in the Grand Canyon Forest. A Sagebrush growing between the Tree and the Quadrat.

Plate III



Ring grass coming into an Area cleared by Prairie Dogs. Atriplex canescens and Chrysothamnus, Plnats not grazed by Prairie Dogs as a Rule, share the Ground with Ring Grass in the Background.
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Eurotia lanata. society surrounded by Chrysothamnus and Atriplex.
Successional Stages in the Grassland between Williams and Grand Canyon.

Plate IV

Incipient Recovery under Over-grazing. Blue Grama returning to a Flood Swale or Playa in Chrysothamnus-Atriplex Associes produced by the removal of the original cover of Blue Grama.

Juniperus monosperma killed in Competition with Chrysothamnus and Blue Grama. The Blue Grama has since been Grazed out.

Plate V.

Grama grass park in Quercus undulata-Rhus trilobata chaparral, Prescott. Grasses are Bouteloua curtipendula, B. gracilis, B. eriopoda.

The rock ridge assoies in grassland, Seligman. Afew Junipers are present, The grasses on the ridge are Andropogon scoparius, Bouteloua curtipendula, B. gracilis, and Aristida divaricata. The lower part in the foreground contains a Fallugia paradoxa chaparral associated with Texas timothy, blue grama, and western dropseed.

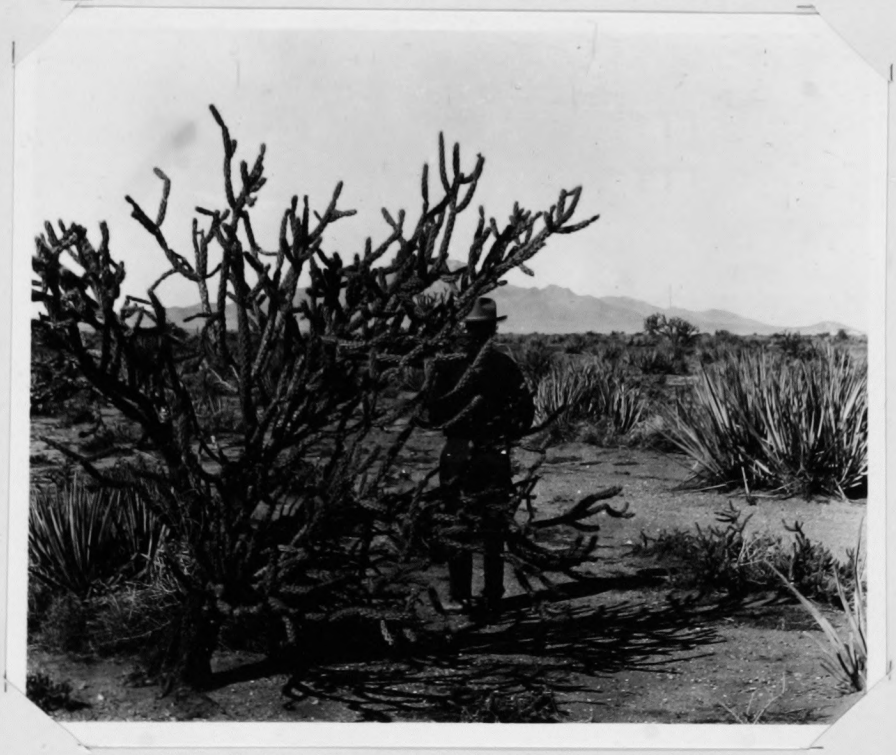
Plate VI.

Typical grassland association, Seligman upper Big Chino Valley. This grassland averages 61 per cent blue grama and 39 per cent wooly-foot grama.

Last stage in the over-grazing of this grassland, Seligman. Only Gutierrezia left, not a single grass plant for miles to reseed the range.

Plate VII.

Nearly typical grassland of the lower edge of the formation. Grasses average 63 percent wooly-foot grama, 19 percent galleta grass, 7 per cent dropseed, and 11 per cent blue grama. Gutierrezia (over-grazing indicator) is common as well as Yucca baccata, a sub-dominant of this edge of the grassland.



Overgrazed phase of the lower edge of the grassland formation. This area is about two miles in diameter and completely surrounded by grassland.

Plate VIII.

Yucca arborescens in Fouquiera-Franseria-Opuntia-Yucca association of the desert scrub climax. In the wash are several plants of Tubosa grass. Near Yucca, Arizona.

Larrea-Franseria association in the desert scrub climax, Sacramento Valley. In the foreground is a Tubosa grass plant and a pipe-stem cholla with Muhlenbergia growing up through it.
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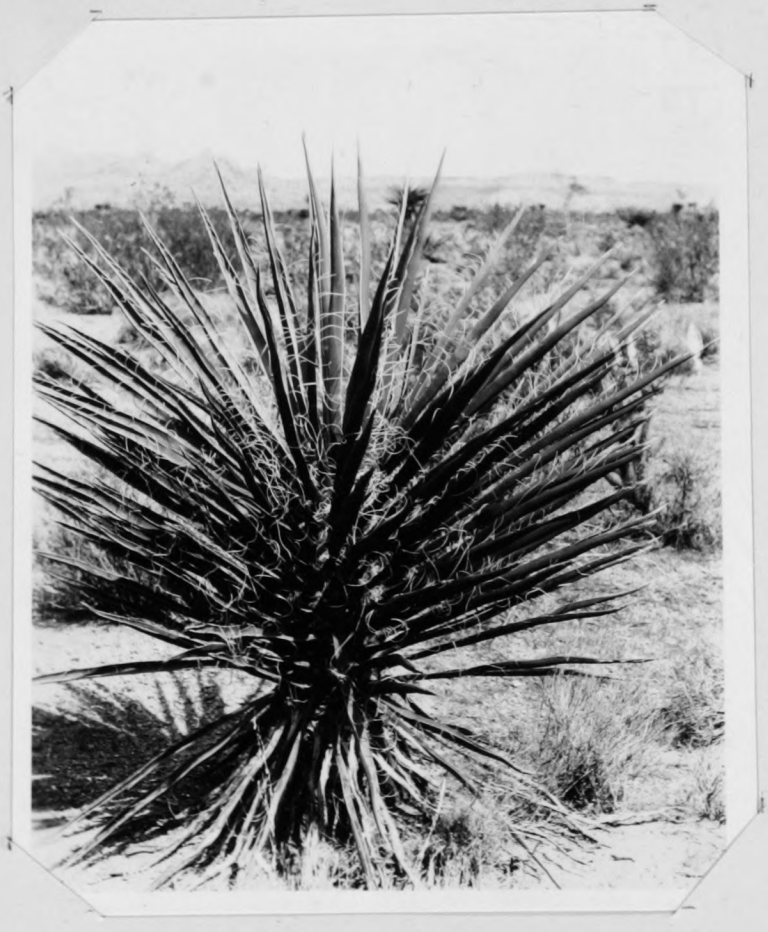
Plate IX.

Hilaria rigida in foreground, Hilaria mutica in background in the Larrea-Prosopis association of desert scrub climax, 25 miles north of Phoenix, Arizona.



Typical plant of Yucca baccata, Oatman, Arizona.