PACIFIC SOUTHWEST
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Experiment Station

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MICROCOPYING WILDLAND MAPS FOR DISTRIBUTION AND SCANNER DIGITIZING

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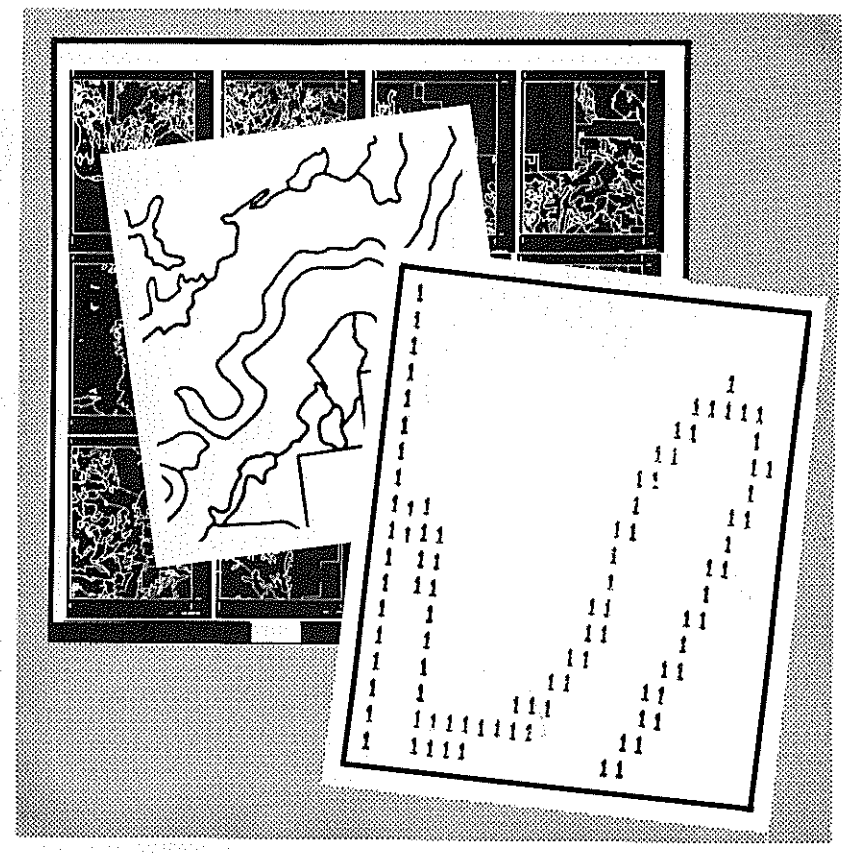

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SUMMARY

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Maps for wildland resource inventory and management purposes typically show vegetation types, soils, and other areal information. For field work, maps must be large-scale. For safekeeping and compact storage, however, they can be reduced onto film, ready to be enlarged on demand by office viewers. By meeting certain simple requirements, film images are potential input to computer-mapping systems.

Microform is a collective term for reduced images called microimages, stored on transparent or opaque stock. Two popular microforms are microfilms and microfiche. A variety of form sizes and image reductions complicates selection of films for maps and text. Both maps and page-size text must be accommodated to obtain the savings possible from joint use of the same equipment.

In a study of current literature on microcopying, several competing types of microforms were considered. Among the several, only roll microfilm and microfiche were judged acceptable for application to wildland maps. Each alternative should be considered in the light of the likelihood of its becoming widely available and standardized, suitability for automatic scanning, cost for film storage and reproduction, quality of projection equipment, and archival durability. The widespread popularity of roll microfilm stems mainly from the fact that standardized film and projection equipment abound. Although microfiche is less widely used, it may in time grow in importance relative to other microforms.

With the choice narrowed to two basic forms, the next step is to match the most common resource map sizes to a few film formats. About 50 combinations are available if only a few reductions, map sizes, and film formats are selected. The number of possibilities is much greater if the marked variation in map size by latitude is used to calculate microimage sizes. Allowing for the extreme case, i.e., all contiguous United States, a standard double-frame 35-mm microfilm at a twenty-fourfold reduction (abbreviated 24X) will serve all purposes. Microfiche alternatives are more complex. At low reduction ratios, either nonstandard formats are necessary or maps must be sectioned in one of several ways.

The smaller the microimage the more important the film for a given resolution. Four types of microfilm were investigated: silver halide, diazo, vesicular, and color. Silver film is the most common and only one to meet archival standards. Diazo is the most economical of all for numerous distribution copies. Neither vesicular nor color film have marked advantages over the other two and were excluded from scanning experiments.

Ocular viewing of map microimages is far less demanding than digital conversion by a scanning microdensitometer. Variable widths or uneven line densities, which are visually tolerable, increase the cost of computer input. Consequently, the resolving power of silver and diazo microfilms was measured by scanning the U.S. National Bureau of Standard's Microcopy Resolution Test Chart 1963-A. The results reflected the characteristics of the scanning microdensitometer more than the film properties for a given line width and resolution. Test scans ranged from intervals of 2 μm to 12 μm. Despite the complications introduced by scanner mechanisms, it seems evident that 24X is the limit for fine lines (0.01 inch or 0.25 mm). A reduction of 42X is attainable only if exceptional environmental conditions are provided. An economic choice will probably be 24X reduction onto microfiche or roll microfilm for most users.

Most wildland users are familiar with maps produced by the U.S. Geological Survey. The USGS produces large-scale topographic maps at a representative fraction (RF) of 1:24,000. Forest resource maps are often enlargements of them, and a typical township map at 4 inches per mile (RF 1:15,840) requires a 30-inch square sheet of paper (6 sq. ft.). In California, several thousand of these large-scale maps are used on the National Forests for timber resource management each year. Such large maps are needed for sketching in plot locations or logging operations and general field work. But in the office, a small map would save space and still be useful for measurement and general reference.

Technology is available to greatly reduce the awkwardness of handling maps. Various types of microforms were brought into practical use more than 30 years ago (Veaner 1971). Almost all equipment is designed for page-size material—the most common input. An important exception is a decade-old development—computer-output-microfilm (COM). In this automated process, paper is eliminated by directly writing on film. Another recent innovation is the use of color—despite its cost and low resolution.

Microform is a collective term for storing micro-images, generally on fine grain film (U.S. Dep. of Commerce 1969). A well-known form is microfilm, widely available in 16- and 35-mm rolls. Another important form is microfiche, in which images in a grid pattern are recorded on a short length of wide (105 mm) film. Only these two forms are considered here.

Not discussed are methods of handling microfilm, forms intended primarily for library cataloging (micro-opaques), storage/retrieval apparatus, or software. Reduction ratios greater than 48:1 (48X) are excluded in our study because separate equipment would be required for text and map material.

Can microform technology be extended from text to maps? It would be uneconomic to use microforms just for maps. But once the setup cost is incurred to distribute and enlarge microforms, then the added cost of a special use is relatively small. Moreover, benefits will be greatest when microform technology can be applied to map data without substantially changing existing procedures. Selecting the best method for microfilming maps for ocular use requires only a general understanding of microforms. Additional facts are required if the images are to be automatically digitized for input to computer-mapping systems.

This report describes a study of microcopying techniques for processing wildland maps for distribution and for digitizing. The application of microfilm and microfiche to map processing is described.

MICROIMAGE DIGITIZING

Automatic Digitzing is Required

A decade ago, input to computer-mapping systems was prepared by using paper and pencil. As a step toward automation, the pencil was replaced by recording coordinates on magnetic tape. With either method a large map format is necessary. Microcopying would reduce map storage cost, but this gain would be offset later by enlargement to the map's original size. Hard copy could be avoided if the microimage were projected from the rear onto a translucent screen. The saving of paper is attained at the additional cost of optics and mechanical linkage in the digitizer hardware. Clearly, manual line tracing is not materially assisted by reducing maps onto film.

Two new methods of digitizing maps—automatic line following and scanning—require a microimage. Unlike manual line tracing, both methods allow only lines; it is necessary to record all other map details on a separate layer or in a color which the film cannot detect. Automatic line following is done under computer control with an operator deciding the digitizing sequence when ambiguities occur. The method is being tested on census data, but has not as yet proved suitable for digitizing forest maps (Amidon 1974).

Automatic scanning collects optical densities or "gray levels" at successive intervals on the micro-image by using a microdensitometer. Major application areas are in medicine and aerial photography. The grey levels are input to pattern recognition computer programs. The scanning equipment is useful for the simpler problem of map digitizing in which the grey levels are divided into two groups: lines and background. The success of this approach depends heavily on the preparation of the original maps. Extraneous details, shading or dust can complicate this basically simple binary discrimination.

An Operational Scanning System

The Wildland Resource Information System (WRIS) routinely processes several hundred maps each year (Russell and others 1975). The system relies on automatic scanning, although simple maps can be digitized manually. National Forest maps of timber types, land-use categories, and administrative boundaries are drawn on stable plastic with ink lines ideally 1.2 mm wide. Each map is reduced 10X onto a 4- by 6-inch copy negative and scanned with a spacing and aperture of about 40 (formerly 60) μm. Computation cost is almost directly related to the number of density readings. A finer spacing decreases the manual labor in computer image editing, but increases scanning and computer time. The trade-off is an economic decision, subject to the threshold imposed by resolution limitations.

Automatic digitizers with a comb (one-directional) scanning pattern are faster with smaller images because nonfunctional time intervals between lines, while the stage is returning, are shortened. In using a Photometric Data Systems PDS 1010 microdensitometer,[1] we have saved 4 to 5 hours for a 1¼ million-point scan by going from a 10X to a 20X reduction. For other digitizers the gain will be less because the scanning paths, such as spiral or boustrophedonic (two-directional as in plowing), were designed to minimize nonfunctional time. If the recording rate is kept constant, digitizing time will vary directly with the area scanned.

Aside from digitizing time, the principal gain from increased image reduction is reduced storage space, with a tenfold reduction easily obtainable. Other advantages are not attributable just to micrographics but to microforms in general and to COM in particular.

PREFERRED MICROFORMS AND STORAGE METHODS

Microfiche and Roll Microfilm

Even with the microform field narrowed to two types—microfilm rolls and microfiche—there are still important choices.

Microfilm (35 mm) has rectangular frames, either single or double (1 or 2 pages). Frames can be positioned in two ways on the film. In *cine* orientation, the sides of the image are parallel to the long edge of the film. In strip orientation, the top and bottom of the image are parallel to the long edge of the film. This arrangement is also called *comic,* because frames are side-by-side on the roll.

Microfiche sizes and formats vary widely, but in recent years certain forms have become dominant. The microfiche considered here are limited to 105- by 148.75-mm or roughly 4- by 6-inch negatives or positive transparencies. A fiche has an identifying header, about ½ inch wide along the top edge, with room for one to three lines of titling. Color stripes may be placed behind the header as selection keys. Below the header, which is legible without magnification, are rows and columns of frames. Any single frame may contain a few eye-legible characters but most hold data unreadable without magnification.

Frame sizes vary, and therefore, the number of images per fiche is not standard. Recent trends in government use, particularly defense documentation, suggest consideration of just two frame sizes and four reduction factors. Since a frame can be single or double, there are 16 possibilities for microfiche in addition to the 8 for microfilm. As we explain later, matching conventional map sizes and reduction factors results in just a few alternatives.

Serial and Random Storage

Data on 35-mm film can be stored either sequentially or randomly, but not by the same equipment. High-speed serial searches are possible with motor-driven reels. At the opposite extreme microfilm can be handled as short strips stored in jackets or even singly in aperture cards.

Microfiche is a compromise between serial and random storage. Depending on the frame size selected, each fiche can store from 1 to 60 single-page images at 20X or 1 to 98 images at 24X. These are commercially available, popular reduction ratios. Computer-controlled writing in single frames and at 48X allows 270 frames on a 4- by 6-inch fiche. These are conservative reductions. Books are available at 75X, and ultrafiche is defined as more than 90X. Libraries can purchase 3- by 5-inch fiche with 1000

[1] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

images in a 50-by-20 matrix. One ultrafiche format accommodates 3280 pages of 8½- by 11-inch original size at 150X on a single 4- by 6-inch fiche (National Microfilm Assoc. 1973). At such high densities, the distinction between sequential and random storage methods, i.e., by reels and fiche, starts to blur.

SELECTION OF MICROFORM FORMATS FOR MAPS

Page-size Material Determines Choices

Reducing page-size documents usually involves few decisions because the process has already been designed for this purpose. There is abundant information available on the advantages of microfilming conventional text material. Major factors to be considered are space savings, suitability for reproduction, amount of use, availability of viewing and copying machinery, and preservation of materials (Lynden 1975). Despite decades of experience with microphotography, the use of microforms is still largely directed toward libraries. There is a tendency to identify microfilms "as substitutes for crumbling and unwieldly volumes of newspapers and for out-of-print material not available elsewhere" (Salmon 1974, p. 194). This retrospective viewpoint is a hindrance to the effective use of microfiche. Certainly there is a need for preserving and reissuing rare or fragile works and for general maintenance of research libraries. Yet microforms are not restricted to archival purposes.

The greatest growth potential lies in the direction of original publication on microform—particularly microfiche. The gain is achieved by adapting text composition to micropublication technology, which is the opposite of past practice. The principal advantage for publishers is a negligible inventory because copies are made on demand. Users benefit not only from lower storage and distribution costs, but also by selecting only those fiche containing desired chapters or sections of a set of volumes.

The publication of technical reports and periodicals on microforms is growing in popularity. Options include roll film or microfiche available separately or in addition to the paper copy. A notable exception is a periodical of interest to wildlife resource managers, "Wildlife Disease." Individual articles are not available on paper but only on 60-frame microfiche and occasionally in color (Presidente and others 1974).

The most recent development in the use of microforms as a medium of original publication is the substitution of film for paper. Text material is assembled and revised by computer programs and stored on magnetic tape. Instructions on the tape control electronic writing on film at 32,000 lines per minute. This rate is at least 15 times faster than an impact printer (National Microfilm Assoc. 1974). A study of COM use by the U.S. General Accounting Office showed that conversion of reports to microfilm at eight federal installations would save $1 million annually (Comptroller General of the U.S. 1974).

COM is suitable for dynamic applications requiring frequent updating such as directories, parts lists, and catalogs. An excellent example is maintenance of computer system documentation which requires frequent, scattered changes. At the Lawrence Berkeley Laboratory, Berkeley, Calif., over 2000 pages of system documentation are available to any user on 11 microfiche at 48X for a setup cost of about $25. Most of this cost is due to the labor of determining which files are current and updating the request program accordingly. Each additional set of silver halide microfiche produced under computer control costs about $5. For sets of 50 or more, it is more economical to make diazo copies.

Forest Map Sizes

Since maps are usually larger than text pages—the size for which most equipment is intended—the reduction ratio must be greater for maps than text to fit within a microform frame. Excess reduction will deteriorate resolution to the point where map details become illegible. Some maps cannot be reduced directly to one frame. They must be either sectioned or reduced to an intermediate negative, with loss of detail inevitable.

Theoretically a township is square—each side is 6 miles on the ground or 2 feet on a map at a representative fraction of 1:15,840. But few townships actually are square. Township shapes vary considerably, and a microform frame must be selected to cover all possibilities. This variation requires an extensive advance search and measurement of all irregular townships—a major inconvenience. Instead, an allowance for some distortion can be specified in advance, with occasional exceptions handled by sectioning. Lineal distortions of up to 30 percent could be tolerated with double-frame, 48X COSATI (Council on Scientific and Technical Information) microfiche. Single-frame 35-mm microfilm (48X) has enough extra space to accommodate slightly greater distortion. Allowing for a 40 to 50 percent waste of film space essentially defeats the microimage approach.

The systematic approach offered by all mathematical projections is almost a necessity to gain any advantage from miniaturization. Although many map sizes and scales are available, some variation of the USGS 7½′ quadrangle is generally used. Instructions for making polyconic projections at selected scales, in the contiguous United States, are readily available (U.S. Geological Survey 1964). We limit ourselves to the familiar 7½′ maps, and the two RF's of 1:24,000 (2.64 inches per mile) and 1:31,680 (2 inches per mile). An RF of 1:15,840 (4 inches per mile) is not considered both because it usually occurs in a township format, and it is an awkward size for a quadrangle (about 35 inches, in longest direction).

Quadrangle widths get narrower as latitude increases (*table 1*). It must be decided in advance of filming whether coverage will be statewide, regional or national. For example, at latitude 42 degrees and greater as in Oregon and Washington, a 7½′ 1:24,000-scale map can be reduced 24 times onto a single frame of 35-mm film. But a double-frame format would be needed to cover all quadrangles in the continental United States.

The final step is to calculate quadrangle dimensions at commercially available reductions and see if the map "rectangle" will be accommodated by the microform frame.

Reduction Ratios

For each map scale there are 24 possible microimage recording layouts; the product of four reduction ratios and six microformats. The 24X and 48X reductions should be favored, if possible, because their use should increase after recent standardization efforts. In 1971, the Council on Scientific and Technical Information (COSATI) voted to drop 20X in favor of 24X. The Department of Defense (DOD) changed from 42X to 48X, gaining 62 frames, for a total of 270 page-size frames per 4- by 6-inch fiche under computer control (Gordon 1971). Despite these changes, both 20X and 42X systems continue to be widely used in business applications. Therefore they cannot be disregarded. The document size containable by a frame depends on the reduction ratio.

For 35-mm with a strip orientation, the document dimensions (inches) are:

A. Single frame (18 by 24.5 mm or 0.7087 by 0.9646 inch)

Reduction ratio:	*Width*	*Height*
20	14	19¼
24	17	23
42	29¾	40½
48	34	46¼

B. Double frame (36 by 24.5 mm or 1.429 by 0.9646 inch)

Reduction ratio:	*Width*	*Height*
20	28½	19¼
24	34¼	23
42	60	40½
48	68½	46¼

For microfiche, commercial format, the document dimensions (inches) are:

A. Single-page format, 98 images/fiche (10 by 12.5 mm or 0.3937 by 0.4921 inch)

Reduction ratio:	*Width*	*Height*
20	7¾	9¾
24	9¼	11¾
42	16½	20½
48	18¾	23½

B. Double-page format, 49 images/fiche (20 by 12.5 mm or 0.7874 by 0.4921 inch)

Reduction ratio:	*Width*	*Height*
20	15½	9¾
24	18¾	11¾
42	33	20½
48	37¾	23½

For microfiche, COSATI format, the document dimensions (inches) are:

A. Single-page format, 60 images/fiche (11.75 by 16.5 mm or 0.4626 by 0.6496 inch)

Reduction ratio:	*Width*	*Height*
20	9¼	12¾
24	11	15½
42	19¼	27¼
48	22	31

B. Double-page format, 30 images (23.5 by 16.5 mm or 0.9252 by 0.6496 inch)

Reduction ratio:	*Width*	*Height*
20	18½	12¾
24	22	15½
42	38¾	27¼
48	44¼	31

Table 1—*Dimensions of 7½′ quadrangles, at two representative fractions, by selected latitudes*

Latitude North	1:24,000		1:31,680	
	Width (E-W)	Height (N-S)	Width (E-W)	Height (N-S)
	inches			
25° Florida	20.7	22.7	15.7	17.2
32° Mexico-California	19.4	22.7	14.7	17.2
42° California-Oregon	17.0	22.8	12.9	17.3
49° Washington-Canada	15.0	22.8	11.4	17.3

Any map would fit within a frame if reduced repeatedly, but at a one-step reduction only half of all possible combinations meet the specified sizes and ratios (*table 2*). For the two representative fractions all maps but one will fit within a single frame at a 48X reduction. Yet at 42X only the COSATI double-page format allows both scales. This table also shows that all quadrangles for the contiguous 48 States fall within a double-frame, 35-mm microfilm, at 24X or more.

Microfiche cannot be used at 24X, given the conventional frame sizes assumed. Sectioning of maps into 3¾′ quarters or smaller with 24X reduction is an alternative to massive reductions of entire maps. Of course, quartering a map may result in a more than fourfold increase in fiche area. The commercial, double-page fiche has 49 frames (24X) and could store nine maps conveniently with 13 or 49–(9 x 4) frames either wasted or perhaps used for titling (*fig. 1*).

Another alternative is to split the quadrangle in two with the most advantageous orientation for the cut being east to west. Then any 3¾′-(latitude interval)-by-7½′ quadrangle at either scale would fit with a 24X reduction in a COSATI double frame. Only maps of RF 1:31,680 would fall within the smaller, commercial format frame at 24X.

Table 2—*Reduction ratios for which any 7½′ quadrangle in the contiguous United States will fall within a microform frame*

Microform	*Reduction Ratio*[1]			
	20	24	42	48
35-mm Microfilm:				
Single frame	–	B	A,B	A,B
Double frame	B	A,B	A,B	A,B
Microfiche:				
Commercial:				
98 images	–	–	B	B
49 images	–	–	B	A,B
COSATI:				
60 images	–	–	B	A,B
30 images	–	–	A,B	A,B

[1] A=RF 1:24,000
B=RF 1:31,680

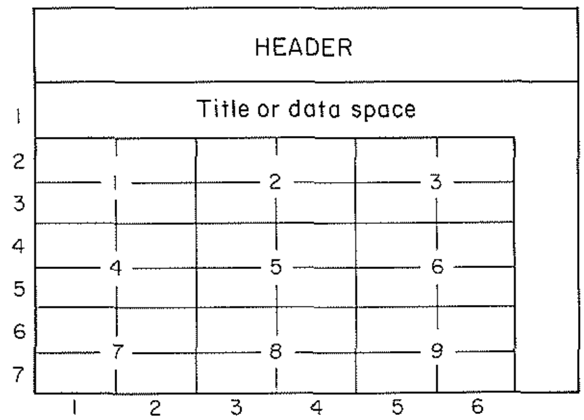

Figure 1—Nine 7½′ maps, each sectioned into four 3¾′ quadrangles to fit in 36 of 49 microfiche double frames.

Maps need not be sectioned either physically or exactly. Each frame could include a narrow strip of each neighbor. The overlap helps because the microimage frames are separated by a narrow margin.

CONVENTIONAL MICROFORM FILMS

Silver Halide Film

Archival permanence is attainable only with silver halide film and correct processing. Standard methods are followed to determine durability of silver images. Comparable standards do not exist for diazo and vesicular film. Test procedures are particularly needed for judging the potential durability of nonsilver films. Although nonsilver forms *may* be satisfactory for many years, longevity cannot be assured. It is lack of information, rather than contrary evidence, that rules against nonsilver films.

Nonsilver Diazo Film

The camera and intermediate copies are made of silver halide, but distribution copies are often diazo or, less frequently, vesicular. Choosing diazo over halide copies can result in cost savings of 20 to 25 percent.

Diazo is a dye image produced by an ultraviolet light and developed by an ammonia process. Blue images are most common, but other colors are available. Diazo is a nonreversing film. A copy of a negative is a negative. The microimages have several properties favoring scanner digitizing at great reduction ratios. The grainless image results in a very high resolution–exceeding 1400 lines/mm. The image is homogeneous and the dye molecules permeate the entire coating–not just the surface. This characteristic in combination with the plastic used for fiche (which is tougher than camera film) makes diazo less susceptible to scratches. In addition, flat forms receive less wear than roll films which may be driven at high speeds through reader transport systems. Special coatings to make roll films resistant to abrasion have not, to date, proved successful (Williams 1970).

The advantages associated with a dye image also lead to its principal limitation. The dye is subject to fading, particularly with prolonged exposure to ultraviolet light. And so another copy may have to be made from the halide original. Halftone or shaded areas in general are difficult to reproduce to specified density levels with either halide or diazo film. The problem is greater with diazo, although other types of contrast films are available. In any case, shaded maps are excluded from consideration; sharp ink or scribed lines and characters are necessary.

Vesicular Film

Nonsilver vesicular film is used for distribution copies when information ages rapidly and entire film sets are frequently replaced. Ultraviolet light creates vesicles or "bubbles" which scatter light, rather than absorb it, to create images. The film has been used for storing maps in a motorized retrieval system for military use (Goodwald 1968). More than 28,000 maps were microfilmed to a 35-mm format and then transferred to a scroll of vesicular film 17 inches wide by 400 feet long. Both continuous tone capabilities and a resolution of 150 lines/mm were maintained. This unique system, although too specialized for civilian use, indicates the technical feasibility of using vesicular film for duplication purposes. Vesicular does not seem to have any outstanding advantages over diazo. The attraction of vesicular film is that if certain hurdles are overcome, it may be used for recording, i.e., as camera film.

Color Film Capabilites

Color films for recording microimages are available in both roll and flat forms, but have not yet been widely used for that purpose. The major application is for educational purposes, such as medical slides. Other micrographic uses include color-coded drawings or maps.

Besides lacking permanence because it uses dyes, color film has two other disadvantages. Color duplication is a costly process requiring the training of personnel or waiting for service at commercial film processing laboratories. More serious, the best conditions for line images work against those for color. High contrast yields more legible lines; low contrast favors good color fidelity. A compromise must be struck. As a result, resolution is reduced in comparison to that of black-and-white films. Reductions greater than 24X should be avoided. An original color negative has a resolving power of 90 lines/mm, but a print (second copy) has about 70 lines/mm as determined by tests at a 20:1 reduction (Rickman 1973, p. 358). In practical terms, a 7½-minute, 1:31,680 quadrangle is the largest scale map that will fit in a 35-mm double frame at 20X. Reducing color microfiche requires special consideration of type size and face to maintain legibility. For these reasons, as well as the potential focusing problem for microdensitometry created by three dye layers, we do not consider color film a desirable microimage storage medium.

RESOURCE MAP IMAGE RESOLUTION

Resolution Test Chart

The problem of finding a suitable reduction from map to microimage is solved by finding the most compact form with a process that is reversible to the eye and a scanning digitizer. Resolution–the ability of the microfilming system to distinguish fine details sharply–is the key consideration. Statements concerning resolving power are approximate unless contrast and other test conditions are specified (Altman 1961). A controversial, but nevertheless standard, basis for judging resolution is a test chart provided by the National Bureau of Standards (Fouquet 1963) (*fig. 2*). The targets are usually placed in the first or last frame of each microfiche for quality control. Resolution is defined as the ability of a system to separate images of closely spaced lines. A set of five charts costs $18 (1975 prices) (U.S. Dep. of Commerce 1974).

Each of the patterns contains five vertical and five horizontal stripes and a number. A line is defined as a dark stripe with a light stripe of equal width alongside it. Each number is the count of lines/mm for that pattern. The eye can resolve 10 lines/mm at a normal reading distance. Fine-grain microfilm has a resolution of at least 600 lines/mm and, with a well corrected lens, the net resolution is likely to exceed 200 lines/mm. The largest value on the NBS chart is 18, which provides 432 lines/mm at 24X or twice the resolution needed to test the finest microfilm and lens combinations.

Resolution of Map Lines

Ink lines on forest resource maps, at the customary scales considered so far, are usually 0.01 inch (0.25 mm) or wider. Detecting and separating these fine lines can be simulated by scanning black stripes of the same size on an NBS test chart. The target of two lines/mm, before reduction, represents 0.01-inch (0.25-mm) lines. The NBS definition of a line includes both the black and white portion (0.5 mm) so the black line is half that, or 0.25 mm. Theoretically, the density sampling interval cannot be more than one-half the width of a map line to assure a line will not be broken. This is an upper limit for density spacings. The lower limit is indefinite because two or more map lines can almost touch but be separated by an infinitely small amount.

The only reductions of maps onto films or fiche considered relevant are 20X, 24X, 42X, and 48X. A 0.25-mm line on the original map reduces to 12.5 (i.e., 0.25/20), 10.4, 6.0, and 5.2 μm. Actually 48X is not attainable commercially as a one-step reduction. The planetary cameras which are both suitable for precision cartographic work and generally available cannot exceed 42X.

The difference between 42X and the 48X standard COM reduction ratio can be accommodated in one of two ways. First, a 42X nonstandard arrangement of frames on a microfiche can be used in a microfiche reader with zoom lens capability. Adjustable magnification is preferred to the second choice, which is to achieve a 48X in two reductions at the cost of lost resolution.

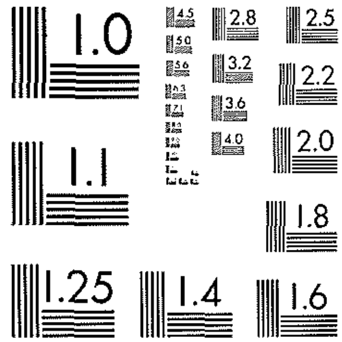

Figure 2—A National Bureau of Standards test chart (1963-A) used for determining overall microform system resolution.

Line-Scanning Test Conditions

To find out if a resolution of two lines/mm on the source map was readily attainable, given commercially available materials and copy procedures, we did a scanning test.

A precision planetary camera ordinarily used for engineering drawings was used to make 24X and 42X reductions. Several exposures were made to give a range of densities on standard (630 lines/mm) silver halide 35-mm microfilm. It is a customary business practice to protect the original negative by making an intermediate working copy, usually silver halide. We scanned not only the original but also a diazo microfiche copy to allow for a realistic loss of resolution caused by reproduction. High-speed scanners intended for digitizing type fonts, X-rays, and other large images record at coarse intervals; steps of 25 μm are typical. We used a PDS 1010 microdensitometer, which is slow but designed for steps as fine as 2 μm.

We scanned all of the target patterns on the NBS resolution chart at several square grid spacings. For 24X the readings were taken at 12, 10, 6, and 2 μm with equivalent apertures. For 42X the readings were 4, 3, and 2 μm with corresponding apertures.

One would expect individuals to disagree as to which target's lines are just barely separable under any given viewing conditions. The inherent variability of judging results can be reduced by making microscope comparisons or, as we preferred, by comparing density output from scanning microimages.

Line separation depends on the density level or "slice" selected. We grouped the 1024 possible density values into 64 categories. In coarse patterns the change from one density level to another was imperceptible. Once the threshold of separability was reached in finer patterns, results were quite sensitive to the density slice. At density level 12, the lines in the 2.2 target reduced 42X were completely separate. Increasing the grey level to 13 caused the lines to join in four places. We consider a resolution of 92 lines/mm as unattainable (*fig. 3*).

The condition of the scanning device used strongly affects line resolution. The PDS-1010 scanning microdensitometer we used recorded billions of densities over a 5-year period. The complex mechanism is subject to wear which is difficult to quantify. We found a directional bias in the scanning process, that is, horizontal lines separated before vertical ones. Scanning the same targets with a rented PDS 1010A microdensitometer verified the source of the problem to be mechanical—and not one due to the film. Continual machine maintenance, as well as inspection of test targets, is essential to assure high resolution capabilities.

Image Quality

The frequency distribution of densities provides ways of determining scanned image quality. One of these is the degree of concentration at the two modes (one representing lines, the other background). A high concentration of density values at the modes usually indicates sufficient separation.

Contrast ratios were computed from the modes for line and background densities. Commercial scans gave contrast ratios from 21:1 to 25:1 at 24X for silver halide and diazo images of the NBS test chart. A sample of 10 WRIS negatives of silver halide film had an average contrast ratio of 27 when scanned on the same machine. All these ratios are essentially "medium" and indicate sufficient leeway for selecting the density slice.

CONCLUSIONS

At great reductions and with density recordings at intervals of a few micrometers, either the film or the scanner become a limiting factor. Our experience suggests that the behavior of the scanning device is the most important factor. For example, before we overhauled our densitometer we could resolve about 40-50 lines/mm. With another, similar model, 90 lines/mm were resolvable.

Because map scanning is expensive, satisfactory results must be obtained with a high degree of certainty. We can barely resolve 0.01-inch (0.25-mm) map lines at 42X with commercial microfilm processing, a conditioned environment, and a finely adjusted microdensitometer. Since these conditions are difficult to maintain, we conclude that 24X is the maximum reduction onto microfiche recommended for production work. At this reduction, satisfactory results can be expected even with the second copy of the original negative and routine scanner maintenance.

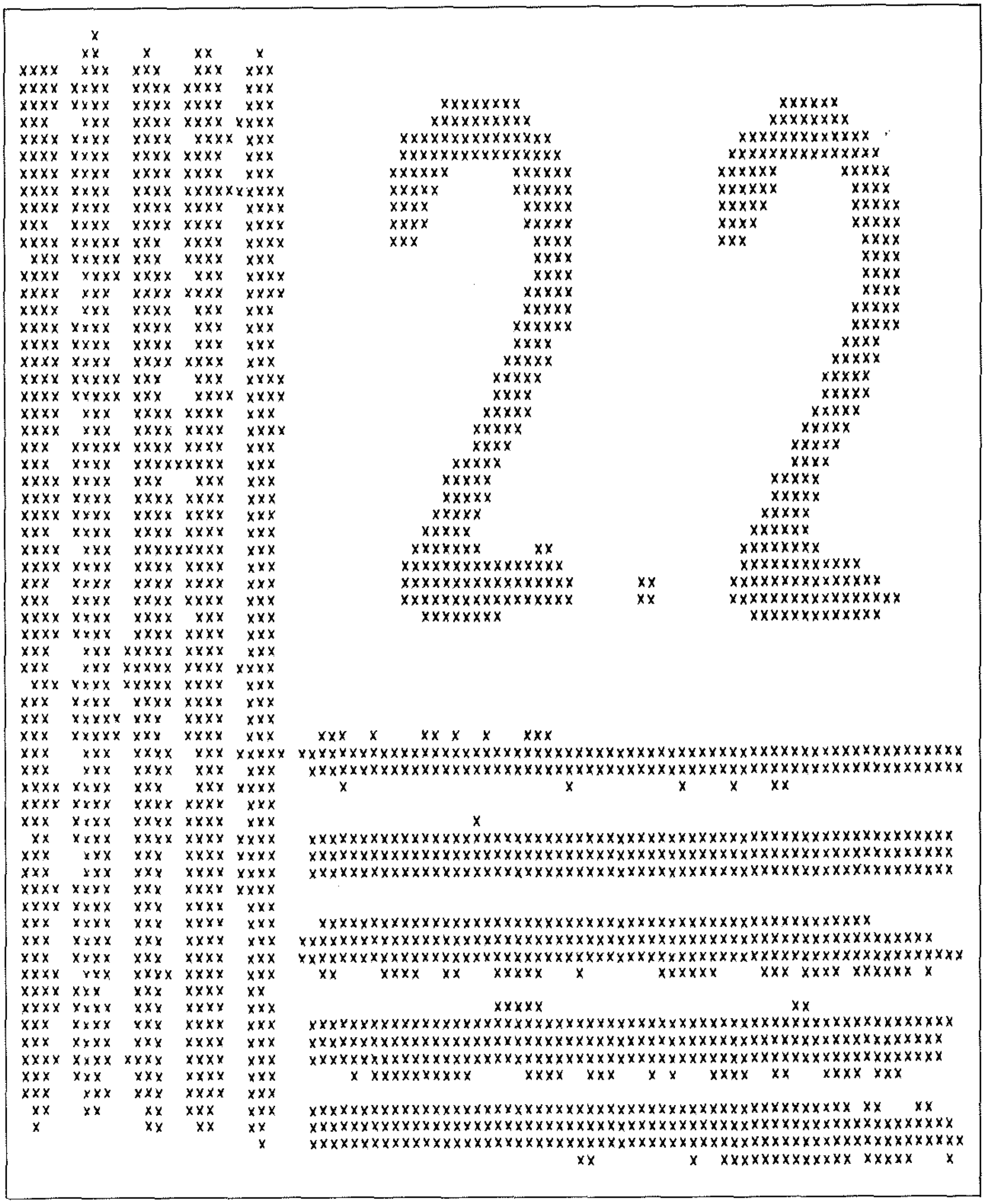

Figure 3—Separability is sensitive to the density slice. On the 2.2 target, at 42X, lines which were separate at density level 12 merge in four places at 13.

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Images in graphic or printed form can be reduced in size by microcopying. Microform is a collective term for stored microimages. Conventional microform films include silver halide, nonsilver diazo, vesicular, and color. Criteria for selecting the proper format include map quadrangle size and reduction ratio. Among several competing types of microforms, only microfilm and microfiche were judged acceptable for application to wildland maps. Microimages can be digitized by automatic techniques. With careful planning, it is possible to digitize automatically forest map microimages for input to computerized mapping systems. Other benefits of microcopying include a reduction in the cost of handling and shipping the original documents, savings in space, and making archival copies more lasting.

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