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Evaluating STREAM TROUT HABITAT on Large-Scale AERIAL COLOR PHOTOGRAPHS

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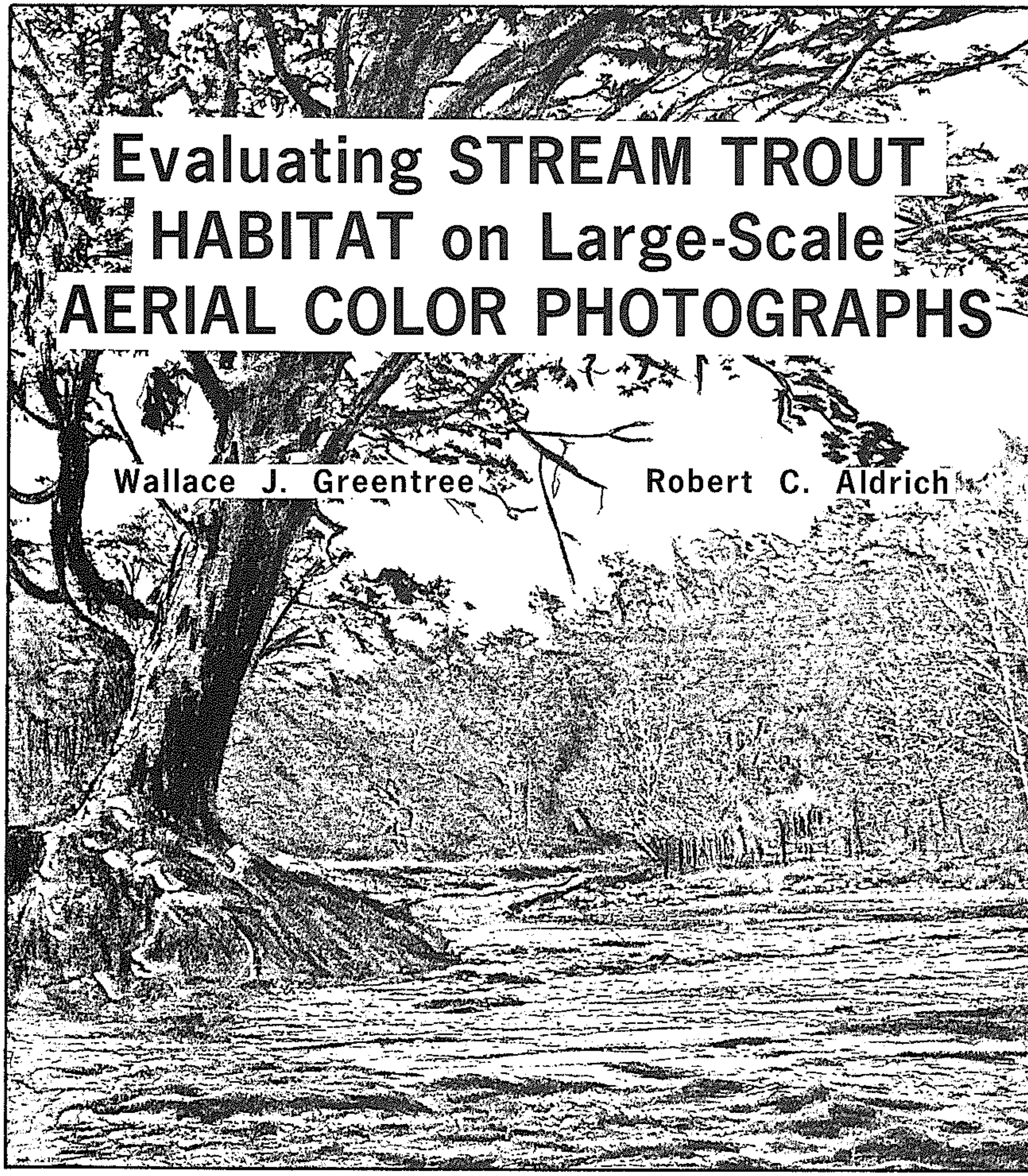

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SUMMARY

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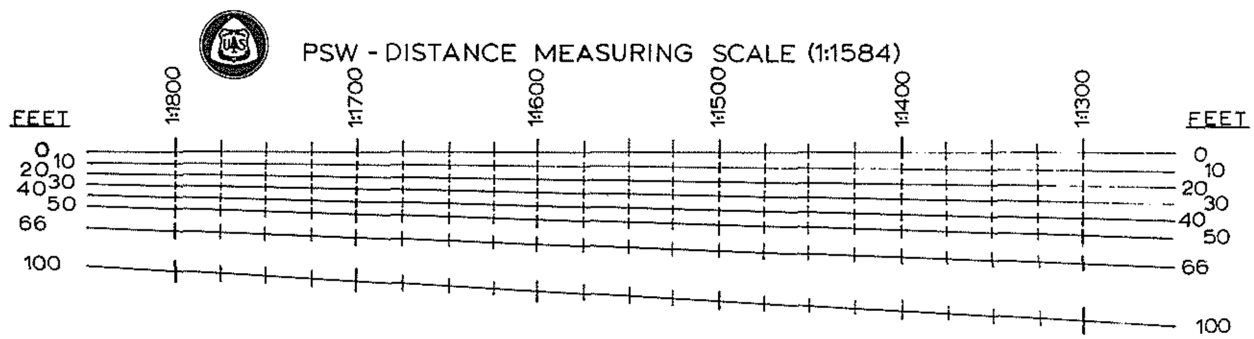
Retrieval Terms: trout habitat; photointerpretation; habitat evaluation.

Large-scale aerial color photographs were used to evaluate trout-habitat conditions on a portion of Hat Creek in northern California. Two 70-mm Maurer KB-8 cameras with Anscochrome D-200 and Ektachrome Infrared, type 8443, were flown at three scales: 1:600, 1:1584, and 1:6000. Stream and streambank conditions were studied on the photographs and defined in terms of habitat evaluation requirements. A photointerpretation test showed that 92 percent of the habitat conditions could be identified correctly on the normal color photographs. Changes in stream vegetation as a result of rehabilitation efforts could be detected and measured on photographs taken 1 year apart. A scanning microdensitometer was used to see if film density was correlated with water depth; the correlation on normal color film was 76.4 percent and the correlation on color infrared film was 73.5 percent. Estimates of water depth made by parallax measurements resulted in poor accuracies. Shadow length measurements of streambank vegetation converted to brush and tree heights were 86 percent accurate. A technique to measure the degree of shade created on a stream by streambank vegetation is described and evaluated. Two photointerpretation aids were developed: a scale of particle sizes to categorize bottom types, and a distance-measuring aid to check actual photograph scales. The cost of large-scale color evaluation of stream trout habitat was estimated to be from $200 to $250 per mile of stream.



The PSW distance-measuring scale was devised for use in determining actual photographic scale of each triplet. The scale, which is printed on acetate, is placed over the 100-foot ground marker panels on the photographs and moved until the 100-foot index mark on the scale matches the distance between panels. The photo scale is read opposite the index mark.

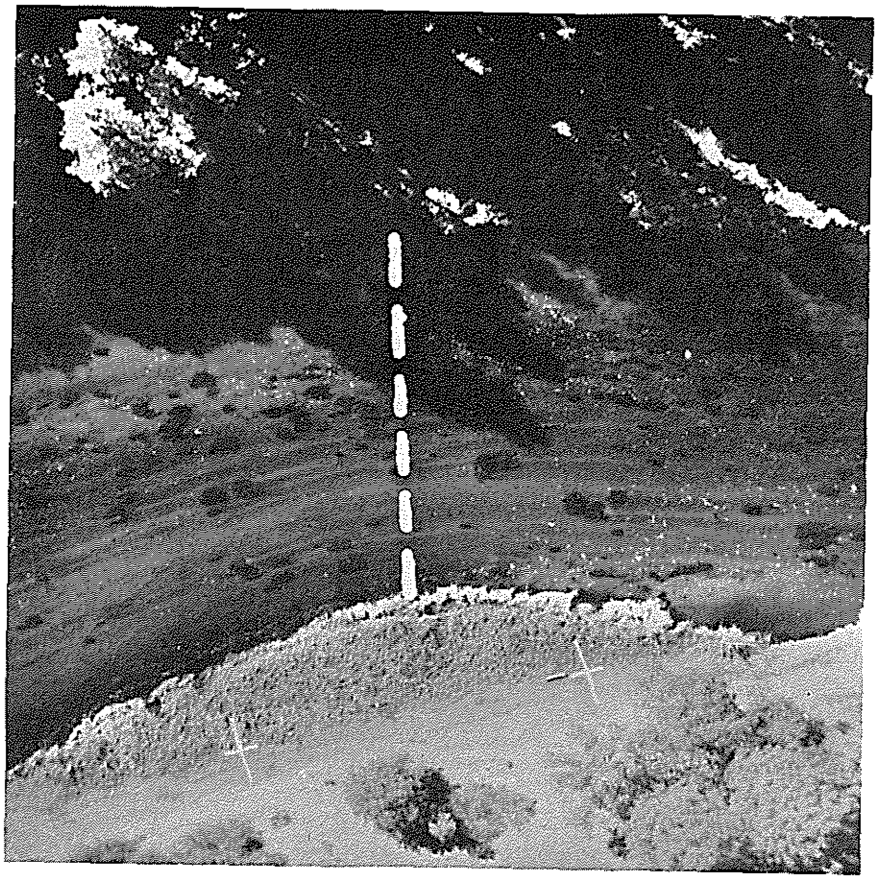


Figure 1—The dashed line across the stream marks one transect; the two crosses on the streambank are 100 ft apart and are the ground marker panels. The black-and-white photo was reproduced from the original 1:1584 color infrared transparency and enlarged three times.

In management of wildlife, evaluation of streams as trout habitat may be required, to determine when conservation efforts should be made. Transect methods requiring instream measurements of habitat parameters are presently used for such evaluation. Instream measures are time consuming and expensive and may not provide enough data for good habitat evaluation. New developments in stream habitat sampling with large-scale aerial color photography, however, may improve measurements for some parameters and give more information at a lower cost. These photo sampling techniques, together with some ground measurements, can provide baseline data of the habitat under various flow conditions.

In fall 1968 and 1969, large-scale aerial color photographs were taken of a 3.5-mile portion of Hat Creek, in northeastern California. The photographs were studied to determine their usefulness for evaluation of stream trout habitat. The study site, near the town of Burney, is a crystal-clear stream, which meanders through meadows and pine and oak-covered hills at about 3000 feet elevation (914 m), and is famous for trout angling. By 1968, however, the stream had become overpopulated by rough or non-game fish which limited the trout populations. Rehabilitation efforts in fall 1968 and adherence to stream management guidelines since then have made this portion of Hat Creek a productive trout stream again (Barnhart 1970).

The aerial photo coverage of Hat Creek included color and color-infrared photographs at three different scales (1:600, 1:1584, 1:6000). The 1968 series were taken before a joint effort was made by Federal, State, and private conservation organizations[1] to rehabilitate the stream. The 1969 series were taken to assess the rehabilitation program.

Measuring trout habitat conditions on large-scale color photography is a relatively new application of remote sensing. It has special requirements and presents new problems. This paper looks at these requirements and problems and (1) outlines areas where photographs will be most beneficial, (2) describes techniques and aids for measuring habitat conditions, and (3) presents the potential user with enough information to enable him to make his own decision —"can large-scale color photography help me evaluate trout habitat?"

METHODS

Aerial Photography

Most of the methods presented in this paper were originally designed for use in forestry. In applying them to the special problem of trout habitat evaluation, we sometimes tried more than one method. For some measurements, we had to design and make specific photo aids.

Two photographic flights were made over the Hat Creek study site. The first, on October 8, 1968, was made immediately after the stream had been chemically treated to reduce undesirable fish and had been restocked with trout. The second flight, a year later on October 8, 1969, was designed to allow us to evaluate changes or potential changes in stream habitat that were associated with rehabilitation efforts. The two sets of photographs were used for both conventional photointerpretation and for automated interpretation using optical film density.

The photography was obtained using two Maurer[2] KB-8 70-mm cameras (with 6-inch focal-length lenses) mounted in a Forest Service Aero Commander. Two color films, Anscochrome D/200 (color) and Ektachrome Infrared, type 8443 (CIR), were exposed simultaneously with 60 to 80 percent overlap for stereoscope viewing at three relatively large scales—1:600, 1:1584, and 1:6000.

In preparation for the photographic flight, we located four study transects along the stream banks. Before each flight, at each transect location, two sets

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[1] California Cooperative Fishery Unit, U.S. Fish and Wildlife Service; Forest Service, U.S. Department of Agriculture; California Department of Fish and Game; Pacific Gas and Electric Company; and Trout Unlimited.

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

Table 1—*Trout stream habitat criteria*[1] *in California*

Instream Conditions	
Aquatic vegetation	Cover types
Emergent	Logs, debris, and boulders (above water)
Submergent	Logs, debris, and boulders (below water)
Bottom types	Man-made structures
Silt	Shade (overhead)
Sand	Turbulent surface water
Gravel, fine (>1.0 inches)	Surface velocity
Gravel, coarse (1 to 3 inches)	Slow—less than 1.0 f/s, surface smooth
Rubble, fine (3 to 6 inches)	Fast—greater than 1.0 f/s, surface rough
Boulders (12+ inches)	General habitat
Bedrock	Pools
Plant waste	Runs
Water depth	Riffles
Less than 0.5 ft	
0.5 to 1.5 ft	
1.5+ ft	
Streambank Conditions	
Bank cover types	Bank types
Deciduous (d), evergreen (g)	Low, undercut
Weeds and shrubs; 0 to 4 ft	Low, no undercut
Trees; 15 to 50 ft; 50 to 100 ft; 100+ ft	High, undercut
Annual grasses, brown or green	High, no undercut
Gravel, rocks, boulders	Eroded bank
Bare soil	
Bedrock	
Overhanging vegetation or debris	

[1] Based on Lagler 1956, White and Brynildson 1967, and correspondence with Dr. Roger A. Barnhart, Leader, California Cooperative Fishery Unit, Humboldt State College, Arcata, Calif., 1969, and with Fisheries Research Center, Division of Wildlife, Fort Collins, Colorado, 1973.

of 10-foot panel markers were placed for later photographic scale determinations.

Photo Analysis

After processing the 1968 films, we used the resultant color and CIR transparencies to locate the four transects which would represent trout habitat conditions along the stream (*fig. 1*). Three overlapping photographs for each transect were removed from the roll of film and mounted in clear acetate envelopes for stereoscopic viewing. Points marking the ends of transects were pinpricked on the triplets, to help in locating the transects on the ground as well as to locate the scan line for optical film density measurements.

Defining Habitat Conditions

In preparation for the photointerpretation, we needed to define important features that could be measured on a vertical photograph. A review of the literature and an examination of the large-scale photographs helped us to separate these features into two broad groups—instream conditions and streambank conditions (*table 1*).

Instream conditions are important criteria because the stream provides trout with primary needs such as food, shelter, and proper conditions for reproduction. During the day and under the cover of darkness, trout choose shelter spots in the stream for rest, protection, and feeding. Stream habitats also affect trout stream insects. Most choose to live in shallow, swift riffles, and their distribution is dependent on bottom types, water depth, and water velocity.

Streambank conditions are important criteria because the bank provides cover. Bushes, trees, and the streambanks themselves afford shade that not only shelters the fish, but also affects water temperature. According to Needham (1969), "Water temperature is probably the most important single factor governing the distribution of all species of trout." Streambank vegetation also helps control erosion and influences the supply of land insect and plant litter that enters the stream.

Once the habitat conditions had been defined, conventional photointerpretation techniques were used to determine how these conditions could be measured. The photographs were examined on a light table with the aid of an Abrams Stereoscope at both two and four times magnification (*fig. 2*), in order to better define the physical and biological features of trout habitat that could be seen on each color film at each photographic scale. We also determined that the time lapse between photographic flights allowed us to see changes in habitat conditions 1 year after the reduction of nongame fish populations.

Instream Conditions—Aquatic vegetation was identified by appearance and color. Bottom types were classified by size of particles and physical appearance. A scale of particle sizes was developed (*fig. 3*) as an aid in categorizing bottom types into one of four size classes: 1 to 3 inches, 3 to 6 inches, 6 to 12 inches, and 12 inches or more. The transparent film aid was placed on the photo image in question and moved

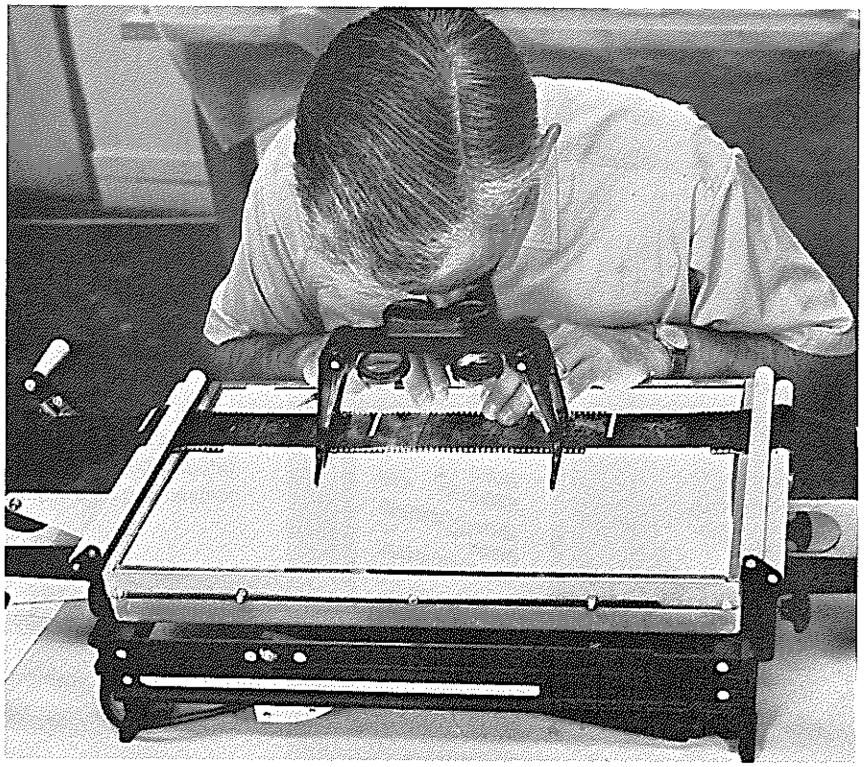

Figure 2—An Abrams stereoscope on a Richards light table was set up for stereoscopic viewing of 70-mm color transparencies.

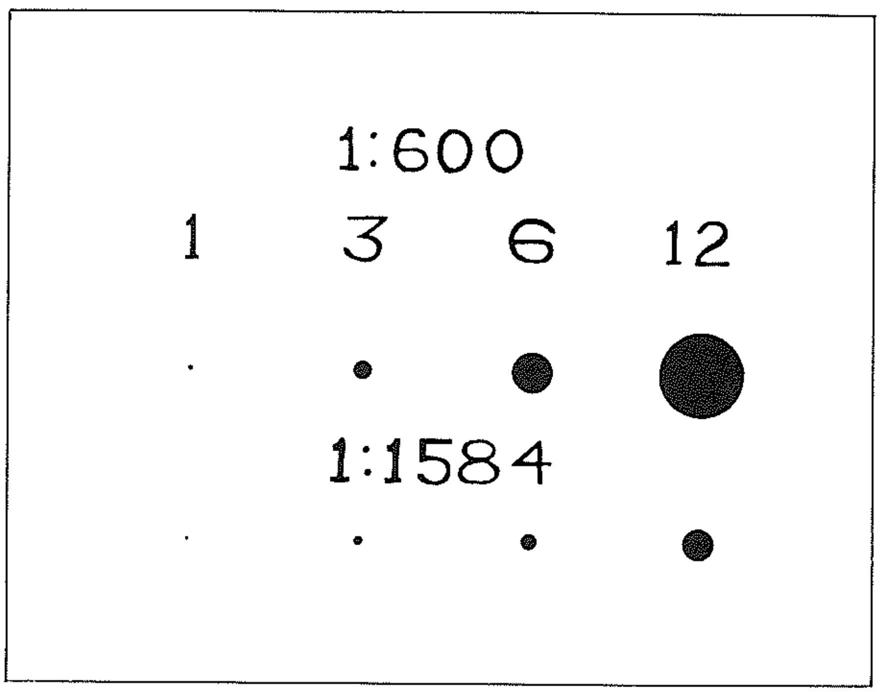

Figure 3—A particle-size scale was devised for categorizing stream bottom types into one of four size classes. The scale shown here is 22.5 times larger than the scale used for photointerpretation.

Figure 4—The Photometric Data Systems (Model 1000) scanning microdensitometer and data acquisition system.

until the particle size on the film equaled the average condition on the stream bottom.

Water depth estimates were made with parallax measuring devices designed for use on 70-mm film. Two devices were tried—a parallax bar and a parallax wedge. With either method parallax readings are taken on the photo at one point on the water surface and another on the bottom of the stream. The difference between the two readings, or differential parallax, is used in the parallax formula (see Appendix A) to obtain the value for water depth.

Another method tried for estimating water depth requires measurement of optical film densities. In this phase of the study we used an automatic scanning microdensitometer (MDT) (*fig. 4*) to measure optical film density along each of the four transects on 1:1584 color and CIR transparencies. Each transparency was placed in turn on the MDT and positioned so that scans would be made between the points marking the transects. Then the MDT was programed to record automatically the film density along the transect lines. Each transect was scanned four times—once without a filter (clear), and once each with red, green, and blue MDT filters (Wratten 92, 93, and 94). "Normalized" film densities[3] were used in regression analysis techniques to test the hypothesis that water depth can be predicted from optical film density.

Conventional photointerpretation techniques were used for identifying cover types, surface velocity, and general habitat types on the four-transect study area.

Stream Bank Conditions—Shoreline vegetation, such as bushes and trees, provides most of the shade cover on the stream. Also, certain bushes and trees help to govern the quantity of land insects and plant litter entering the stream. The procedure which resulted from our effort to determine which bushes and trees contribute to these relationships is described in

[3] These were computed by subtracting the film density measured with unfiltered white light from the red-, green-, and blue-filtered film densities. This lessens the effect of exposure differences within and between photos.

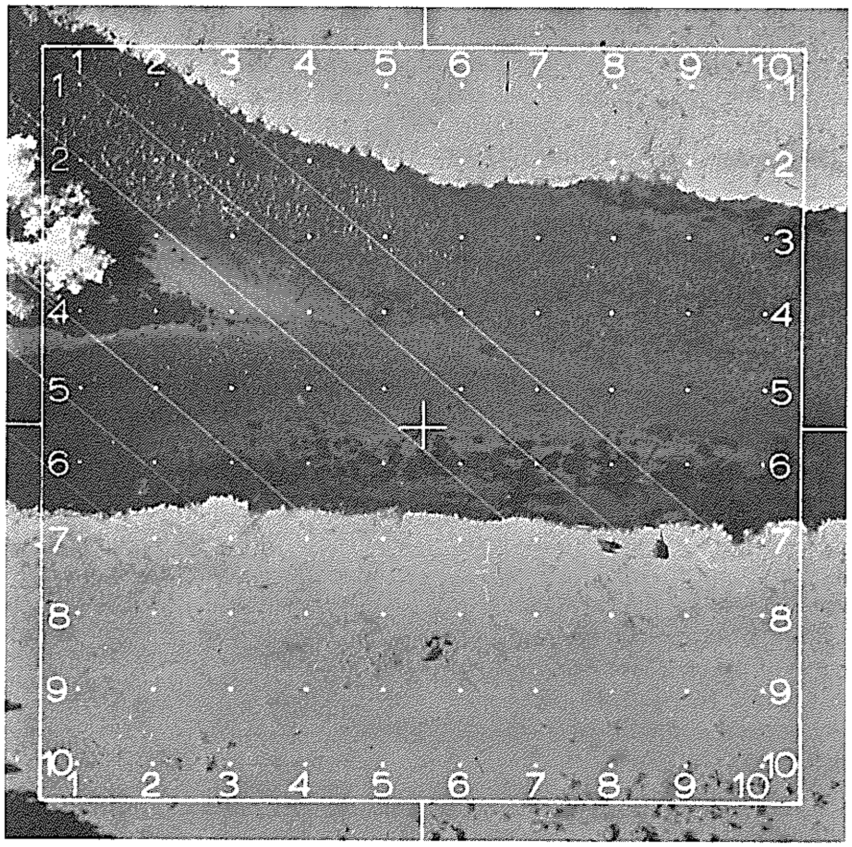

Figure 5—A 100-dot grid was overlaid on each triplet for interpretation of habitat conditions. This black-and-white photo was reproduced from a color infrared transparency and enlarged two times. Diagonal lines through the center of the picture are power lines.

Appendix B. Essentially, it required finding values for solar azimuth and solar altitude for the time, date, and latitude of photography. The solar values were used for determining shadow position and tree heights from length-of-shadow measurements on the photographs. The solar values were expanded for every hour of the day. The expanded solar values were used with stream direction to determine which bushes or trees affected the stream habitat throughout the day. Bushes and trees were identified on the photographs as either evergeen or deciduous, and their crown sizes were measured as an aid in the overall evaluation of shadow effects.

The remaining streambank vegetation types—bare soil, gravel, rocks, boulders, and grasses—were classified by conventional interpretation techniques.

Bank types were classified by interpretation of form, shape, and height. Heights were estimated by photo comparisons and by measuring with a parallax bar.

Photointerpretation Test

An interpretation test was made to classify trout habitat conditions according to the eight major classes listed in *table 1*. Only the 1:1584 color photographs from 1968 and 1969 were used in this initial test.

One interpreter examined trout habitat classes at each of 100 dots on a grid template which overlaid the center photograph of the photo triplet for each of the four transects (*fig. 5*). The scale of each triplet was determined by measuring the distance between ground marker panels with the PSW distance-measuring scale (*fig. 6*). The area immediately under and within a 3-foot radial distance of a grid point was examined to determine if the point was in water or on the streambank. Each point was then classified by the appropriate habitat condition identified in this study.

Ground Measurements

Using the 1968 photography, we located the four sample transects and marked them with a metal stake on each bank of the stream. Two men then waded the stream and recorded bottom types and water depths at 1-foot intervals across each transect. The clarity of the water allowed us to determine the bottom types by physical form. Water depths were measured with a 0.01-foot calibrated stick. Also, we recorded cover classes, such as a submerged log, at the 1-foot measuring point.

Total heights of 48 bushes and trees located within the study area were measured with a Spiegel-Relaskop.[4] These measurements were used to check the accuracy of heights estimated using both parallax-measuring devices and shadow-length measurements.

To verify the photo habitat classifications, 95 points—representative of major habitat classes—were checked in the field. Ground photographs of these sites were used with aerial photographs to make interpretation aids (*fig. 7*).

[4] The "Spiegel-Relaskop," invented by Dr. W. Bitterlich of Austria, is a small (14-ounce), ruggedly constructed hand instrument. This single instrument can be used to make optical measurements of tree basal area, tree height, tree diameter, tree form class, and distance.

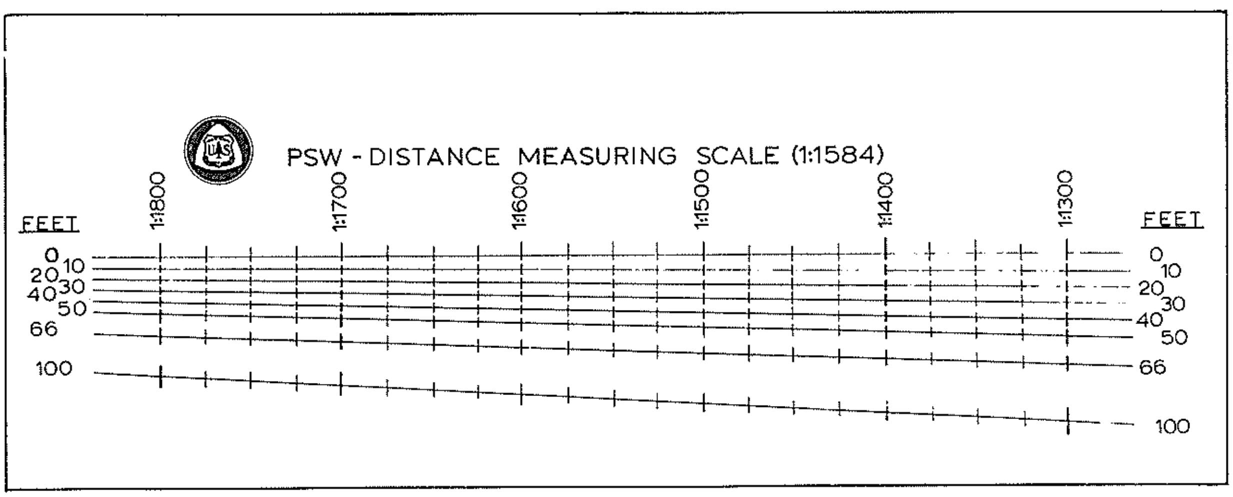

Figure 6—The PSW distance-measuring scale was devised for use in determining actual photographic scale of each triplet. The scale, which is printed on acetate, is placed over the 100-foot ground marker panels on the photographs and moved until the 100-foot index mark on the scale matches the distance between panels. The photo scale is read opposite the index mark.

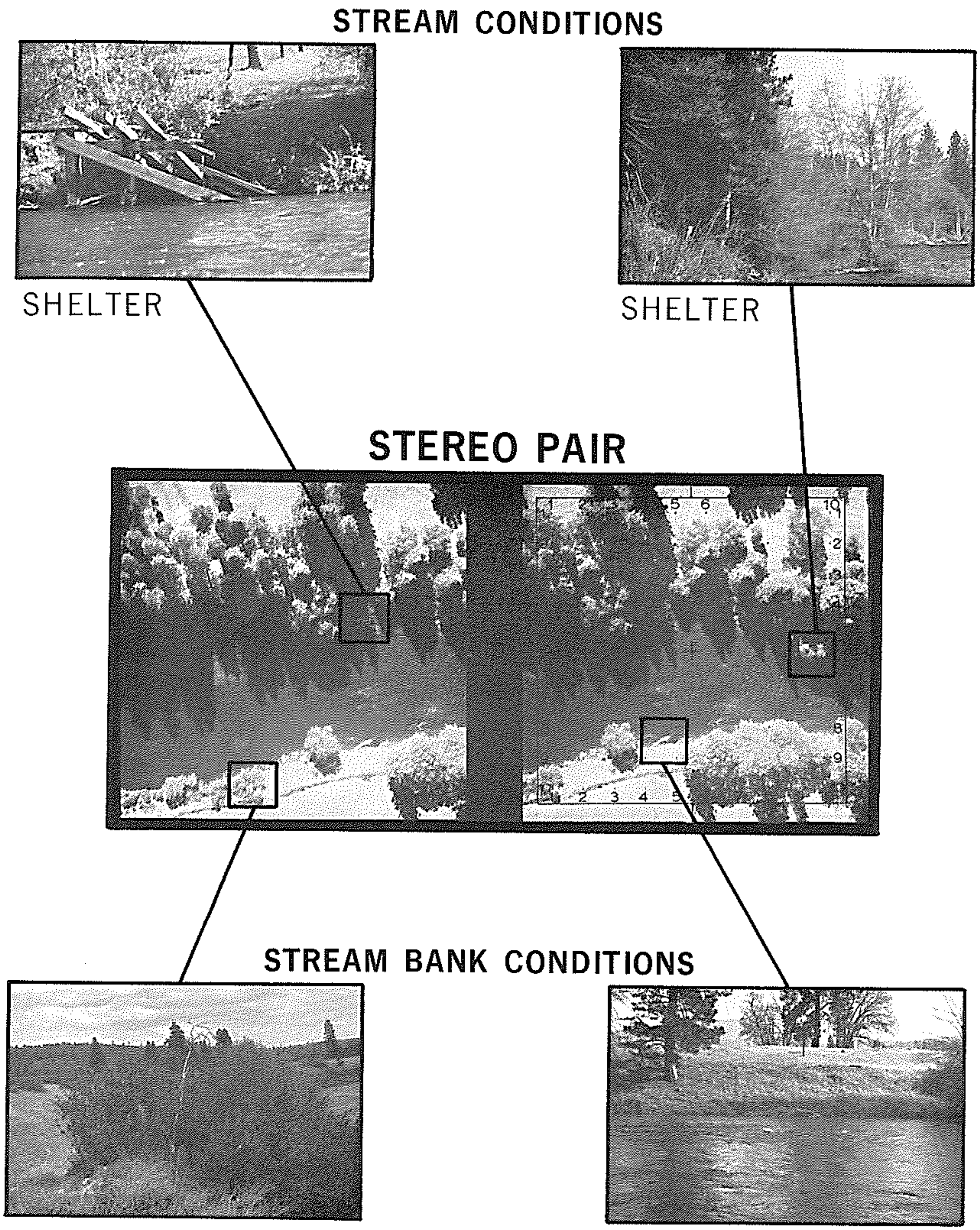

Figure 7—Four trout habitat classes are shown on this interpretation aid.

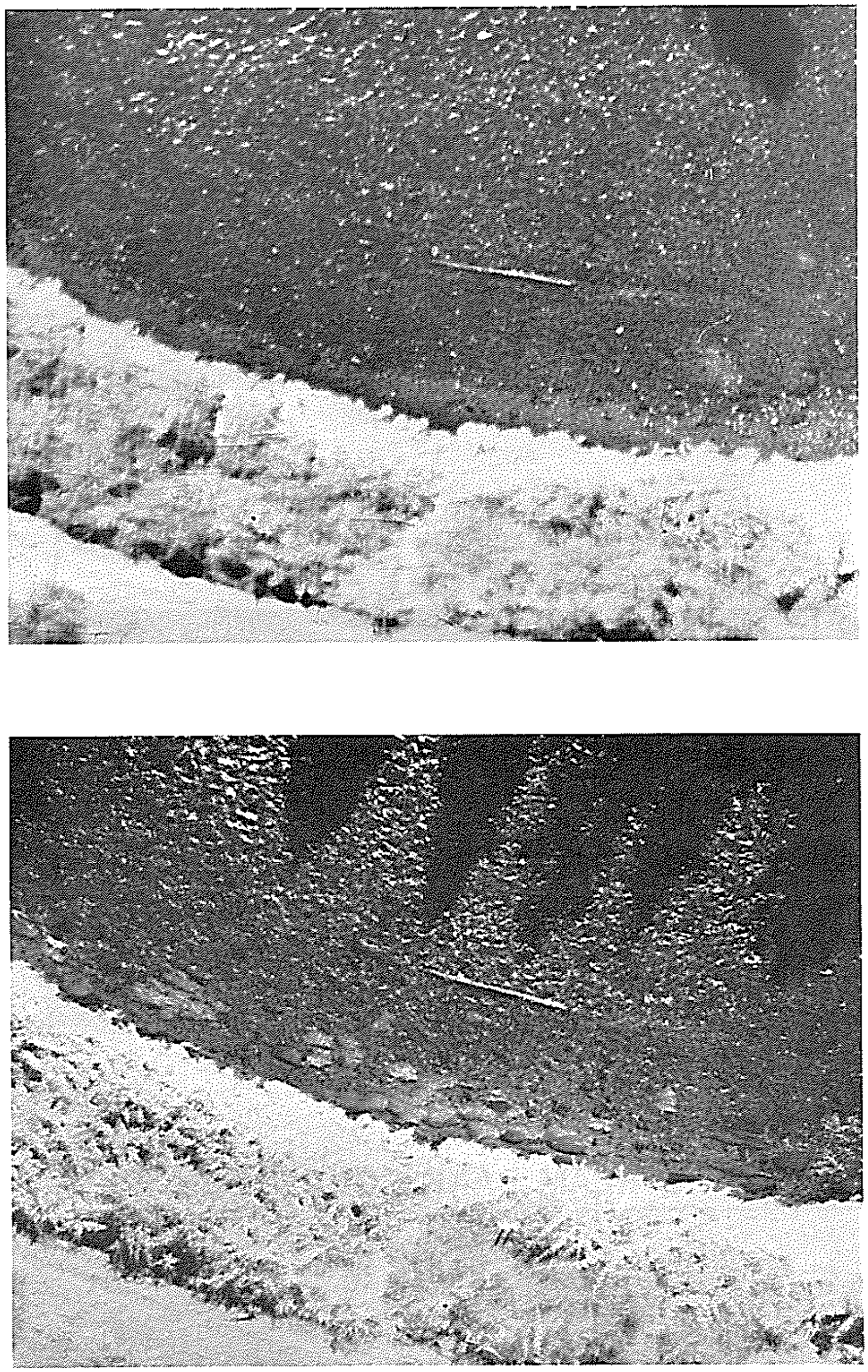

Figure 8—Photographs taken 1 year apart (1968, *top,* 1969, *bottom*) show the increase in aquatic vegetation following rehabilitation efforts. The black-and-white photographs were made from color infrared transparencies and enlarged 2 times.

RESULTS AND DISCUSSION

We have evaluated two color films and three photographic scales for classifying the limited stream trout habitat conditions present in four small study sites. Although this study was limited in scope, we feel the techniques and results reported here justify further investigation, particularly for evaluating high-use, high-value streams.

Interpretation of Habitat Conditions

Large-scale aerial photographs show some interesting possibilities for habitat evaluations. We found that the 1:1584 normal-color photographs gave the best overall results. On properly exposed color photographs at this scale, the interpreter can readily discern the form, shape, and color of instream and streambank features.

Instream Features

At the 1:1584 scale, aquatic vegetation was easier to identify on the CIR photographs than on normal-color photographs. Healthy vegetation appears bright red on these photographs, so that it is possible to identify beds of vegetation and determine their vigor. Increases in vegetation 1 year after removal of non-game fish were quite evident when 1968 and 1969 photographs were compared (*fig. 8*).

It was possible to describe aquatic plants with greater detail from the 1:600 photographs. This scale would be most useful to a fisheries biologist because of the amount of visible details. For instance, the trout-cover value and the quality of submergent and emergent aquatic plants can be assessed. Also, since certain types of trout stream insects are associated with aquatic vegetation, the biologist can subsample these plants in the stream for insect population estimates, with reference to photographs of the total aquatic vegetation present.

At 1:600, color photographs provided a more detailed description of stream bottom types than of the 1:1584 scale. Where the water surface was smooth and was not obscured by overhanging vegetation or shade, we were able to recognize the general types present in Hat Creek. The particle-size scaling aid (*fig. 3*) was used to categorize these types into size classes. When the bottom type is known, certain inferences about insect fauna can be made: for instance, certain bottom types provide habitat for larvae and nymphs of stream insects which are trout food, and trout food productivity varies with bottom type.

Water depths could be estimated by parallax measurement methods on those portions of the stream which did not have rough surfaces and were clear of overhanging vegetation and shade. Our most useful estimates were made on 1:1584-scale photographs that had been properly exposed for the stream—1968 color and 1969 CIR were best in this respect.

Other underwater features that can be seen best at the 1:600 scale include submerged logs, brush, limbs, and boulders. Root mats at the sides of the stream and on tree isles in the stream were also observed. These features can be classified and evaluated for their value as cover for trout and habitat for certain trout stream insects.

On those portions of Hat Creek where the stream width exceeded 100 feet, the 1:600 photographs did not give bank-to-bank coverage. This lack of coverage made it difficult to fully assess the bottom and underwater cover types. Better planning of photographic missions can reduce this problem, and two flight lines which sidelap may be required.

Surface velocity classes were best estimated at the 1:1584 scale on the CIR photography, but we were also able to classify them at the 1:6000 scale. The two classes (fast and slow) were inspected for water surface characteristics. Water classified as "fast" has a rough, rippled appearance with many white reflecting surfaces interspersed with clear water. "Slow" water has a smooth surface and appears clear. Reflections from rough surface water in full sunlight are more apparent on CIR than on color photographs. On CIR film, however, no surface details are visible in dense shadow (black) areas. Surface characteristics of slow and fast water types can be misleading if winds are affecting these surfaces at the time of photography. Wind effects on a slow water surface, such as a pool, may give it the appearance of a rough water surface.

After bottom types, water depth, cover types, and surface velocity types have been determined, the interpreter can further categorize the stream into general habitat types such as pools, runs, and riffles. Pools are habitat types of considerable depth for the size of the stream and have slow-flowing water with smooth surfaces. Within the study area, pools were difficult to classify because of the general character of lower Hat Creek. Run and riffle habitats are defined in the Hat Creek Management Plan (Gerstung

1975) as follows: "The . . . 'run' habitat . . . averages about 115 ft in width, 4-5 ft in depth and . . . is characterized by grassy undercut banks, a bottom of sand and silt with scattered gravel patches, boulders and sunken logs, and an abundance of rooted aquatic plants. The riffle section . . . is wider (mean width 126 ft), shallower (1.5 to 3 ft deep) and characterized by . . . faster velocities . . . [a] bottom . . . of rubble, boulders, some gravel and sparse plant growth." By recognizing these categories, the interpreter can assess the habitat in terms of shelter, resting spots, feeding spots, and spawning grounds. The 1:1584-scale photographs, both color and CIR, were useful for defining pools, runs, and riffles. We preferred the color photographs because surface details in shadow areas can be seen better. Color film is a better penetrator of water (Fritz 1967) and has a greater exposure latitude, resulting in better shadow penetration.

Streambank Features

It was easier to identify undercut banks on CIR photographs than on normal-color photographs on all three scales of photography. On the CIR photographs, moist grasses, which occur along undercut banks, appear in hues of bright red, and are thus more apparent than they are in the green hues of normal-color photographs. Undercut banks are important because they offer excellent cover for trout during the day.

The 1:1584 color photographs are adequate for distinguishing between conifers, deciduous hardwoods, and brush. Delineation of these vegetation types makes possible assessment of cover value for trout as determined by seasonal shade. Also, plant litter entering the stream can be evaluated: the plant litter from deciduous species is greater than from evergreen species. A portion of these wastes becomes habitat and a source of food for certain bottom-dwelling insects.

Bank features found along margins of the stream may be part of streambank conditions or part of instream conditions. Visibility of photographic details of these features depends on the scale and type of photography used. A scale of 1:600, color, was best for indentifying those at the water line, such as overhanging limbs and branches, debris washed up on the bank, undercut banks, cattail marshes, and mouths of tributaries. Bank cover types such as annual grasses, rocks, gravel, sand, and bare soil can be assessed at the stream margins for signs of erosion or other possible causes for unstable bank conditions.

Stream margin conditions up to 50 feet from the water's edge can be evaluated best on the 1:1584 color photographs. All the conditions identified on the 1:600 scale can also be observed at the 1:1584 scale; however, the detail is not as good. Additional features that can be seen include signs of cattle grazing, roads and trails, and in a broader view, ecological zones such as wooded reaches, meadows, and marshy stretches.

A more comprehensive view of streambanks and surrounding terrain, at distances greater than 50 feet, was obtained on the 1:6000 photographs. Color or panchromatic photographs at this scale would be useful for preparing special-purpose maps and for management planning. For example, a drainage basin map could be prepared by updating an existing map with these photographs. Another possibility is to prepare a photo mosaic from enlarged copies of the 70-mm photographs. The mosaic would serve as an updated map and overlays could be made and used for management planning purposes.

The streambank coverage seemed almost ideal at the 1:1584 scale. Where the stream was near the center of the photograph, we could see 50 feet on either side of the stream. Fifty feet from the bank of a 100-foot-wide stream seemed adequate to assess most of the shadow cover on the stream from nearby trees. However, not all trees could be seen on the photographs, for several reasons. First, if the stream was not in the center of the photograph (because of meandering by the stream or the aircraft) the 50-foot distance was not covered. This problem may be lessened by use of a slower aircraft (90 m/h or less) or a helicopter during the photo run. Also, trees taller than 50 feet and trees on moderate-to-steep slopes, whose shadows extended beyond 50 feet, were not covered by the photography. On the Hat Creek study area, a few steep slopes support trees 100 feet tall, or taller. When such slopes are on the east or west side of the stream, a slightly smaller scale of photography may be needed to fully assess the shadow effects.

Accuracy of Interpretation

From a total of 400 points interpreted on the photographs 95 points were selected at random and checked for accuracy on the ground (*table 2*).

Unfortunately, in such a small sample, not all classes were represented; aquatic vegetation and one bottom type, four streambank cover types, and two streambank types were checked and verified in the field. Aquatic vegetation was correctly identified in all cases where it was visible on the photographs and

Table 2—*Accuracy of classification for four trout stream condition classes using conventional photointerpretation techniques: color photographs, 1:1548 scale, taken 1968 and 1969, Hat Creek, California*

Stream condition	Points correct	Points incorrect	Total
Aquatic vegetation			
Submergent	6	0	6
Bottom types			
Sand	2	0	2
Subtotal	8	0	8
Bank cover types			
Bare soil	2	1	3
Gravel, rocks, boulders	3	0	3
Grasses, green	37	6	43
Grasses, brown	4	0	4
Subtotal	46	7	53
Bank types			
Low bank, no undercut	13	17	30
High bank, undercut	1	3	4
Subtotal	17	20	34
Total	71	27	95

not obscured by overhanging vegetation, shade, or rough surface water. Sand was correctly identified and was found to be associated with smooth surface water near banks of the stream and sandbars.

In most instances, bank cover classes were as we had identified them on the aerial photographs. One exception was on areas where dead grasses and bare soil were misinterpreted several times on the 1968 photographs. The film had been exposed for water (dark) rather than for streambanks (light), causing a "washed out" or overexposed appearance of the streambank details. Streambank interpretation errors were minor, however, when considered in relation to the amount of stream detail observed on film that had been exposed for water.

Results were often incorrect when bank types were classified by combining interpretation of form and shape with height estimations. Heights were based on photo comparisons with familiar objects. These inaccuracies (*table 2*) may be due in part to the following problems: (1) difficulty in determining how far the rising ground bordering the stream extends upward and to what point it still can be defined as part of the bank, (2) difficulty in determining the top of some irregularly-shaped banks, and (3) difficulty in determining margins of the stream when they are obscured by vegetation such as cattails or other high marsh grasses.

Accuracy of Measurements

Measurements of stream trout habitat parameters by means of aerial photo measuring devices, aids, and techniques were checked for accuracy.

Bottom types and water depths were measured directly on the photographs. Size of bottom types was measured with a particle-size scaling aid (*fig. 3*). Water depths were measured with parallax devices and microdensitometer techniques.

Particle-size—Accuracy was checked by comparing bottom types found in the ground measurements along each transect (at 1-foot intervals) to the photo-identified bottom type falling closest to the transect types. Stream bottoms with rough-textured appearance, such as rubble, rocks, and gravel, were correctly identified in most instances at the 1:1584 scale. The interpreter had some difficulty in differentiating fine (3- to 6-inch) and coarse (6- to 12-inch) rubble types when using the 1:1584 scale aid. With the larger 1:600 scale aid, the fine and coarse rubble types could be more readily classified.

Water Depth—Water depth was difficult to measure with either a 70-mm parallax bar or a parallax wedge because differential parallax (dp) readings are uncertain. The dp value is directly affected by the ability of the interpreter to locate and measure parallax accurately at the surface and on the bottom of the stream. This was nearly impossible to do. For instance, surface readings could not be taken on clear smooth surface water or in shadow areas. Sometimes, however, we were able to obtain a surface reading near the bank and water interface. Bottom types also affected our ability to make dp readings; that is, it was easier to locate a point on boulders and rubble than on sandy or silty bottoms. No bottom readings were made where the water surface was rough or covered by shadows. Where stream conditions permitted dp readings to be made, we found that depth estimates were within ±2 feet of the actual value. A factor for diffraction at the air-water interface was not used in the estimate. It generally took less time for an interpreter to make a set of dp readings with a parallax wedge than with the 70-mm parallax bar.

Correlation coefficients were calculated for the relation of actual stream depths to optical film density measured with a microdensitometer (*table 3*). The best correlations were obtained on the normal-color transparencies. Smooth water surface transects (*fig. 9a*), with little or no surface reflections, were more highly correlated than rough surface transects (*fig. 9b*). Thus, predictions of water depths are most reliable when there are the least water surface effects.

The high correlation on transect 2 (CIR) was unexpected because clear bodies of water absorb infrared energy and usually appear dark or black on

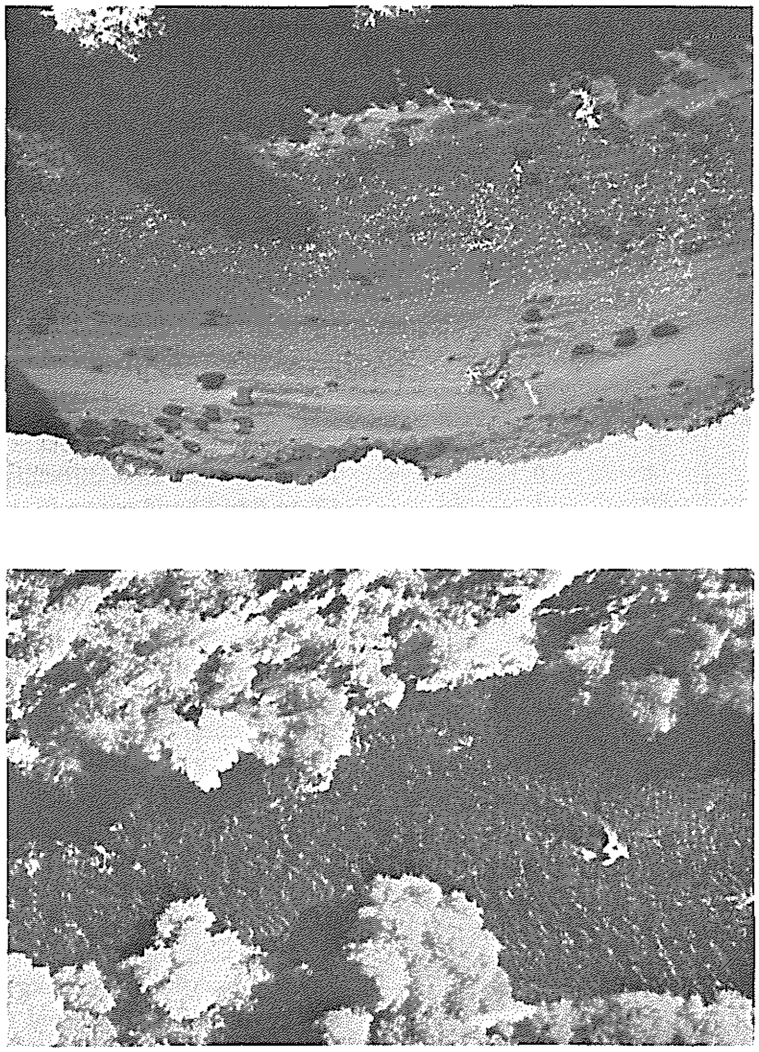

Figure 9—The best correlation between film density and water depth was achieved where the surface of the water was smooth. Here some reflections are seen in midstream on a smooth surface (*top*), but on a rough surface (*bottom*) water surface effects are pronounced.

CIR transparencies. A dark image would result in high uniform density values above 3.00 on a scale of densities ranging from 0.00 to 4.00. However, our data showed density values ranging from 2.30 to 2.97, and the increases or decreases in values were comparable to changes in water depth (*fig. 10*). We tried the same analysis on the 1969 film density values, but apparently changes in the stream since 1968 resulted in poor data correlations. Further work is required to fully explain the reasons for this poor correlation.

Table 3—*Correlation coefficients for the relation between optical film density and water depth, according to film type and transect (1968 photography, 1:1584 scale, Hat Creek, California)*

Transect no. and water surface	Film density/water depth correlation coefficient (%)	
	Color	CIR
1, rough	0.560	0.651
2, smooth	.818	.891
3, smooth	.860	.790
4, rough/smooth	.716	.496
Mean	.764	.735

Streambank

A distance-measuring scale was used at the actual scale to make length or width determinations of various stream features. Parallax methods were used to measure heights of banks and vegetation. Measurement of shadow length on the photographs was also

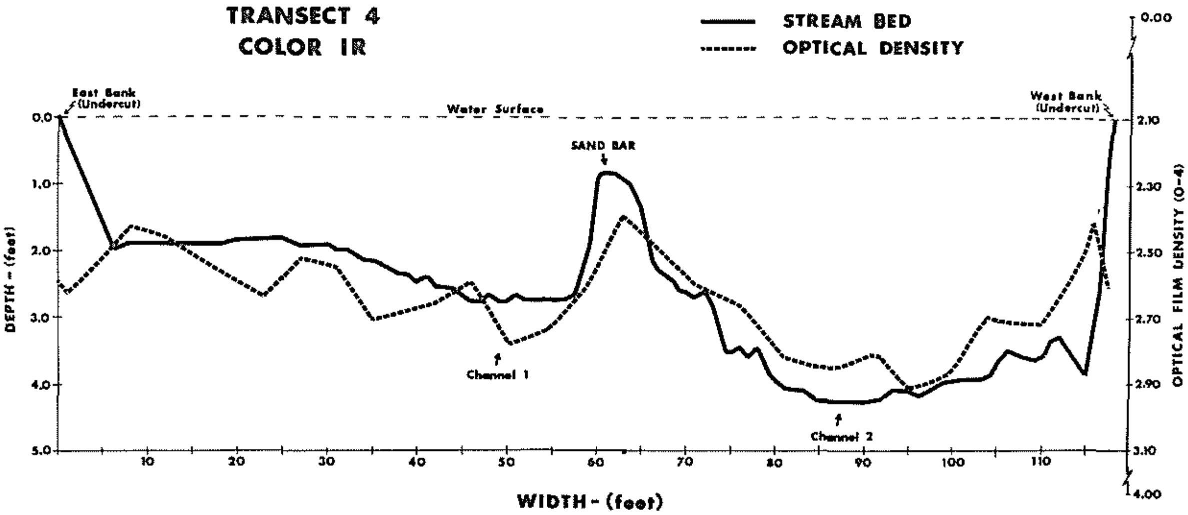

Figure 10—A comparison of optical film density and water depth was made for transect 4 across Hat Creek. Film density was measured on color infrared film at a scale of 1:1584.

used for height determinations. Shade effect tables were developed and used to evaluate shade cover for various times of the day.

Distance—Careful measurements between two points, using the proper scale factor, gave distance accuracies within ±0.5 ft. Distance could be measured using either the 1:600 or 1:1584 aids on the appropriate photography.

Bank Heights—Measurement of stream heights on 1:1584-scale photographs with a 70-mm parallax bar worked satisfactorily for banks whose slope extended sharply upward from the edge of the water. Bank heights associated with marsh grasses (2 to 6 inches above water level) were difficult to estimate because the parallax differences were too small to measure accurately. Further work is needed to establish streambank classes that can be measured by parallax methods, and to develop procedures for measuring length of slope and percent of slope.

Vegetation Heights—Streambank vegetation (bush or tree) heights were measured by three interpreters using the 70-mm parallax bar method and the shadow length method. Using these methods, the vegetation was categorized into one of five height classes (*table 4*).

When using the parallax bar, the low percentage of correct estimates for smaller vegetation classes (0 to 4 ft, 4 to 15 ft) is partially due to the physical shape of the vegetation. Most of these samples were either bushes or small trees without well-defined tops and shapes as viewed on the photographs, which made it difficult for the interpreter to locate the highest point of a bush or tree for dp measurements. Our data indicate that a ±0.10-mm deviation from the true dp

Table 4—*Percentage of vegetation samples classified correctly, by height class, measurement method, and interpreter (color and color infrared, 1:1584 scale, taken 1968 and 1969, Hat Creek, California)*

Height class (ft)	Number of samples	Interpreter 1		Interpreter 2		Interpreter 3	
		Parallax	Shadow	Parallax	Shadow	Parallax	Shadow
		Percent					
0 to 4	8	44	100	60	100	11	100
4 to 15	9	67	67	67	78	75	100
15 to 50	12	79	92	80	100	93	100
50 to 100	11	82	100	27	82	82	91
100+	4	67	80	0	50	33	67
Mean, all classes		68	88	47	82	59	92

Table 5–*Relation of shadow length to height class on 1:1630 (actual scale) photographs taken on October 8, 1968, at 1120 hours PST,*[1] *Hat Creek, California*

Shadow lengths measured on photo (inches)	Vegetation height class (feet)
0.000 to 0.040	5 (0 to 5)
0.041 to 0.080	10 (6 to 10)
0.081 to 0.160	20 (11 to 20)
0.161 to 0.240	30 (21 to 30)
0.241 to 0.320	40 (31 to 40)
0.321 to 0.401	50 (41 to 50)
0.402 to 0.481	60 (51 to 60)
0.482 to 0.561	70 (61 to 70)
0.562 to 0.641	80 (71 to 80)
0.642 to 0.721	90 (81 to 90)
0.722 to 0.801	100 (91 to 100)

[1] Latitude 40°58′20″ N; longitude 121°33′11″ W.

could affect total heights by 10 feet or less depending on the height of the vegetation.

Measurements of vegetation height using the shadow method were better than those using the parallax methods. The relative ease of measuring shadow lengths with either an inch rule or shadow wedge makes this an appealing method.

One disadvantage of the shadow method is that inaccurate measurements can be made in measuring shadows on moderate-to-steep slopes. Shadow lengths increase or decrease depending on direction of the shadow in relation to slope and position of the

Table 7–*Shadow position by hour of day–October 8, 1968, Hat Creek, California*

Time (PST)	Shadow azimuth	Time (PST)	Shadow azimuth
0800	297°36′19″	1200	355°45′27″
0900	310°23′12″	1300	23°30′23″
1000	325°46′12″	1400	40°59′42″
1100	344°04′36″	1500	55°12′37″
[1]1120	350°41′42″	1600	67°08′29″

[1] Time of photography in this study.

vegetation on the slope; that is, a tree located on top of a steep slope casts a longer shadow downslope than a tree located near the bottom of a slope. The problem may be reduced by applying a slope correction factor to the height estimates. These factors were not computed for this study.

Shade Effect–Tables illustrating the effects of shade created by streambank vegetation were developed for the October 8, 1968, photography (*tables 5, 6, and 7*). *Table 5* converts shadow length in inches at 1120 hours on October 8, 1968, to height class in feet. For example, if the shadow of a pine tree is measured and found to be 0.171 inches, it falls in the 0.161 to 0.240 group, and is in the 30-foot height class.

Once the height class is known, the tree's shadow length and position on the stream for any time of day can be determined from *tables 6 and 7.* For example, a tree of height class (30 feet): from *table 6,* at 0800 hours, the shadow length value is 0.608 inches; from *table 7* the position of the tree's shadow on the stream is 297°36′19″. With this information it is possible to assess the effects of the tree's shadow on

Table 6–*Shadow lengths*[1] *by hour of day–October 8, 1968, Hat Creek, California*

Time (PST)	Shadow length at vegetation height-class (feet) of . . .										
	5	10	20	30	40	50	60	70	80	90	100
						Inches					
0800	0.101	0.203	0.405	0.608	0.810	1.013	1.215	1.414	1.621	1.823	2.026
0900	.065	.131	.262	.393	.523	.654	.785	.916	1.047	1.178	1.309
1000	.049	.098	.196	.294	.392	.490	.587	.685	.783	.881	.979
1100	.041	.083	.165	.247	.330	.412	.495	.577	.660	.742	.825
[2]1120	.040	.080	.160	.240	.320	.401	.481	.561	.641	.721	.801
1200	.040	.079	.158	.238	.317	.396	.475	.554	.633	.713	.792
1300	.040	.080	.159	.239	.319	.398	.478	.557	.637	.717	.796
1400	.054	.109	.218	.327	.436	.544	.653	.762	.871	.980	1.089
1500	.077	.154	.307	.461	.614	.768	.921	1.075	1.228	1.382	1.535
1600	.131	.262	.524	.785	1.047	1.309	1.571	1.833	2.094	2.356	2.618

[1] Shadow length values are for the upper limit of each height class.
[2] Time of photography.

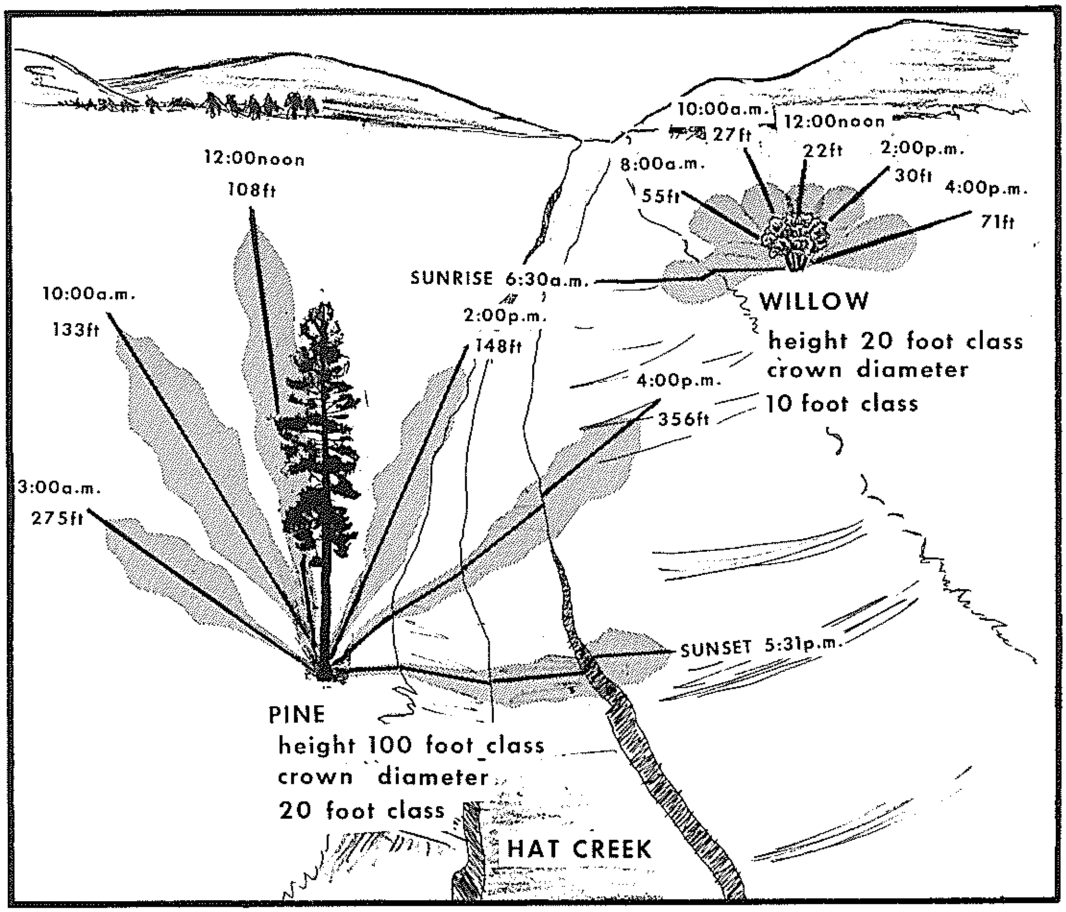

Figure 11—The effects of shade caused by two trees on a portion of Hat Creek—October 8, 1968—are shown diagramatically.

the stream throughout the day in terms of shade cover for trout. The example *(fig. 11)* shows shadow effects of two trees—one on the east bank and one on the west bank of a north-flowing stream, and how changes in shadow position during the day might affect trout cover. The shadow of the pine tree affects the stream from 2 p.m. until sunset and no shadow affects from the willow tree. In this example, a trout would seek protection from direct sun rays under cover offered by the pine. Since trout have no eyelids and seek shelter in shadowy places to shield their eyes (Schwiebert 1974), this protection is needed more during afternoon hours than early morning hours.

Other measurable factors include size of shaded areas and portions on the stream covered by shadow at various times of the day. The pine with a 60-foot-wide shadow across the stream would provide a larger area for protecting trout from direct sun rays. When coupled with other conditions such as a submerged log or boulder, the shaded area further enhances good trout habitat. Although cover value of the willow is not as good as that of the pine, the willow would rank higher as a source of plant and insect supply to the stream. The willow may have branches which overhang the water, making it easy for insects and plant litter to fall off into the water. There they become part of the food supply for both trout and aquatic insects.

Habitat Evaluation Cost

The cost of evaluating stream habitats using large-scale color photography varies depending on such factors as (1) the air distance to the stream, (2) the number of streams and distance between streams to be photographed, (3) the length of the stream, (4) the scale of photography, (5) the number of criteria and photo techniques to evaluate habitat, and (6) the number of ground checks required to validate photo classes and to obtain additional data. Several costs remain relatively constant. These include aircraft flight costs, photographic cost, and photointerpretation costs. Below we have estimated the costs for large-scale photography using two 70-mm cameras for an evaluation of a stream in Shasta County, California. One camera with a 9-inch lens takes normal-color photography at a scale of 1:1600 and a second camera with a 3-inch lens takes 1:4800-scale coverage with panchromatic film. The distance from the aircraft home base is 190 nautical miles. The length of the stream is 10 miles, and because of meanders we have cut it into five sections, each approximately 2 miles long. It is assumed that an interpreter will examine each center photo in a triplet and count or map essential habitat criteria for selecting random ground-check points. The cost of ground checks, a very essential part of habitat evaluation, is not included in our cost estimates. Ground check costs vary widely depending on the sample intensity and the amount of details required.

	Cost[a]
Aircraft flight costs:	
Aircraft cost (5h, at $105/hr)[b]	$ 525.00
Crew cost (8h, pilot & photographer)	128.00
Subtotal	653.00
Photographic costs:	
Film–color, one 100-ft roll @ $50.00	50.00
pan, 1/3 of 100-ft roll @ $15.00	5.00
Film processing and printing	20.00
3 man-days	150.00
Mosaic construction (1 man-day)	40.00
Interpretation (color) 150 triplets (transects) @ 6 per day = 25 man-days	1,100.00
Materials	100.00
Subtotal	$1,465.00
Total cost of photo evaluation	$2,118.00

[a] Costs to the Government without profit margin.
[b] Aero Commander, twin engine; time includes cross-country time from the San Francisco Bay Area.

CONCLUSIONS

Aerial photography described in this study can be a valuable tool for evaluating stream trout habitat. Most characteristics of trout streams are visible and are described directly on the photographs. Some conditions such as average size of stream bottom aggregates, depth of water, streambank heights, and heights of streambank vegetation are estimated using special measuring aids. Degree of shade on the stream can be evaluated using a technique that includes measurement of vegetation shadow lengths and vegetation positions in relation to the stream and the use of solar position diagrams or solar formulas. Habitats supporting trout stream insect production can potentially be evaluated using the photographs as a base from which to sample and collect this biological data.

The best overall scale and film for evaluating streambank conditions is normal color at 1:1584 scale. Exceptions to this are areas where low grassy areas with undercut banks occur and where healthy aquatic vegetation is found–here color infrared was the better film. Also, reflections from rough surface water were easier to see on CIR film.

The largest scale (1:600) photographs were better for detailed descriptions of stream conditions and are preferred by fishery biologists. Complete coverage of the stream width is possible at this scale when stream width is less than 100 ft. Color infrared at this scale worked well for assessing aquatic vegetations, whereas color was best for bottom types.

APPENDIX

A: Helpful Formulas

Most of the formulas used in this study may be found in a photointerpretation textbook or in an ephemeris. Because formulas vary in details, however, those we used are given here. They were selected for ease in computation with a tabletop calculator.

Parallax: Used for finding water depths using parallax measuring devices.

$$D_w = \frac{(fl \times dp) \times scale}{(p \times 25.4) + dp}$$

in which

D_w = water depth
fl = the camera lens focal length in feet (in this case 0.5 feet)
dp = parallax difference between the water surface and the stream bottom (mm)
Scale = the photo scale factor (denominator of the representative fraction)
p = air base measurement (inches) (distance between principal point and conjugate point for each stereo pair)
25.4 = conversion factor for inches to millimeters

Solar Altitude: Used in formulas for finding shadow azimuth and in formulas to convert shadow length to tree height.

$$\sin x \text{ (solar altitude)} = \cos a \cos b \cos c \pm \sin a \sin b$$

In which

a = latitude of photo (obtained from topographic map of area photographed)
b = solar declination for the date of photography (obtained from a solar ephemeris for particular year required)
c = hour angle or difference in longitude of sun at actual time of photography (calculated for time of day at which the air photo was taken).

An example for obtaining the hour angle is found in the textbook *Aerial Photographs in Forestry* (Spurr 1948, p. 230).

Solar Azimuth: Used for finding shadow direction.

$$\sin y = \frac{(-\cos b)(\sin c)}{(\cos x)}$$

In which

sin y = sun's azimuth
cos b = solar declination for the date of photography
sin c = hour angle at actual time of photography
cos x = solar altitude

Shadow length to height conversion: Used to obtain streambank vegetation heights.

$$H = (L)(\text{RF factor})(\tan x)$$

In which

H = height of tree in feet
L = measured shadow length on photograph to the nearest 0.01 or 0.001 inch
RF factor = scale for photograph on which shadow measurements are made in feet (denominator of the representative fraction)
tan x = tan value for the solar altitude x.

B: Procedures for Determining Degree of Shade on a Stream

A. Complete the following steps once for each date and time of photography.

1. Find the values for altitude and azimuth of the sun. One convenient way is to use computer-generated solar position diagrams. The diagrams are for each 2° of latitude from 0°–90° and show altitude and azimuth of the sun when time, date, and latitude of photography are known (Clark 1971).

Another way requires solving equations for solar altitude and azimuth (See Appendix A). Even though the calculations are lengthy, the values obtained are more accurate than those taken from the diagrams; the equations are based on apparent positions of the sun in the sky, whereas the diagrams use average position of the sun for each 2° of latitude.

2. Determine the shadow position. Using the solar azimuth equation, the solar azimuth at 1120 hours on October 8, 1968 (the time and date of our photography) at a latitude of 40°58′ is -9°18′. Shadow position is the back azimuth (±180°) degree reading of this value or 350°42′.

3. Determine a true north line. True north is found on a single photograph by placing the center of an azimuth circle (0° to 360°) or protractor on the center of a tree crown with a well-defined shadow. Align the shadow with the 350°42′ mark on the protractor. Without moving the protractor, locate 0° and mark this point on the photograph. A line connecting this point and the center of the tree crown is a true north line.

B. Complete the following steps to determine which bushes or trees affect the stream. Measurements are made on photo stereo triplets.

1. Determine the position of a bush or tree in relation to the stream. Once the true north line is established, the position of any bush or tree in relation to the stream is found by measuring with a protractor on a single photograph.

2. Determine the distance of each bush or tree from the stream. The distance is measured perpendicular to a tangent at the nearest point on the streambank using the appropriate scale factor on the distance measuring scale.

3. Determine the height of a bush or tree. Heights can be measured in a number of ways using parallax devices (Weber 1965; Wert and Myhre 1967), or shadow length (Spurr 1948). We tried two methods for measuring vegetation heights:

(1) A 70-mm parallax bar which measures differential parallax (dp) in units of 0.001-mm on stereophotos. The parallax principles used to estimate depths of water also apply to vegetation height measurements, with dp measured at the top and bottom of a tree.

(2) A ruler or shadow wedge which measures shadow lengths in increments of 0.01 inch or 0.001 inch on a single photo. The solar altitude value and the measured length of a shadow are used in the shadow height equation (See Appendix A). A height-class table based on measured length of shadow can be prepared when many heights are needed. *Table 5* (see text) is an example for the October 1968 photography.

C. Determine shadow azimuth and shadow length for a range of times other than the time of the photography. This step is made simplest by preparing tables, similar to *tables 6 and 7* in text, for assessment of shadow effects throughout the day. With additional photography for each of the four seasons, these tables may be expanded over a year's time.

D. Complete the following steps on those bushes and trees which affect the stream.

1. Determine whether a bush or tree is evergreen or deciduous. This is done by interpretation of crown shape, color, and branching characteristics.

2. Measure the crown diameter of a bush or tree. Use the distance-measuring scale or a crown diameter wedge.

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