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A Simple and Inexpensive Method of Obtaining Low-Altitude Photographs of Vegetation Using a Tethered Balloon

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ABSTRACT — Simple and inexpensive methods of obtaining low-altitude photographs of vegetation (and other biological phenomena) are not widely known. In a study of spatial patterns of vegetation and disturbances in an oak savanna and woodland environment in Minnesota, we have used a camera attached to a tethered balloon to obtain photographs of areas ranging in size from 100 to 1000 m^2. The balloon used is an inexpensive off-the-shelf model (1.67 m diameter). The balloon has a net lift of approximately 1500 g when hydrogen is used as the inflation gas. A camera and a radio receiver are mounted on a gimbal suspended beneath the balloon. The shutter is controlled from the ground with a radio controller system used for model cars. Camera height and horizontal position are established by means of a tether line held by an operator on the ground. The system should work well in virtually any vegetation type except closed canopy forests. When combined with other conventional overhead and aerial photography systems, the balloon system can be an important part of an integrated system of aerial reconnaissance and mapping at multiple spatial scales.

Key words: Aerial photography, balloon photography, remote sensing, oak savanna, oak woodland

Remote sensing of vegetation yields a variety of benefits. These benefits include the ability to collect certain types of data more reliably and efficiently than on the ground (especially spatial patterns); and the acquisition of new insights as a result of seeing the landscape from a new perspective. However, in most instances, investigators have been limited to using either very high or very low vantage points to obtain overhead images of vegetation.

Typically, remote sensing of vegetation is conducted from satellites and aircraft (Colwell 1983, Campbell 1987). Images obtained from these vantage points enable the viewer to see spatial patterns with linear dimensions ranging from tens of meters to hundreds of kilometers. Despite the obvious advantages of such observation, there are problems and limitations with high altitude remote sensing. Generally, details of spatial patterns with linear dimensions less than 10 m are not clearly discernible, if visible at all, in high altitude imagery. The logistics involved in conducting high altitude remote sensing can be complicated, and finally, high altitude remote sensing is often costly.

Obtaining overhead images of very small vegetation plots (1m^2 or smaller) is relatively straightforward, and techniques have been described by several investigators (Wimbush et al. 1967, Pierce and Eddleman 1970, Wells 1971, Goodwin and Walker 1972, Ratcliff and Westfall 1973, Wein and Rencz 1976). In these instances, a camera (or two cameras for stereophotography) is attached to a frame and positioned approximately 1 m above the ground and over the plot. Goodwin and Walker (1972) and Owens et al. (1985) have attached a camera to a boom, thereby raising the vantage point to 7 m and similarly the size of the plot to approximately 14 m^2. In the majority of these studies, the primary objective was to record the species composition in the plots. The purpose of the overhead photography was to reduce time spent in the field by obtaining a photo record of the plot that could then be analyzed in the laboratory at a later date. An investigation of spatial pattern *per se* was not an objective of these studies.

Simple and low-cost methods of obtaining aerial photographs of intermediate-sized areas of vegetation (25-2500m^2) are not widely known. The development of simple, low-cost, low-altitude aerial imagery techniques would enable investigators studying vegetation patterns (as well as other biological phenomena) in this intermediate size range to reap the same kind of benefits as do those who use overhead imagery to study either much larger or much smaller patterns.

In a study of the spatial patterning of vegetation and disturbances in an oak savanna and woodland environment, we have used a camera attached to a tethered balloon to obtain photographs of areas ranging in size from 100 to 1000 m^2. The purpose of this paper is to describe this camera-balloon system, to illustrate the kinds of information it can yield, and to describe how it is being used in conjunction with other overhead and aerial photographic methods to map the spatial and temporal patterns of vegetation and disturbances in the oak woodland at several spatial scales.

STUDY SITE AND SYSTEM

The study site consists of 27 ha of sand plain oak savanna and woodland habitat located at the Cedar Creek Natural History Area in Bethel, MN. Aerial photographs dating back to 1938 indicate that, except for a 1-ha area which was abandoned more than 30 years ago, the study area has not been cultivated. Prior to the institution of controlled burning on the site in 1987, the area had not been burned since 1955. Bur oak, *Quercus macrocarpa*, and northern pin oak, *Q. ellipsoidalis*, are the dominant trees on the study site. Owing to the long absence of fire, a variety of understory trees and shrubs (hazel, cherry, seviceberry) are common under the oak canopy, and some have invaded the openings, which are dominated by prairie forbs and grasses.

Pocket gophers (*Geomys bursarius*) are common in the study area, principally in the openings. Data obtained from a 6-ha grid on the study site consisting of cells 10 x 10 m showed that gopher mounds are significantly more common in cells without trees than in cells with trees. However, not all areas within openings are equally disturbed. Gopher disturbances actually consist of a network of small disturbances made up of noted (mounds) and arcs (tunnels). Studies at Cedar Creek (Reichman and Smith 1985; Reichman 1988; Davis, Villinski, Banks, et al. 1991; Davis, Villinski, McAndrew et al. 1991) have shown that individual plants respond to the spatial variation within these networks. The rates of survivorship, growth, and reproduction of individuals of *Berteroa incana* (hoary alyssum) and *Penstemon grandiflorus* (large beardtongue) are dependent upon how close the plant is to a node or arc in the network (Reichman and Smith 1985, Reichman 1988, Davis, Villinski, Banks, et al. 1991, Davis, Villinski, McAndrew et al. 1991). Even though the survivorship of individual plants of *P. grandiflorus* is reduced when they are growing near a node or arc in the network, overall density of *P. grandiflorus* is higher in areas where gophers are active, probably because the bare soil provides germination sites (Davis, Villinski, Banks, et al. 1991; Davis, Villinski, McAndrew et al. 1991).

Thus, an understanding of the distribution and persistence of herbaceous plants like *P. grandiflorus* in the oak woodland requires knowledge of patch dynamics in the oak woodland occurring at several different spatial scales. For example, it is necessary to know the rate of mound production in areas where gophers are active since this determines the probability of an individual plant being buried (small area patch dynamics). It is also necessary to know how stable are the boundaries of gopher-disturbed areas since this determines the perimeter of favorable habitat for *Penstemon* (intermediate area patch dynamics). Finally, it is necessary to know how stable are the boundaries of the openings in the woodland since this determines the perimeter of favorable habitat for the gophers (large area patch dynamics).

PHOTOGRAPHY AND MAPPING AT DIFFERENT SPATIAL SCALES

The first step in establishing rates of boundary movement and patch formation at widely different spatial scales is to map the current positions of landscape features, boundaries, and patterns at the different spatial scales. Then, ongoing monitoring and subsequent mapping can be used to establish the temporal dynamics of the landscape. To make these maps, we are photographing the study site at altitudes ranging from 3-3400 m and creating the maps using ARC/INFO.

Very Low and High Altitude Photography via a Bipod and Fixed-Wing Aircraft

The smallest (<10 m^2) and largest (27 ha) areas are photographed using techniques similar to those commonly used in other studies. Photographs of the small plots (Fig. 1) are taken using a portable and adjustable bipod that can support a 35 mm camera up to 8 m above the

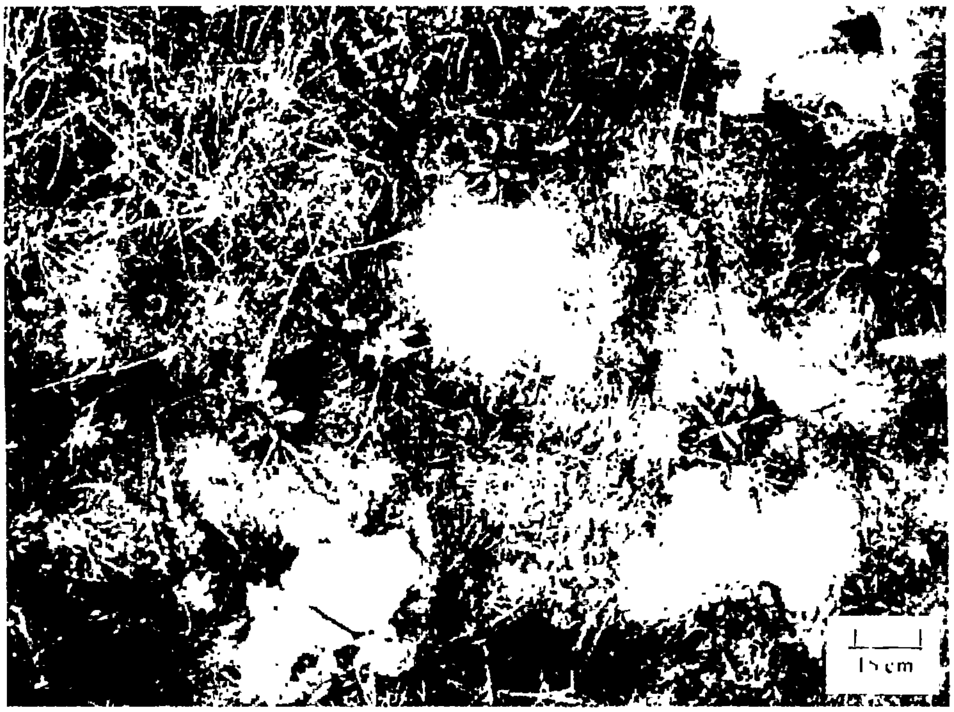

Figure 1. Photograph taken from a height of 3 m using the bipod described in the text. Visible are several *Penstemon grandiflorus* plants growing in sparse vegetation and in association with pocket gopher mounds. The photograph is a reproduction of a color print (Kodacolor 64).

ground. The bipod used is one modeled after Johnson (1979). Future monitoring of these plots will provide data on rate of mound production and longevity of mounds. The entire study site has been photographed from the air several times during the past 50 years by commercial photogrammetry firms, first in 1938 and most recently in 1988 (Fig. 2). These and similar future photographs taken from fixed-wing aircraft will provide data on the rate and direction of movement of the tree boundaries over time and of the longevity of individual openings in the woodland.

Low Altitude Photography Using a Tethered Balloon

Despite the valuable information obtainable from the bipod and fixed-wing aircraft, there are a variety of important landscape patterns and features that cannot be discerned from photographs obtained by either of these two methods. For example, the areas of high gopher activity cannot be distinguished in the high altitude photographs, and they are much too large to be included in the bipod photos. Thus, neither technique will be useful in monitoring changes in the locations of the boundaries of these patches. Similarly, neither technique can be used to moni-

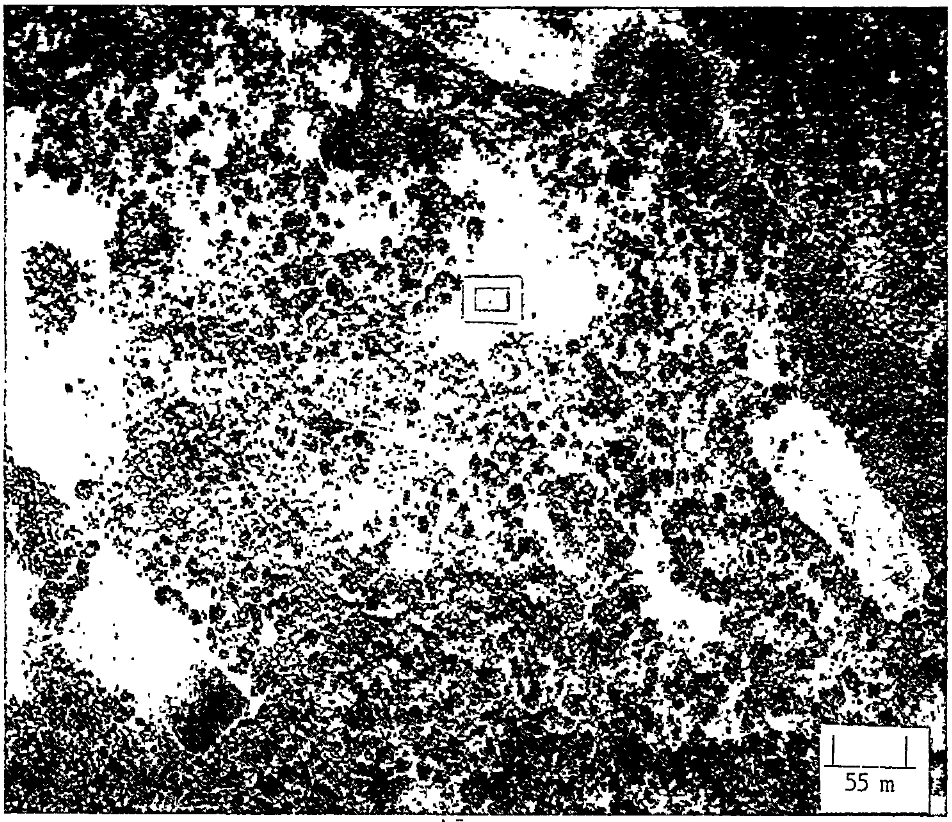

Figure 2. Photograph of the study area taken by Markhurd Corp. from an altitude of 3400 m using a precision 24-inch focal length mapping camera. The photo shown is a reproduction of a photograph taken using infrared sensitive film (Kodak 2443; 9x9 inch format). The location and area photographed using the tethered balloon (Fig. 6) is indicated by the small white square located in the lower portion of the large central opening.

tor the initial invasion of shrubs and small trees into openings. Neither technique can be used to produce photographs for mapping the locations and boundaries of small unburned and incompletely burned areas following a fire. Nor is either effective in monitoring changes in the boundaries of different herbaceous vegetation types, e.g., sparsely vs densely vegetated.

In order to obtain photographs of these intermediate-sized areas (100-2500 m^2), we have used a camera suspended from a tethered balloon (Figs. 3, 4). The balloon system developed for this study was modelled after balloon systems used to obtain low altitude photographs of archaeological sites (Whittlesey 1970, Johnson and Kase 1977, Johnson et al. 1990). The balloons typically used in these archaeological applications range in size from 20-23m^3, require 3-4 tanks (5.52 m^3 [195 ft^3]) of hydrogen gas for inflation, and support a heavy, large format camera. To

Figure 3. The fully inflated balloon and the camera-gimbal assembly just prior to release on tether in the Cedar Creek oak woodland.

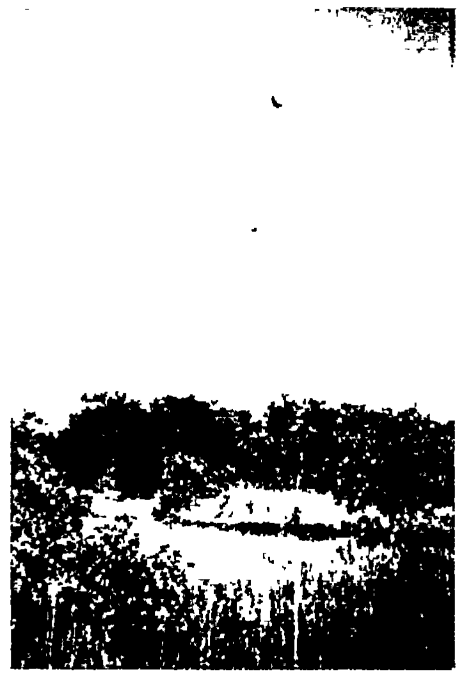

Figure 4. A few minutes after release, the balloon at an altitude of 40 m over the edge of the large central opening.

simplify and speed up the procedures and to reduce cost, we developed a scaled-down balloon system for this study.

The balloon used is an inexpensive off-the shelf model ($87.00 for six balloons, 1.67 m [5.5 ft] diameter, from Andon, Inc., 1230 E. 66th St., Richfield, MN 55423, 612-866-0353). The balloon inflates to 1.84 m^3 and has a net lift of approximately 1500 g when hydrogen is used as the inflation gas. Inflation of the balloon is accomplished by attaching a small length of plastic hose to the gas tank, inserting the other end of the hose into the balloon, squeezing the neck of the balloon tightly against the hose and turning on the gas. Inflation takes approximately 10-15 minutes. Following inflation, the neck of the balloon is inserted through a metal ring, folded back on itself and tied off with cord. The camera assembly (see below) is attached to the balloon by clipping it to the metal ring.

Either hydrogen or helium can be used to inflate the balloon. Helium may be somewhat safer, but provides approximately 10% less lift, and may not be readily available outside the United States. (Balloon photography of archaeological sites has used almost exclusively hydrogen systems.) Hydrogen, which is flammable, can be used safely with common sense, such as keeping the balloon away from open flames and sparks. A tank of hydrogen of the size previously described costs approximately $25.00 (1991) and contains enough gas for three inflations. A tank of helium of the same size costs $53.00.

Once the balloon is inflated, it can be held in the hand and easily moved from one location to another simply by walking with it. We have moved an inflated balloon several miles by sitting and holding it in the back of a pickup truck traveling at approximately 20-25 km/hr. The balloon need not be deflated following every use. Providing a safe and protected place is available (e.g., inside a shed or barn), the balloon can be moored until the next use. The balloon used in this study lost little of its gas after more than a week of mooring. If some lift is lost following mooring, a small amount of additional gas can be easily added to the balloon. Mooring the balloon in this way greatly increases the number of ascents possible from a single tank of gas. If hydrogen is used as the inflation gas, obvious safety precautions need to be taken during storage of an inflated balloon.

The camera and radio received are mounted on a gimbal suspended beneath the balloon (Fig. 5). The purpose of the gimbal is to keep the optical axis of the camera within a few degrees of vertical when the assembly is positioned over the site. As can be seen from the photograph, it is a simple device: the two outer frames are formed from aluminum bar stock and connected with small bolts that serve as the perpendicular axis system. The inner frame supports a small wooden platform on which are mounted the camera, radio receiver, and batteries. The different components are attached to the wooden platform with velcro attachments, which make it possible to adjust the positions of the different components in order to bring the entire system into vertical alignment.

Camera height and horizontal position are established by means of a tether line held by an operator on the ground. The balloon is positioned horizontally by walking with the tether until the camera is suspended above the required site location. If there is wind, the line will be at some angle to the vertical, and this must be taken into account for both the altitude and the horizontal location. Because the tether lines do not hang

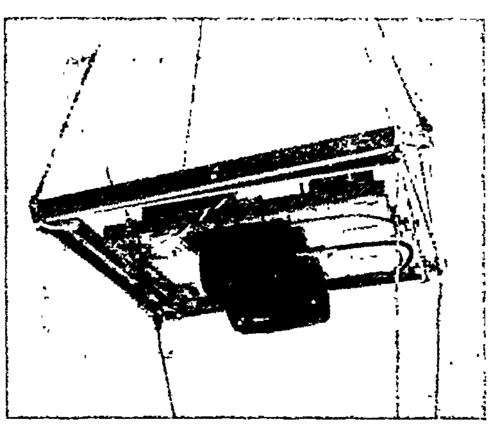

Figure 5. A closeup of the camera-gimbel assembly system showing how the camera, battery pack, and receiver are attached to the self-stabilizing platform.

completely vertical, one can only approximate the precise altitude of the balloon. In addition, it is difficult to see the exact orientation of the camera lens from the ground. Thus, it is usually necessary to take several photographs of the desired area or plot to ensure proper coverage.

A net lift of 1500 g limits the size and/or kind of camera that can be used with this system. (The gimbal assembly of the system described weighs 750 g.) An Agfa compact camera (255 g, 39-mm focal length, f/2.8 lens, with an automatic advance, and f-stop and shutter speed set automatically) is being used in this study, but there are many other compact 35-mm cameras that would work as well. The camera shutter is controlled from the ground by adapting a radio controller system used for model cars and boats. (Check with a local hobby store for available systems and frequency or use restrictions.) If the camera has an electronic shutter switch, a direct connection can be made from the receiver to the camera. A mechanical arm, activated by the receiver, can also be used to release the shutter. An infrared remote activation device (such as those sold as accessories with some cameras) could be used as well, although these may not be effective if the distance from the transmitter to receiver exceeds 50 m.

Operating the system in high or gusty winds is not recommended, primarily because of the difficulty of establishing a stable camera platform when the balloon is aloft. In certain environments, there is some risk that sudden wind gusts can occur even on otherwise still days. Such gusts would significantly destabilize the platform and potentially could damage the camera assembly if the balloon were near the ground when the gust occurred. We have not encountered any of these problems at Cedar Creek. The use of a second guide line can be helpful in stabilizing the camera platform and in positioning the assembly over the desired spot. Care must be taken with the attachment of all guide lines to the gimbal so that they do not get in the way of the lens. The use of high speed film (e.g., 400 ASA or higher) is another effective way of reducing the effect of an unstable camera platform.

The maximum altitude attainable by the system is primarily limited by the velocity of the wind and the weight of the tether line. The wind pushes the balloon away from the vertical, requiring more line to reach a desired altitude. As more line is paid out, the total mass lifted by the balloon increases, until the mass of the payload equals the lift of the balloon, at which point, no further increase in elevation is possible. Thus, to achieve higher altitudes, the system should be operated on calm days and/or with a lighter tether line. Although we have used only a single balloon in our system, it would be possible to attach two or more balloons to the gimbal-camera system, thereby increasing the lift. This would mean a heavier camera could be used and/or a higher altitude could be reached.

The choice of film type depends on the nature of the project. Color, black and white, and color infrared film all can be used. (The use of color infrared film typically requires the use of special filters.)

The use of ground targets is highly recommended, particularly in areas lacking distinctive vegetation or other landscape features. The targets will enable one to identify precise areas in a photograph and to indicate direction (e.g., a north arrow). Targets are also often the only reliable way to establish scale, since the exact altitude of the camera when each photograph is taken is usually not known. It should be noted that there are basic differences between a conventional topographic or planimetric map and an aerial photograph. Conventional maps are characterized by a constant scale, whereas scale on an aerial photograph will vary with ground elevation. The less relief in the area photographed the less will be the discrepancy between photograph and map, or alternatively, the higher the altitude at which the photograph is taken, the less the discrepancy. In addition, very wide angle lenses can create noticeable distortion at the edges of the photographs. This means that any measurements made near the photograph edges will be affected. Thus, any reference to the scale of a photograph taken with the balloon system should be considered as an average scale only.

With the ability to vary the altitude of the balloon, one can obtain photographs that differ by 1-2 orders of magnitude in terms of the level of resolution and linear extent of land included in the image, and by 2-4 orders of magnitude in terms of the area covered. Fig. 6 shows a photograph taken by the balloon system at an altitude of approximately 28 m. Clearly visible in the photograph are seven small *Q. marcrocarpa* saplings, the smallest of which has a canopy diameter of 30 cm.

Fig. 7 shows a map created from a photograph taken the day after a controlled burn in May 1990 at an altitude of approximately 17 m. The map illustrates a number of distinctive features of the oak woodland, including the concentration of gopher mounds in the openings, the association of dense herbaceous vegetation with trees, and the fact that gopher mounds can act as miniature fire breaks, resulting in small unburned patches of vegetation. Depending on weather and fuel conditions, these patches can be larger than those shown. In 1989, the gopher mounds in the same opening shown in Fig. 7 prevented the fire from burning a patch of vegetation 150 m^2 in size. Such small patches of unburned areas can be important for certain plant species. For example, fires that occur in the late spring on the study site have little effect on the survivorship of *P. grandiflorus* (Davis, Villinski, Banks, et al. 1991); however, they virtually eliminate all reproduction that year in this species (Davis, Villinski, McAndrew, et al. 1991). That is, fires eliminate reproduction in plants that are actually burned. Since this species is associated with bare soil, some plants may never experience a fire when one occurs, even though vegetation 1 m away may be burned completely.

Table 1 shows spatial data obtained from the map of the burned area (Fig. 7). Such data can be compared with data obtained from maps made from future aerial photos of the same area, permitting quantification of changes in boundaries and relative abundances of different patch types.

In summary, a balloon-mounted camera system such as the one

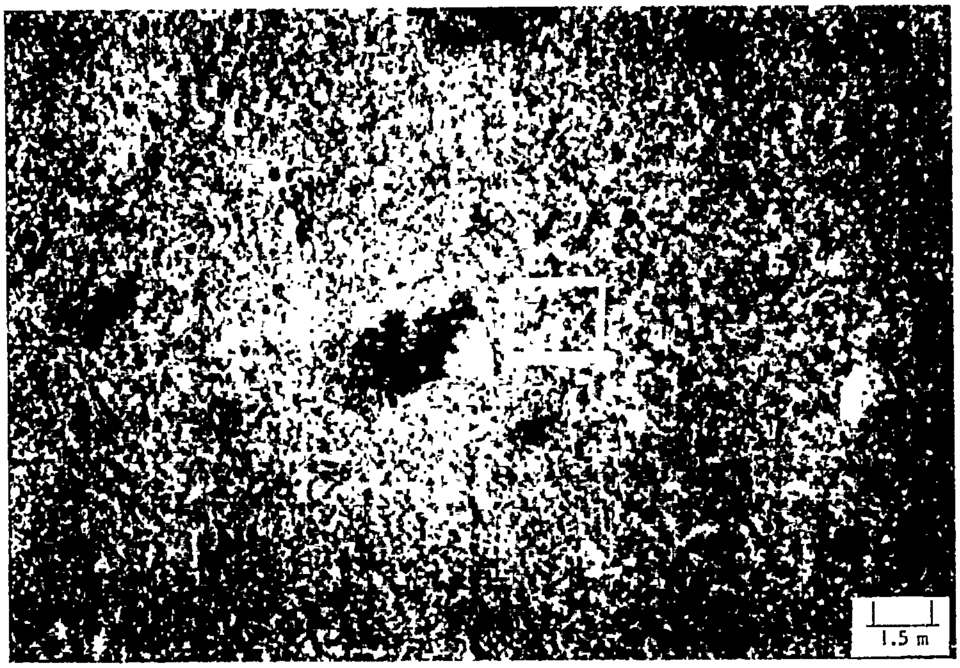

Figure 6. Photograph of part of the large central opening taken at an altitude of 28 m using the balloon system. The total area shown is approximately 450 m². The two white arrows shown are ground targets (1.22 m long) which are pointed north and which were placed 10 m apart on known coordinates of a ground grid system previously established at the study site. Also visible in the photograph are seven *Quercus macrocarpa* saplings and a person (lower left) who is activating the camera shutter using the radio remote control unit. The photograph is a reproduction of a color slide (Ektachrome 400). The location and area photographed using the bipod (Fig. 1) is shown by the white square.

described here can be used effectively to obtain low-altitude aerial photographs of vegetation (and other biological phenomena) at minimum cost. The system should work well in virtually any vegetation type except closed canopy forests. When combined with other conventional overhead and aerial photography systems, the balloon system can be an important part of an integrated system of aerial reconnaissance and mapping at multiple spatial scales.

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Table 1. Areas in m^2 (total, mean, maximum, and minimum) of different patch types at the edge of one of the woodland openings 24 hours following a burn in May 1990. Areas calculated using Arc/Info.

Patch Type	Total Area	Mean Area	Max. Area	Min. Area
Bare Soil (Gopher Mounds)	15.30	0.46	3.96	0.03
Unburned Vegetation	4.17	0.60	2.63	0.03
Trees	29.92	9.97	13.83	3.09
Sparse Herbaceous Vegetation	88.83	22.21	84.85	0.28
Dense Herbaceous Vegetation	84.12	16.82	40.44	0.10

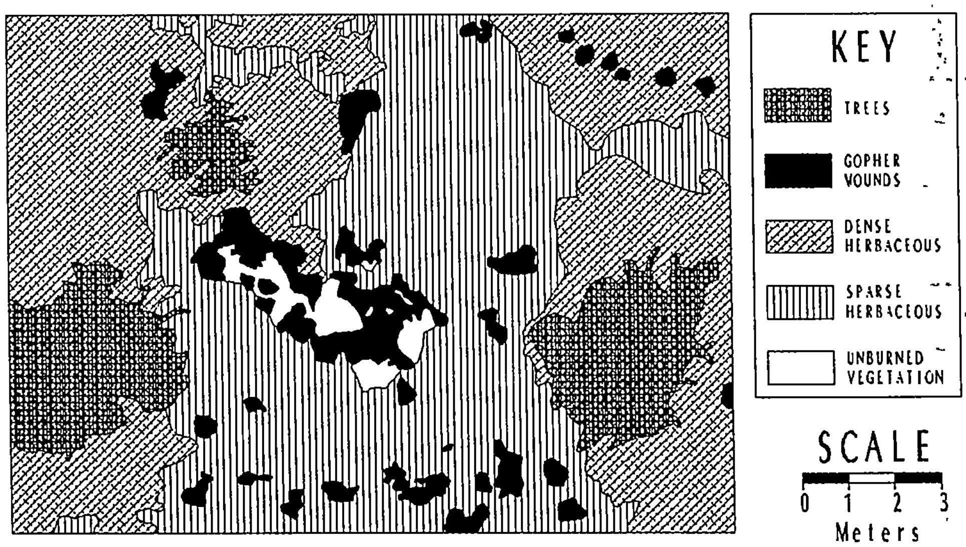

Figure 7. A map of the edge of one of the openings in the oak woodland made from a photograph taken 24 hours after a controlled burn. The photograph was taken at an altitude of 18 m using the balloon system. Map produced using Arc/Info.

LITERATURE CITED

Campbell, J. B. 1987. Introduction to remote sensing. The Guilford Press, New York.

Colwell, R. N., ed. 1983. Manual of remote sensing. American Society of Photogrammetry and Remote Sensing, Falls Church, VA.

Davis, M. A., J. Villinski, K. Banks, J. Buckman-Fifield, J. Dicus, and S. Hofmann. 1991. Combined effects of fire, mound-building by pocket gophers, root loss and plant size on growth and reproduction in *Penstemon grandiflorus.* Am. Midl. Nat. 125:150-161.

Davis, M. A., J. Villinski, S. McAndrew, H. Scholtz, and E. Young. 1991. Survivorship of *Penstemon grandiflorus* in an oak woodland: combined effects of fire, pocket gophers, and plant characteristics. Oecologia:86:113-118.

Goodwin, W. F., and J. Walker. 1972. Photographic recording of vegetation in regenerating woodland. Technical Communication No. 1. Woodland Ecology Unit, Commonwealth Scientific and Industrial Research Organizations, Canberra City, Australia.

Johnson, G. W. 1979. Close-range photogrammetry with a Whittlesey bipod. Proceedings of the American Society of Photogrammetry. 45th Annual Meeting, Washington, D.C. American Society of Photogrammetry, Falls Church, VA.

Johnson, G. W., and E. W. Kase. 1977. Mapping an ancient trade route with balloon photography. Photogramm. Engin. Rem. Sens. 43:1489-1493.

Johnson, G. W., W. L. Johnson, and D. E. Meisner. 1990. Aerial photography of the Nazca Lines. Pp. 271-283 *in* Lines of Nazca (A. Aveni, ed.). Memoirs of American Philosophical Society, Vol. 183. American Philosophical Society, Philadelphia.

Owens, M. K., H. G. Gardiner, and B. E. Norton. 1985. A photographic technique for repeated mapping of rangeland plant populations in permanent plots. J. Range Manage. 38:231-232.

Pierce, W. R., and L. F. Eddleman. 1970. A field stereophotographic technique for range vegetation analysis. J. Range Manage. 23:218-220.

Ratliff, R. D., and S. E. Westfall. 1973. A simple stereographic technique for analyzing small plots. J. Range Manage. 26:147-148.

Reichman, O. J. 1988. Comparison of the effects of crowding and pocket gopher disturbance on mortality, growth and seed production of *Berteroa incana.* Am. Midl. Nat. 120:58-69.

Reichman, O. J., and S. C. Smith. 1985. Impact of pocket gopher burrows on overlying vegetation. J. Mammal. 66:720-725.

Wein, R. W., and A. N. Rencz. 1976. Plant cover and standing crop sampling procedures for the Canadian High Arctic. Arct. Alp. Res. 8:139-150.

Wells, K. F., 1971. Measuring vegetation changes on fixed quadrats by vertical ground stereo-photography. J. Range Manage. 24:233-236.

Whittlesey, J. H. 1970. Tethered balloon for archaeological photos. Photogramm. Engin. 36:181-186.

Wimbush, D. J., M. D. Barrow, and A. B. Costin. 1967. Color stereophotography for the measurement of vegetation. Ecology 48:150-152.

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