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DYNAMICS OF DISTRIBUTION AND DENSITY OF PHREATOPHYTES AND OTHER ARID-LAND PLANT COMMUNITIES

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16. Abstract

Six ERTS images of the Tucson area, Arizona were analyzed to detect seasonal flushes of plant growth. Paired MSS-6 and MSS-5 bulk images were analyzed, using a ratioing technique, on the Electronic Satellite Image Analysis Console at Stanford Research Institute. Because of unique phenology, desert areas, covered only briefly by dense growths of ephemeral plants, are readily discerned. Grassland, evergreen forest, and riparian communities are also uniquely defined by their phenologies. Relatively sterile areas with little or no plant growth are easily discerned as are areas with varying degrees of plant productivity. The ratioing procedure detects plant coverage in excess of a threshold lying between 25 percent and 50 percent. The method is flexible and other coverage thresholds can be used.

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ERTS-A Proposal No.: SR 254

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Introduction. Prior to the launch of the Earth Resources Technology Satellite, vegetation mapping was largely a static cartographic operation for delineating plant occurrences in space. With the launch of ERTS, synoptic mapping of short-term vegetation phenomena has become feasible. The changing volume of plant tissue covering the earth's surface is a temporally variable plant parameter of great importance. Knowledge of the seasonal changes in plant volume are needed to pinpoint likely areas for livestock grazing, to anticipate locust outbreak areas, to help identify crop types and wildland communities, and to estimate primary productivity and evapotranspiration in plant communities. This report describes one approach for measuring, from ERTS imagery, the quantity of green plant tissue covering the soil surface.

The objective of this ERTS investigation is to develop techniques for measuring gross changes in broadly defined plant communities using only bulk ERTS imagery. Previous experience with the problem of obtaining quantitative measures of plant volume from sequential photography (Culler and others, 1972) suggested the possibility of using scene irradiance data from two or more spectral bands. This report describes a method for detecting areas of heavy plant cover by using a ratio between two of the four spectral bands (MSS-5 and MSS-6) to which the ERTS multispectral scanner is sensitive. Use of a ratio largely nullifies problems arising from seasonal changes in sun elevation and atmospheric attenuation. The technique relies on the well-known fact that leaves reflect heavily in the near-IR range but reflect little in the visible range. Leaf reflectance in these two bands is influenced by two distinct plant systems, one involving pigment chemistry, the other, mesophyll anatomy. Both of these systems are closely related to the volume of foliage.

The study has been conducted in an area near Tucson, Arizona (fig. 1), where altitudes vary from about 2,000 feet (600 meters) to about 9,500 feet (2,900 meters) (fig. 2). The vegetation varies from dense evergreen conifer forests on the mountains to sparse desert vegetation on the basal plains. Riparian vegetation occurs at all altitudes. Average annual rainfall within the test sites varies from near 10 inches (250 mm) to more than 30 inches (750 mm) (fig. 3).

As with most arid regions, a dense cover of ephemeral plants develops quickly within desert communities during years of favorable rainfall. The plants reach maturity and complete their life cycles during a period of only a few weeks—any method of measuring these plants must be based on frequent observations. At the other extreme of plant phenologic response in the Tucson region are the evergreen conifers found at high altitudes on the isolated mountains—these plants should change little through the year. The following detectable seasonal trends in plant cover can be expected in the Tucson region:

(1) Small mountainous areas of evergreen conifer forest above about 7,000 feet (2,100 meters) will show dense plant cover at all seasons, unless there is a covering of snow.

(2) Many areas between 5,000 and 7,000 feet (1,500 and 2,100 meters) altitude are dominated by evergreen oaks and will show dense plant cover at all seasons except during a brief spring period (usually in April and May) when the oaks are leafless.

(3) Grassland areas between about 3,000 and 5,000 feet (900 and 1,500 meters) altitude will show maximum plant density during the July to October period coinciding with the summer and autumn rains. The grassland is inactive during the winter.

(4) In general, the persistent perennial vegetation of the desert (areas below about 3,000 feet [900 meters]) is not dense enough to mask the reflectance from desert soils; the plants of these communities will usually be too sparse to be detected by the satellite. Provided rainfall is adequate, there will be a detectable spring maximum of plant activity in the desert corresponding to the time when a dense growth of ephemeral plants develops among the widely spaced shrubs and trees.

(5) Riparian vegetation is winter deciduous at all elevations. At altitudes below about 3,500 feet (1,100 meters), the winter leafless season is short and there will be no cover only during December and January. At higher altitudes the leafless season is longer.

During the initial phase of this study only cloud free images have been used. Because the region is relatively cloud free, 6 of the 13 satellite imaging dates for the Tucson region were cloudless. Our data base includes images from 6 18-day ERTS cycles for the period from 22 August 1972 to 26 March 1973. These cycles represent at least one image for every month except September and October during the August 1972 to March 1973 period of study.

Methods.--The Electron Satellite Image Analysis Console (ESIAC) at Stanford Research Institute was used to analyze the images. Paired MSS-5 and MSS-6 70-mm black-and-white positive transparencies were viewed by a television camera and recorded on the console television discs. With the grey scales as a guide, appropriate adjustments in scene brightness were first made on the console to standardize the grey-scale step versus voltage response for all images. Thematic masks, generated by a ratioing procedure, were displayed on a television monitor and recorded photographically for future analysis and study. The masks, showing areas of assumed relatively heavy plant development, are generated by displaying selected MSS-6/MSS-5 values on the television monitor.

Plant reflectance values given by Billings and Morris (1951) show that green plant tissue (foliage) will reflect approximately 50 to 60 percent of the incident light within the 0.7 to 0.8 micrometer (MSS-6) range and roughly 10 percent within the 0.6 to 0.7 micrometer (MSS-5) range. Where plants grow densely, such as in irrigated fields, the characteristic reflectance in these two bands can be used jointly to distinguish the plants from nearby soil, rocks, bodies of water and other natural surfaces. Because natural plant communities in arid and semi-arid regions rarely attain such dense growth, foliage reflectance is masked to some degree by soil, litter, and rocks. By assuming various mixtures of soil and foliage cover and calculating the MSS-6 to MSS-5 radiance ratios, the curves of figure 4 can be derived. These curves show that for a given MSS-6/MSS-5 ratio a decrease in soil reflectance coincides with a decrease in foliage cover. Because of the variability in soil reflectance within the test site, the vegetative cover percentage represented by a given ratio is variable. Following rains the ratioing procedure will indicate a spurious decrease in community reflectance because of the reduced reflectance of soils when moist (Condit, 1970).

In selecting a ratio to represent areas of relatively dense plant cover, imagery for a date of known heavy desert plant growth was selected and a series of thematic masks representing various ratios was displayed on the console. Figure 5 shows a series of masks for the following MSS-6/MSS-5 ratios: 1.20/1.00; 1.25/1.00; 1.30/1.00; 1.50/1.00; and 2.00/1.00. The date of the imagery was February 18, 1973 (image numbers 1210-17282-5 and -6). Scene reflectance on this date was strongly influenced by vegetation in four different locations: (1) low-lying desert areas with dense ephemeral plant cover, (2) riparian communities below about 3,500 feet (1,100 meters) altitude where ephemeral plants and early foliating trees such as cottonwood grow densely, (3) croplands, (4) and dense evergreen vegetation of the highest mountains. Plants at intermediate elevations were winter dormant on this date. It can be seen that at a ratio setting of 2.10/1.00 most areas were deleted; only the silhouettes of mountains and a few fields remain. At a low setting of 1.20/1.00 most of the low desert area was included along with the mountains. A ratio value of 1.25/1.00 was finally selected as the value that would yield the most information about the various plant communities in the scene. Study of two other series of similar masks representing imagery from contrasting seasons bore out the conclusion that a ratio value between 1.20/1.00 and 1.30/1.00 would probably provide maximum information.

The foliage cover actually represented by a ratio of 1.25/1.00 is not known. From the curves in figure 4, this ratio probably corresponds to foliar cover values of between 30 and 40 percent where soils have high reflectance. As a means of measuring ground cover for comparison with the images, a series of plots was established at five different locations within desert and grassland communities. Foliar cover was measured during the time of each satellite overpass. Cover was measured by estimating the percentage of the soil surface obscured by green plant organs when viewed vertically. Estimates were made at each site in 60 rectangular plots, 2 dm by 5 dm in size. Color photographs were routinely taken at the same 5 stations.

Results.--Six cloud-free images of the Tucson Test Site were analyzed on the ESIAC. The dates represented are August 22, 1972 (cycle 2), November 2, 1972 (cycle 6), December 26, 1972 (cycle 9), January 13, 1973 (cycle 10), February 18, 1973 (cycle 12), and March 26, 1973 (cycle 14). Thematic masks showing areas where the ratio of MSS-6/MSS-5 was 1.25/1.00 or greater were displayed on the console and photographed. Examination of these six electronically "sliced" images (fig. 6) reveals the following:

The highest mountains (Santa Catalina, Santa Rita, Rincon, Huachuca, Whetstone, Baboquivari, and Dragoon) consistently show values greater than the 1.25/1.00 threshold ratio. This is expected because these mountains all support dense stands of evergreen oaks and conifers.

The riparian communities along the two principal rivers crossing the test site, the San Pedro River and the Santa Cruz River, are conspicuous on all images except those for December and January (cycles 9 and 10), months when the dominant species of these communities are dormant and leafless. The vegetation of these riparian areas was active along the full length of these rivers in August. By November the reaches at high altitudes to the south no longer appeared active and by late March the reach of the San Pedro River above roughly 3,500 feet (1,100 meters) altitude had not yet become active. By comparison, plant activity, as interpreted from the thematic masks, was apparent along essentially the entire length of the Santa Cruz River. This reach of the river lies below about 3,500 feet (1,000 meters) altitude (fig. 2).

The low desert areas, such as those seen toward the upper left corner of the images, show little plant growth in August except for low-lying irrigated lands and riparian communities. Many of these same desert areas exceed the 1.25/1.00 threshold ratio in February and March, a period of above average rainfall and of heavy production of desert ephemeral plants. The terrain at intermediate altitudes between the desert and the evergreen forests responds in markedly different manner. There the plant communities are dominated by grasses which are active in the late summer and autumn but dormant in the winter. Accordingly, these mid-elevation areas show response only during the August to early November period.

The six dates for which usable imagery is available fall into three distinct phenologic periods: Summer-fall (August 22 and November 2), winter (December 26 and January 13), and "spring" (February 18 and March 26). In figure 7, masks for the February and March dates are superimposed to illustrate how data for a single season may be pooled. All six masks could be superimposed to show areas of assumed greatest plant activity for the entire August to March period. With all six masks superimposed, areas for which the ratio threshold was exceeded on all dates would correspond to habitats with greatest potential productivity and highest evapotranspiration. Areas where the threshold was never exceeded would represent relatively sterile habitats with least plant growth. The superimposed thematic masks provide a technique for synoptically assessing productivity.

The location of the five ground-truth stations is indicated in figures 6a through 6f (labeled in 6a only). In figure 8 foliar cover data for the five stations is given for the period from October 1972 to September 1973. The only station that fell within an area exceeding the ratio threshold was Mile Wide Road 1. This station lay within a masked area during cycles 12 and 14 when ground-truth data (fig. 8) show that plant coverage values reached approximately 50 and 70 percent, respectively. It appears that values equal to or less than 50 percent coverage are necessary for the area represented by the Mile Wide Road 1 data to be electronically sliced with the ratio set at 1.25/1.00. In addition, this minimum coverage value probably lies above 25 percent because this value, attained on 13 January 1973 (cycle 10), did not cause a response. Furthermore, the highest plant coverage value reached at any of the other ground-truth stations was also 25 percent and this was consistently too low to cause a response. From these observations, it is likely that the percentage cover corresponding to the 1.25/1.00 ratio threshold lies between 25 and 50 percent. This conclusion, based on field samples, is similar to the conclusion arrived at from the theoretical curves of figure 4.

Conclusions.--On the basis of six ERTS images covering three seasons the following conclusions regarding foliage cover measurements seem warranted. The seasonal flushes of dense plant growth can be followed by using MSS-5 and MSS-6 bulk images. Because of their unique phenology, desert areas, briefly covered by dense growths of ephemeral plants, are readily discerned, as are grassland, evergreen forest, and riparian communities. The ratioing procedure used detects foliage coverage values in excess of a threshold lying between 25 and 30 percent although the method is flexible with other coverage thresholds possible. Sterile habitats and habitats of varying degrees of productivity can be defined.

Work during next reporting period.--The foregoing discussion summarizes the accomplishments during the reporting period. Work during the next six months will center on three small areas within the Tucson Test Site. These study areas will be examined through use of large scale enlargements to determine the effectiveness of the ratioing process in following changes within relatively small areas including elongate riparian communities. A trip to Stanford Research Institute is contemplated for December or January. In the meantime, procedures established on previous visits will be used by the SRI scientists in analyzing the images. Grateful acknowledgment is given the scientists at SRI for their important contribution to this program.

Category designation: 1C, 1F, 7J.

e. Discussion of significant scientific results and their relationship to practical applications or operational problems including estimates of the cost benefits of any significant results.

On the basis of six cloud-free image pairs (MSS-5 and MSS-6), estimates of plant coverage over broad areas seem feasible. Seasonal changes in plant foliar cover are readily discerned. Dense cover of desert rangeland by ephemeral species was detected following a winter period of heavy rainfall. Dense cover within grassland areas was detected during the late summer to fall period when that community is active. The cycle of plant growth in riparian communities was followed through much of one season from summer leafy condition to winter deciduous state to spring foliation. Knowledge of the seasonal changes in plant volume may be used to pinpoint likely areas for grazing, to anticipate locust outbreak areas, to help identify plant communities, and to provide a basis for estimating productivity and evapotranspiration in plant communities.

f. A listing of published articles, and/or papers, preprints, in-house reports, abstracts of talks, that were released during the reporting period:

None

g. Recommendation concerning practical changes in operations, additional investigative effort, correlation of effort and/or results as related to a maximum utilization of the ERTS system:

None

h. A listing by date of any changes in Standing Order forms:

22 Mar 73, 22 Feb 73

i. ERTS Image Descriptor forms: N/A

j. Listing by date of any changed Data Request forms submitted to Goddard Space Flight Center/NDPF during the reporting period:

22 Mar 73 and 28 May 73

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Culler, R. C., Jones, J. E., and Turner, R. M., 1972, Quantitative relationship between reflectance and transpiration of phreatophytes—Gila River Test Site: 4th Annual Earth Resources Program Review, Natl. Aeronautics and Space Adm., v. 3, chap. 83, p. 1-9.

Billings, W. D., and Morris, Robert J., 1951, Reflections of visible and infrared radiation from leaves of different ecological groups: Am. Jour. of Botany, v. 38, p. 327-331.

Condit, H. R., 1970, The spectral reflectance of American soils: Photogrammetric Engineering, v. 36, p. 955-966.

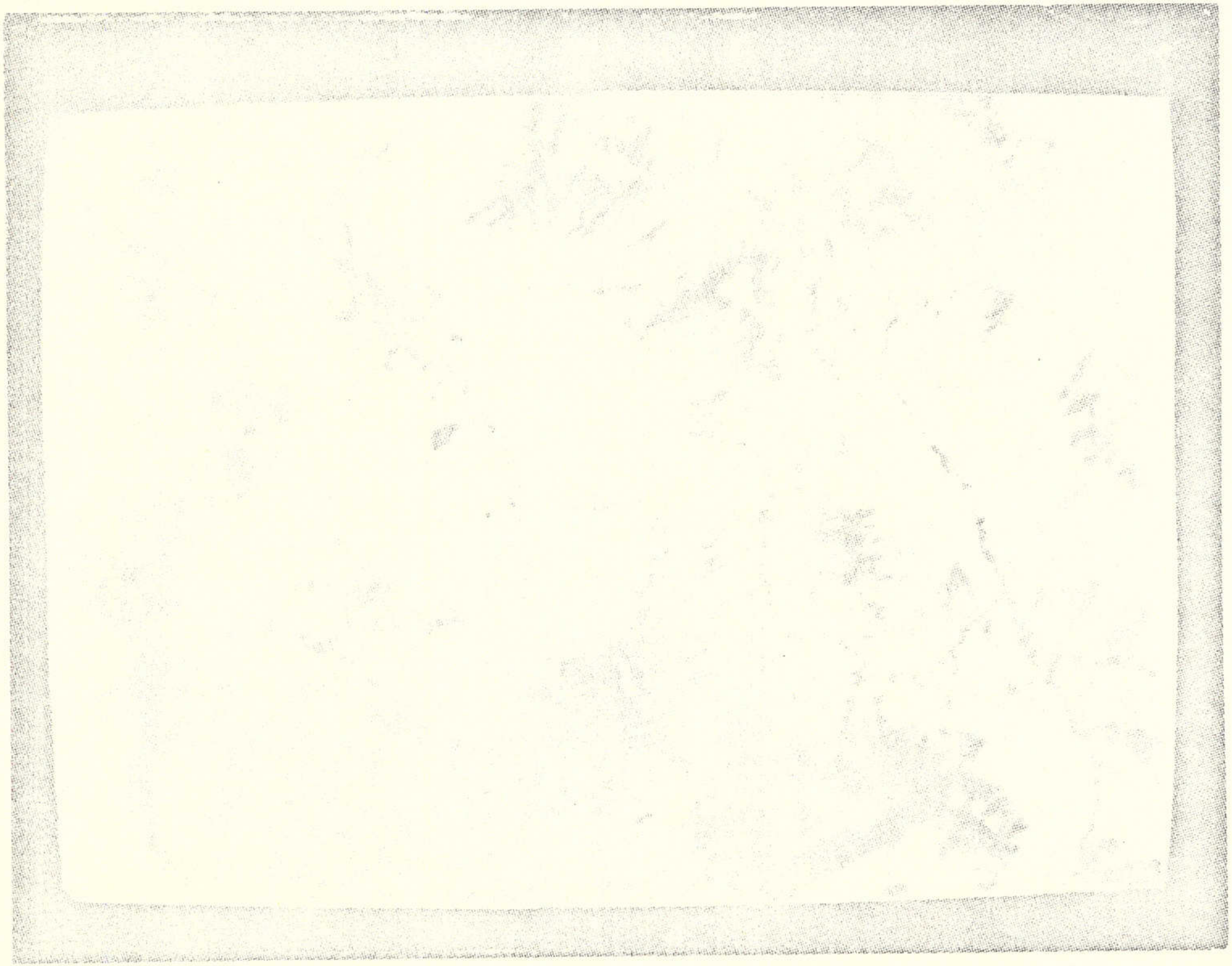

Figure 1.--Tucson Test Site as displayed on ESIAC television monitor (from ERTS image no. 1246-17283-5, March 26, 1973). Area viewed is 128 km by 176 km in size.

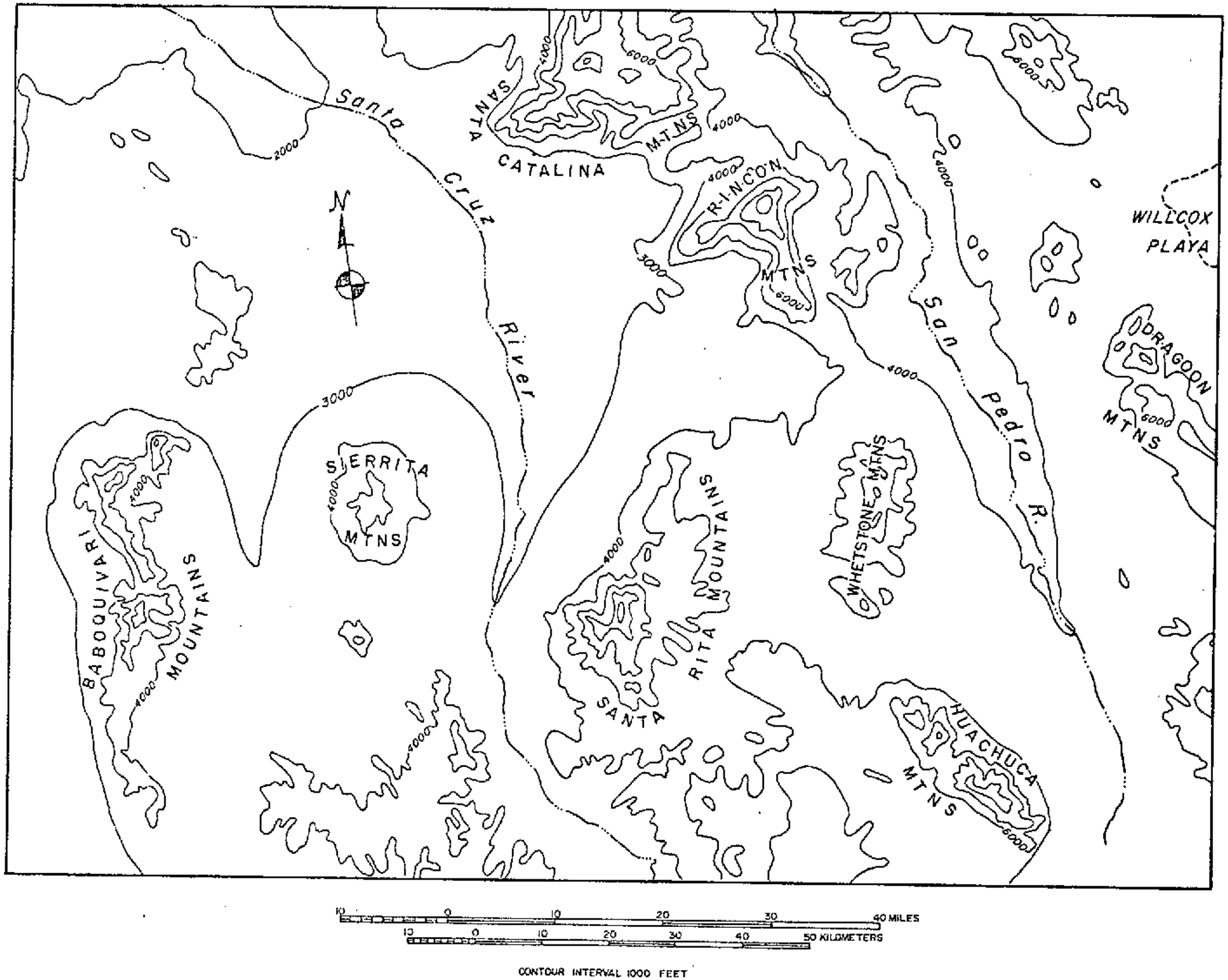

Figure 2.--Topographic map of Tucson Test Site.

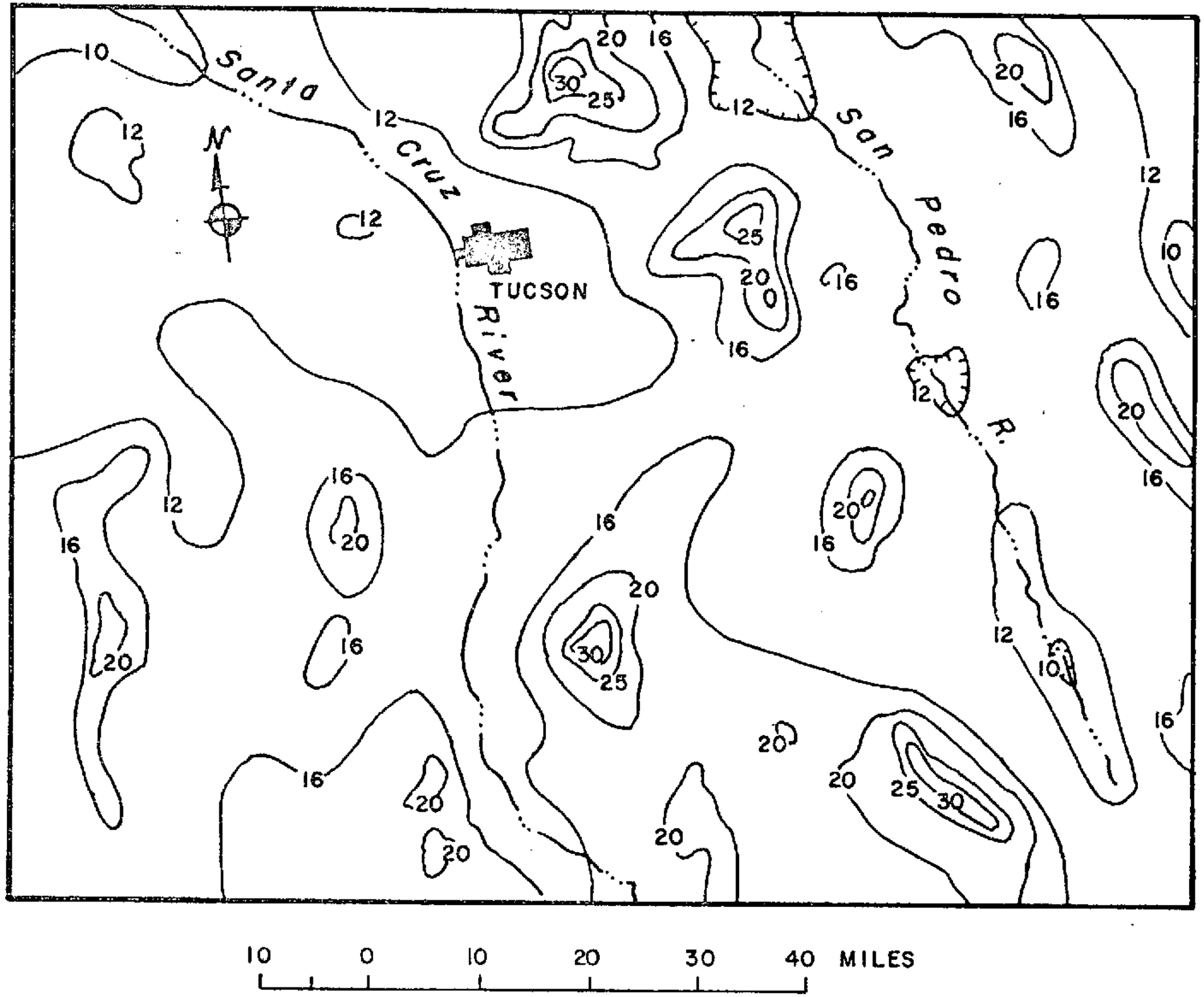

Figure 3.--Average annual precipitation (inches) of Tucson Test Site.

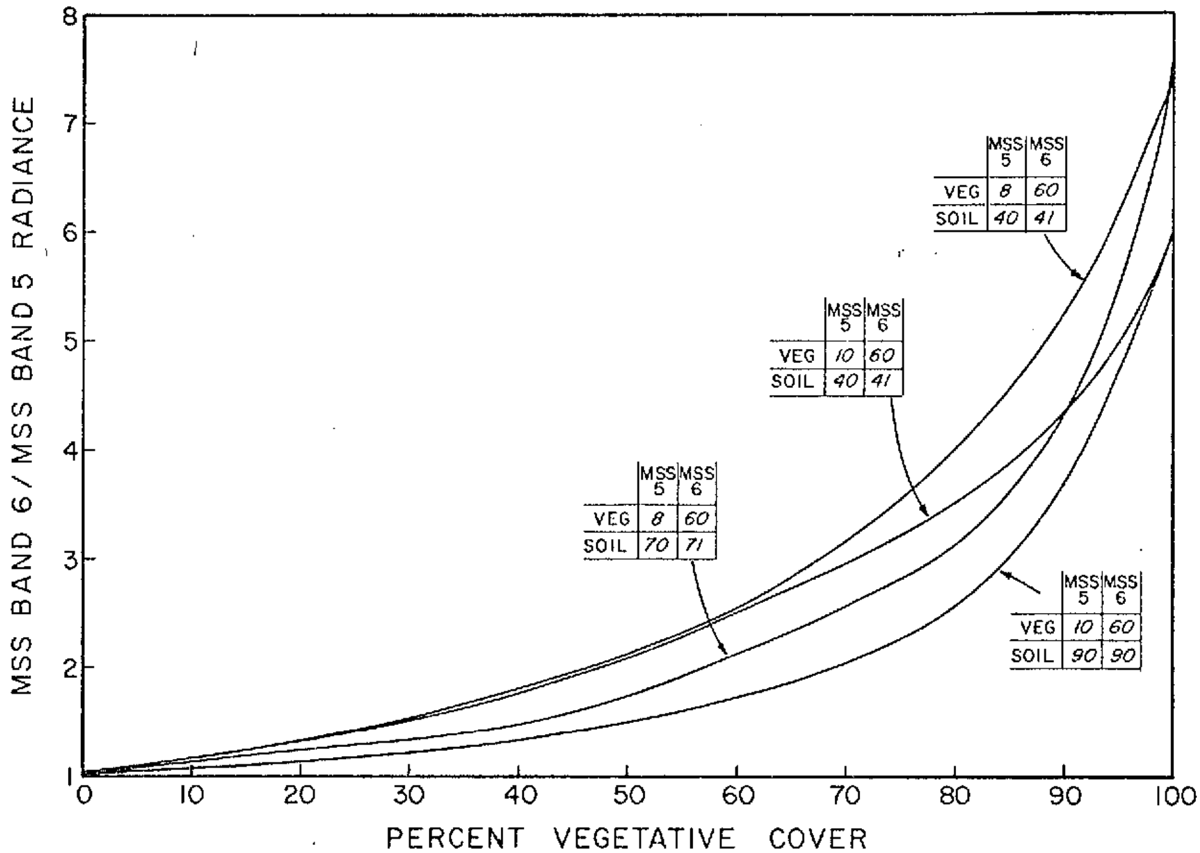

Figure 4.--Change in the ratio of MSS-6/MSS-5 radiance values with change in plant coverage. The four curves represent hypothetical combinations of soil and vegetation reflectances (as percent) in the two spectral bands represented by MSS-5 and MSS-6.

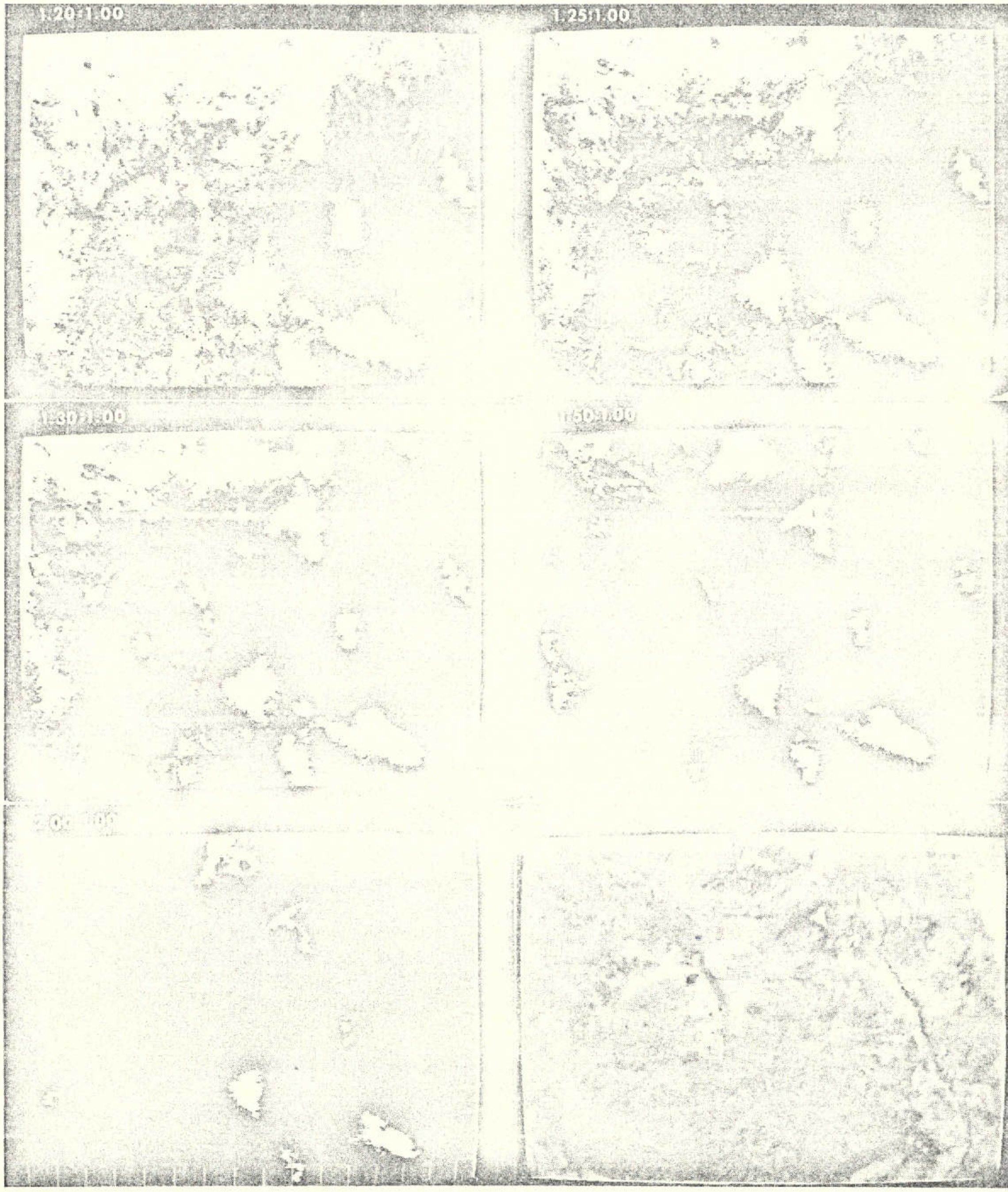

Figure 5.--Thematic masks representing five MSS-6/MSS-5 ratios from ERTS images of the Tucson Test Site for February 18, 1973 (image nos. 1210-17282-5 and -6). For comparison a view of the Test Site is shown at lower right (see fig. 1).

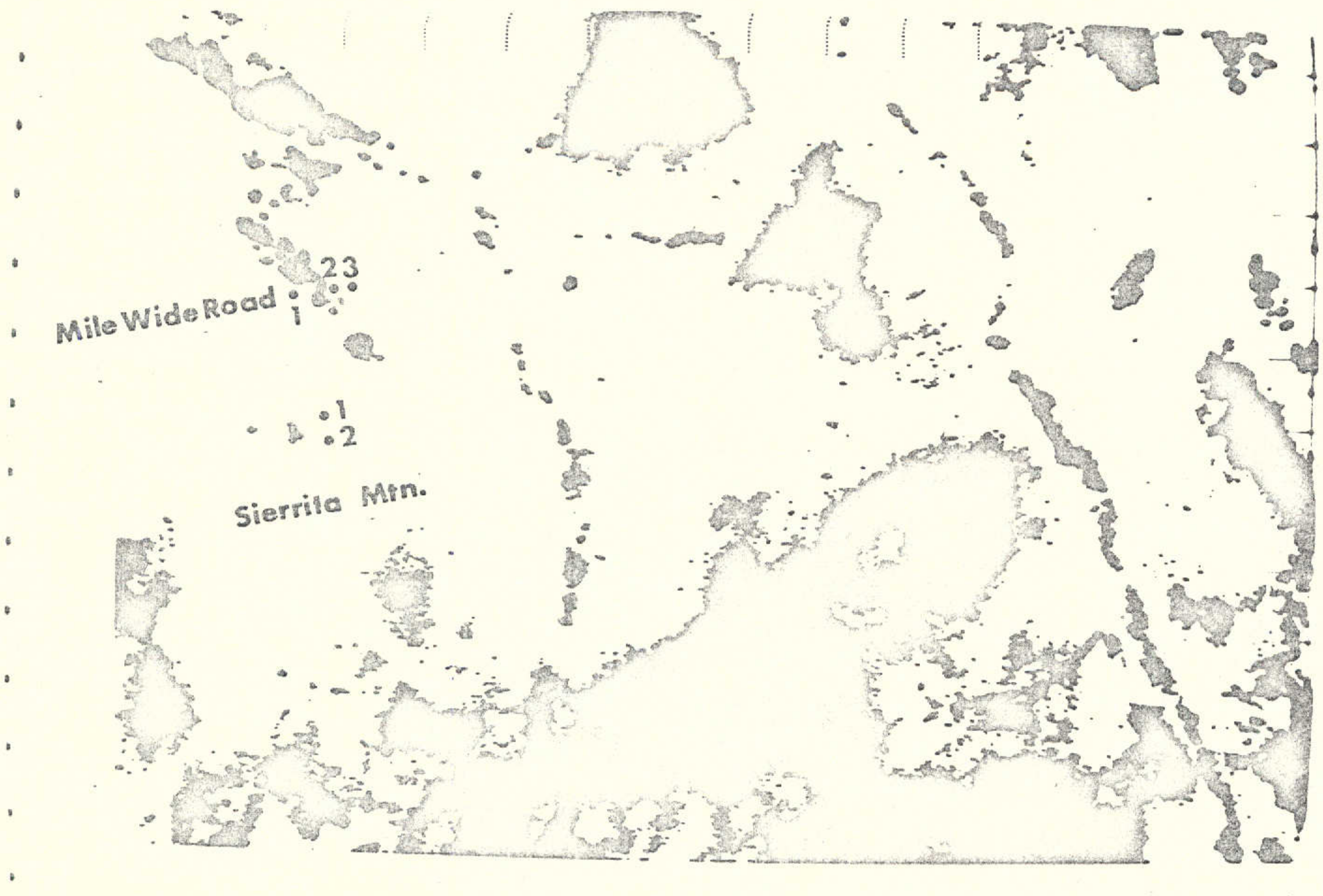

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Figure 6a.--Thematic mask of Tucson Test Site showing areas where MSS-6/MSS-5 $\geq$ 1.25/1.00. Location of five ground-truth stations shown in upper left. August 22, 1972.

Figure 6b.--Thematic mask of Tucson Test Site showing areas where MSS-6/MSS-5 $\geq$ 1.25/1.00. Location of five ground-truth stations shown in upper left (solid circles). November 2, 1972.

Figure 6c.--Thematic mask of Tucson Test Site showing areas where MSS-6/MSS-5 $\geq$ 1.25/1.00. Location of five ground-truth stations shown in upper left (solid circles). December 26, 1972.

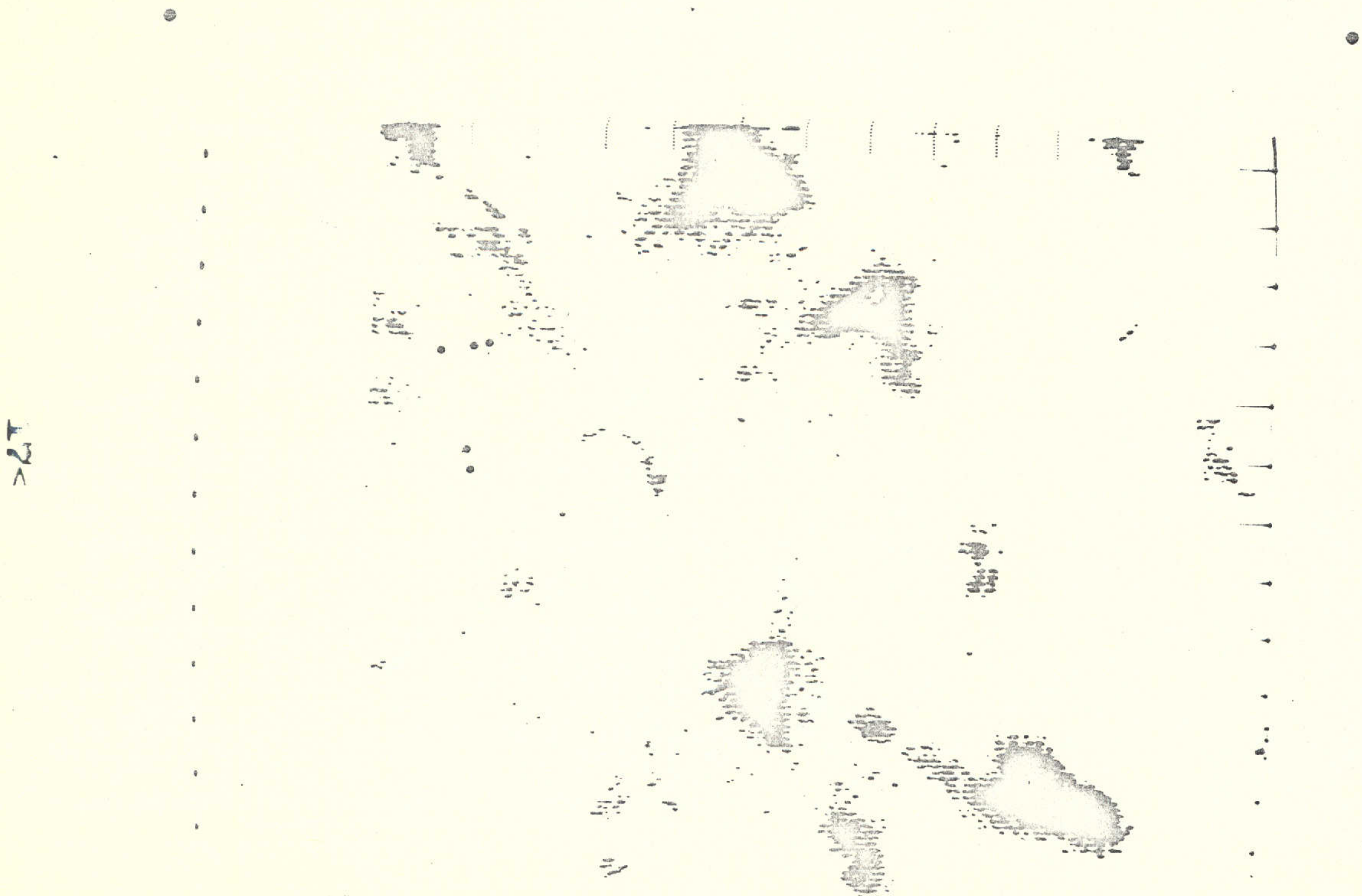

Figure 6d.--Thematic mask of Tucson Test Site showing areas where MSS-6/MSS-5 $\geq$ 1.25/1.00. Location of five ground-truth stations shown in upper left (solid circles). January 13, 1973.

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Figure 6e.--Thematic mask of Tucson Test Site showing areas where MSS-6/MSS-5 ≥ 1.25/1.00. Location of five ground-truth stations shown in upper left (solid circles). February 18, 1973.

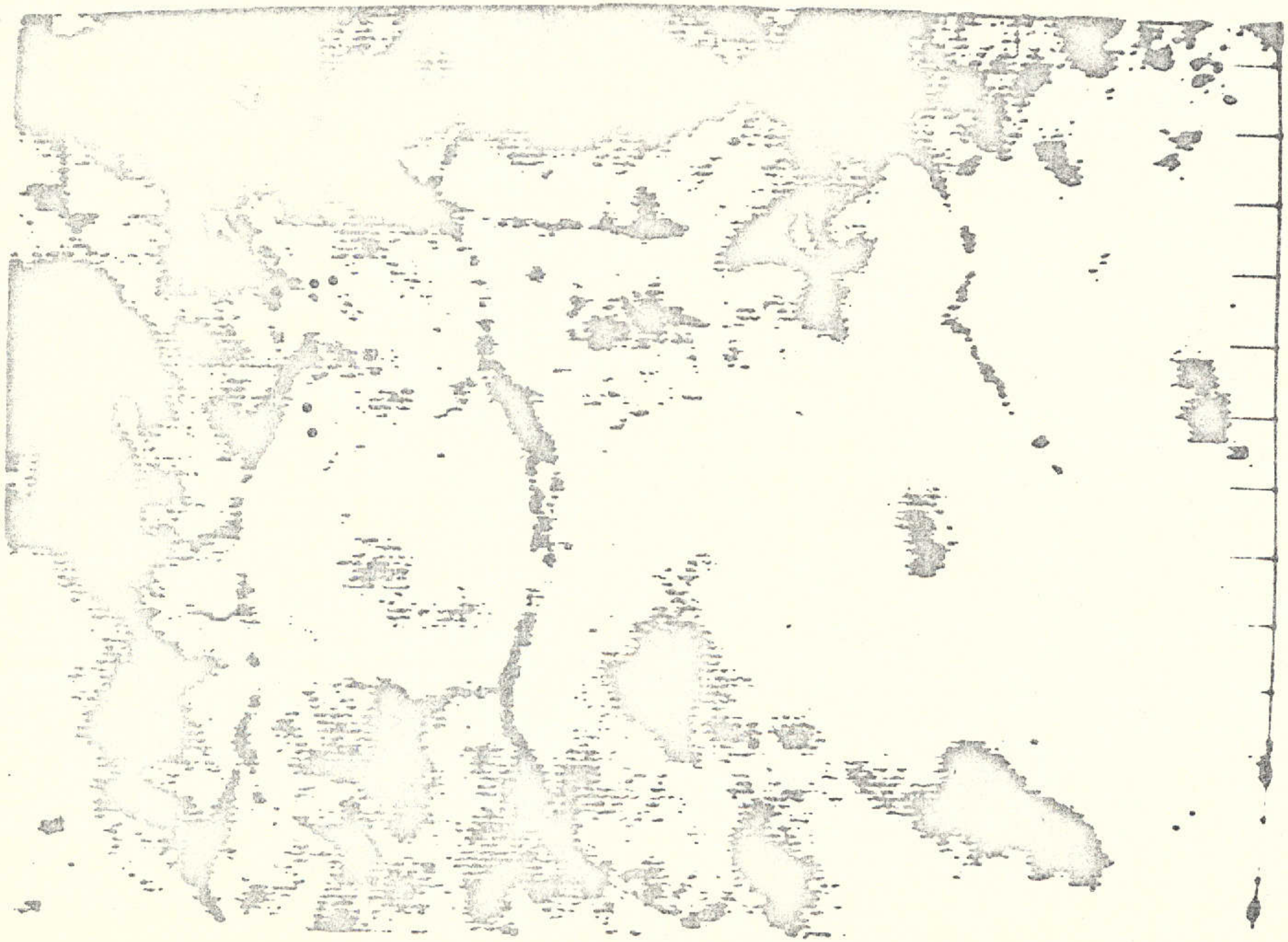

Figure 6f.--Thematic mask of Tucson Test Site showing areas where MSS-6/MSS-5 ≥ 1.25/1.00. Location of five ground-truth stations shown in upper left (solid circles). March 26, 1973.

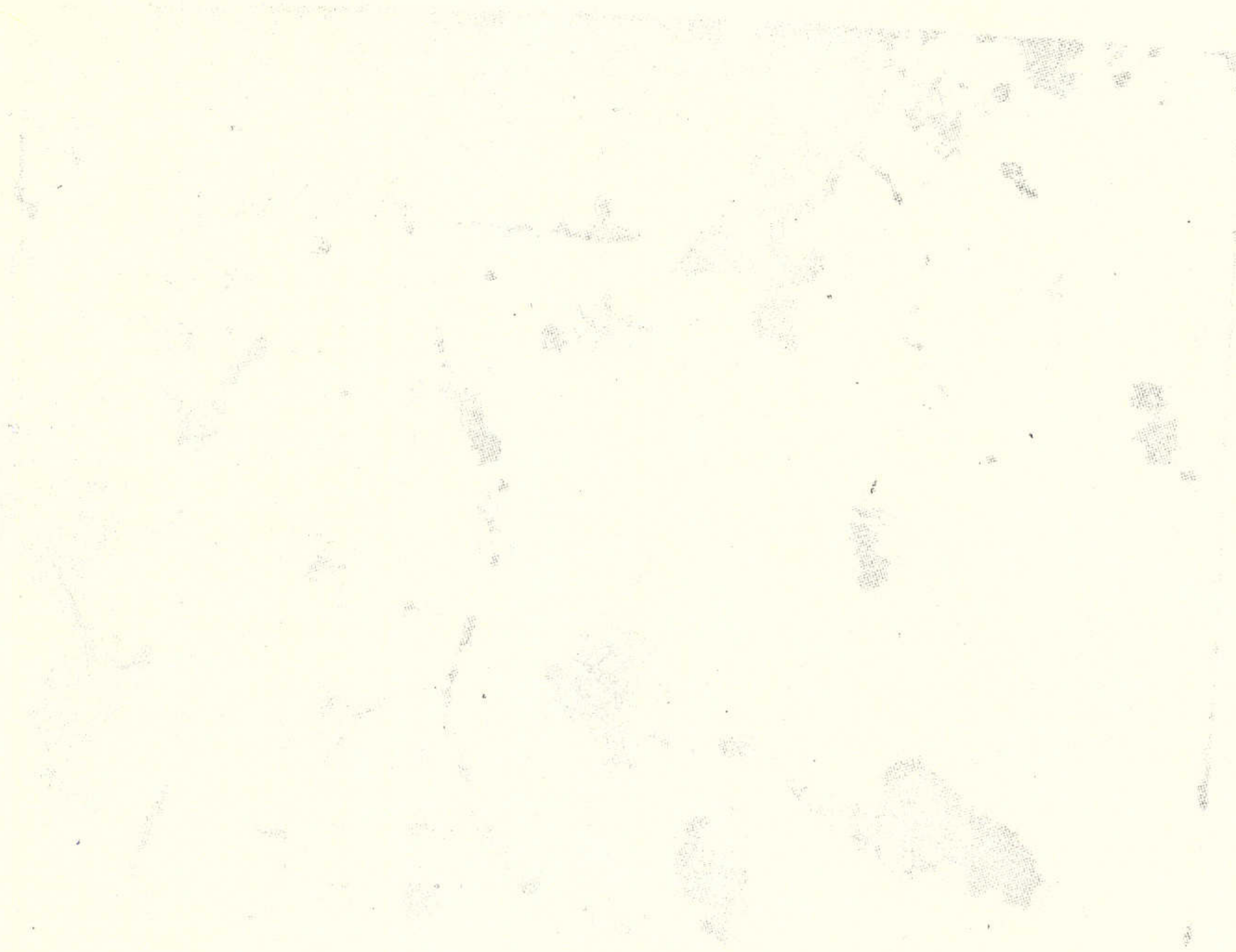

Figure 7.--Superimposed thematic masks for February 18, 1973, and March 26, 1973.

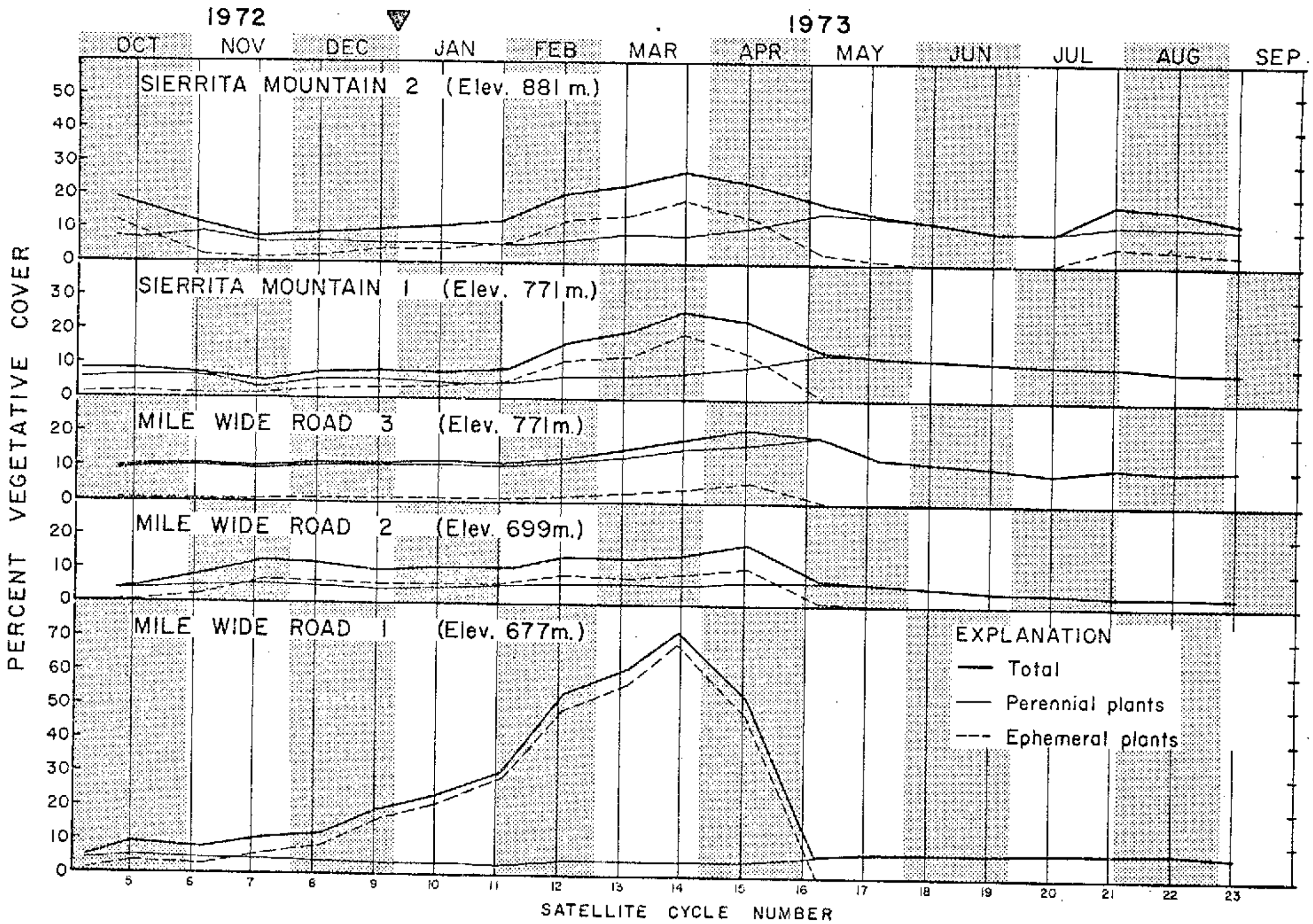

Figure 8.--Changes in vegetation cover at five stations, Tucson Test Site.