

## **Assessment of various methods of canopy cover estimation that yield accurate results with field repeatability.**

HUYNH, M. L. Northern Arizona University, Flagstaff, AZ 86001-5018 USA

### **Abstract**

I used existing literature and interviewed professionals to discern which method of measuring tree canopy cover is the most accurate and useful in the field. I defined the most accurate method as the one that appears to have the least amount of criticism leveled against it. The study focused on the Sierra Nevada ecosystem or a similar mixed conifer forest ecosystem. The results from the literature survey suggest a single method of canopy cover measurement should be adopted to ensure consistency between measurements made by different people and in different forests. Achieving consistency will provide for more uniform management policy between National Forests in the Sierra Nevada region. Consistent measurement will also shape future decisions and interpretation of management policy regarding canopy cover.

**Key Words:** Canopy cover, canopy closure, spherical densiometer, densitometer, and hemispherical photographs

### **Introduction**

The condition of forest canopies is of vital concern to many foresters and forest ecologists. Wildlife concerns, fire behavior, and understory regeneration are just a few management issues that are related to forest canopy (Rettie et al 1997; Huggard 2003). Over the years, many tools have been developed to quantify forest canopy. These tools range in sophistication from simple hand-held convex mirrors to computer analysis of digital photos. Despite the number of tools available to the professional and researcher, the misunderstanding of forest canopy cover and misuse in application of the tools still persist among many (Jennings et al 1999). Often times, misunderstanding of forest canopy can lead to inconsistent forest management that can render a land management plan pointless. The objective of developing a management plan is to provide consistency in management actions on a landscape level. This is of particular importance in the role that canopy cover plays in the management of the National Forests in the California Sierra Nevadas.

The Sierra Nevada Framework (SNF) is a guiding document that gives management direction to all National Forests in the Sierras, affecting a total of seven National Forests and over six million acres within California. Canopy guidelines are an important component of this document. The lack of understanding of forest canopy conditions and the tools to measure it can lead to confusion among managers. This paper will attempt to delineate the differences in terminology used and the specific applications of the various canopy assessment tools employed by professionals. Different tools will be analyzed using the current literature to assess the appropriate situations for their use and recommendations will be made that pertain to the specifics of the Sierra Nevada ecosystem.

Forest canopy plays an important part in forest stand dynamics and wildlife habitability (Reid 1964, Hendrick et al 1968, and Pase 1958), yet the determination of its condition is often confusing and misinterpreted, even among professionals. Sunlight reaching the forest floor is an important component of forest microhabitat. There is a relationship between tree overstory and herbaceous production (Jameson 1968). These forest floor characteristics are important to wildlife and general forest biodiversity.

The terms “canopy cover” and “canopy closure” are two common terms used to describe forest canopy conditions. Although these two terms are implying distinct characteristics of forest canopy, they are often used synonymously and incorrectly. Canopy closure is defined as the proportion of the sky’s hemisphere obscured by vegetation when viewed from a single point (Jennings et al 1999; Zhu et al 2003) and canopy cover is understood to be the vertical projection of the forest floor that is obscured by forest canopy (Jennings et al 1999; Zhu et al 2003). Canopy cover and canopy closure are two very different measurements of forest canopy (see Figure 1). Since canopy cover measures the vertical projection of tree crowns, it is unaffected by

tree heights and the height's of their crowns. These variables are not considered from a canopy cover perspective. Oftentimes, a forest stand's canopy cover does not change as trees grow.

Unless the crowns become denser and grow into each other, canopy cover will remain the same.

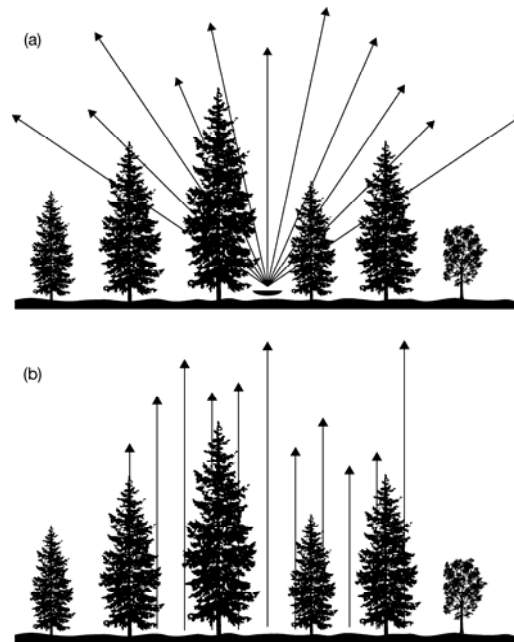


Figure 1. Example depicting (a) canopy closure and (b) canopy cover

Canopy closure measures a forest stands' canopy density from a proportional, hemispherical point of view.

### ***Sierra Nevadas Background***

In the early 1990's, the Sierra Nevada Ecosystem Project (SNEP) was started to assess the environmental, social, and economic condition of the Sierra forests and their communities. The Sierra Nevada Framework (SNF), also referred to as the Sierran Nevada Forest Plan (SNFP), that resulted from this assessment has recommended widespread forest thinning as a solution to the wildfire danger, social, and economic woes of the Sierras. The Healthy Forests Initiative has also bolstered forest activities on Sierra Nevada public lands by providing funding for forest thinning projects and forest restoration projects.

The Sierra Nevadas of California are a large and diverse ecosystem. East of the California Central Valley and west of Nevada, it is a continuous mountain range that stretches north and south, about 360 miles. Situated within this mountain range lies a vast array of fauna and flora and geographical variety. The geology of the Sierras also lends to its diversity. With an active fault system and volcanic activity in the northern region, these forces continuously shape the mountain range. Glaciers during the last Ice Age have created moraines and valleys in places such as Yosemite. In these areas, ecosystem diversity has abounded (Storer and Usinger 1963). The Sierras can be broken into different ecological zones dominated by various tree species. The elevation zones are all approximate and usually decrease in elevation from north to south.

The presence of humans and their activity has existed for thousands of years, although post Euro-settlement actions have caused the most drastic change in the Sierras. The Native Americans that inhabited the Sierras, though relatively low in impact, nonetheless affected the environment around them. Perhaps the activity that had the greatest impact was the lighting of small intensity fires by Native Americans. This was done to encourage growth of certain plant and tree species, reduce potential ambush cover for enemies, and to drive game species out of their hiding cover. The discovery of gold in the Sierras during the mid-1800's and the resulting wave of settlers from all over the world dramatically increased the demand for forest products. The use of forest products steadily increased for over the next century until about the mid-1980's. The growing public awareness and the plight of certain endangered and threatened species such as the Northern Spotted Owl (*Strix occidentalis caurina*) brought national and world attention to logging activities in the west. Public pressure has effectively halted major

logging activity on public lands. Recently, the increasingly danger of wildfires and over-stocked forests as well as Sierra community viability has brought an interest in forest thinning and sustainable forestry.

### *Current Management Implications*

Located within a state that is well known for its public participation and awareness in environmental issues, public land managers there are under constant scrutiny. These pressures from the public demand that land managers apply sound scientific principles to guide their decisions regarding management actions. The use and application of science is crucial to building and maintaining agency credibility. Due to its widespread importance and broad application, forest canopy condition has been used as a guideline to assess forest health and habitat suitability for wildlife. Canopy cover and closure drive many of the guidelines of the Sierra Nevada Framework. The Defensible Fuel Protection Zones (DFPZ's) that protect Wildland Urban Interfaces (WUI) require thinning dense stands to a crown closure of 40%. Much of the Sierras is stratified by crown cover into different California Wildlife Habitat Relationship (CWHR) types. Unfortunately, despite its widespread use, there are still subtle differences in understanding and application that have led to management problems and challenges.

Depending upon the management objectives, the incorrect measure and application of forest canopy condition can lead to drastic results. The Wildlife Habitat Relationship (WHR) model that the California State Department of Fish and Game uses requires several inputs to predict habitability of ecosystems for wildlife. It is an important tool that wildlife biologists and game wardens use to manage fauna in California. Some of the inputs required by the WHR model to predict wildlife habitat suitability are main dominant vegetation, slope, geographic

region, and crown closure (CA Dept. of Fish and Game). Although there is no specific tool required, the California Department of Fish and Game (CDFG) recommends the use of a densitometer built by the Geographic Resource Solutions (GRS) company. The densitometer measures a different component of forest canopy (canopy cover as opposed to canopy closure). Because CDFG does not require a specific canopy measuring device, the WHR model could give differing habitat predictions depending upon the numbers calculated by the forester. The implications of the misapplication of canopy cover versus canopy closure can vary. General, informal interpretations of canopy cover or canopy closure probably do not impact management decisions greatly. It is the scientific application of canopy cover and canopy closure that may affect natural resource management the most. The body of literature regarding the implications of using canopy cover and canopy closure interchangeably was found to be lacking. However, it generally agreed that canopy cover's vertical perspective limits its application in studying ecotones (Matlack 1992; Zhu et al 2003). Canopy closure's hemispherical perspective takes into consideration the lateral effects of forest canopy. This can be of importance for wind protection, incidental radiation effects on microclimate, and edge effects. Canopy cover does play an important role in delineating openings within the forest, especially in applications involving wildlife (Rettie et al 1997; Huggard 2003). What is not known is the danger of using the two metrics interchangeably, although it can be argued that consistency in terminology and application can only lead to greater consistency in management.

Unfortunately, problems such as this are more common than not. Models such as WHR play an important role in management of public lands. Often times, they serve as guidelines for maximum allowable timber harvest and habitat protection. Other management guidelines incorporating forest canopy characteristics are the construction of Defensible Fuel Profile Zones

(DFPZ's), shade retention along streams, and old growth guidelines. The need for a universal understanding and application of canopy cover and canopy closure is vital to consistent management of forests. The tools used by professionals must be accurate and consistent. Otherwise, important guidelines may be misinterpreted and efforts made by land management professionals will be in vain.

The implications of incorrect usage and application of crown condition can vary. In general, forestry and land management is a profession that is based upon science. The correct use of terminology is important, both within professional ranks as well as to build professional credibility with the public. For example, in the 1988 Plumas National Forest Land Management Plan, wildlife conservation recommendations list minimum requirements for crown closure. Currently, the Plumas NF stratifies its forest according to Wildlife Habitat Relationship classes comprised of crown closure, tree species and density. The Sierra Nevada Framework states in its *glossary* section in the Record of Decision (ROD) that canopy cover is also referred to as "canopy closure" and the values for "...canopy cover can be derived in many ways." The general confusion brought on by different interpretations and usage of language and misuse of canopy measuring tools is at least undesirable and at most, detrimental to science-based land management.

The Sierra Nevada Framework places a heavy emphasis on ecosystem management that would protect national forests, wildlife, and human populations from the dangers of wildfire. The Rationale for Decision in the ROD highlights old forest ecosystems, riparian areas, meadows, fire disturbance, and forest health as areas that will receive important management attention. Many of these areas are classified with canopy components in mind and are managed with canopy guidelines. Clearly, the importance of precise use of language and application

regarding canopy cover and canopy closure is obvious. For example, spotted owls are a wildlife species of concern in the SNF. Their Home Range Core Areas (HRCA) requires management to retain canopy closure of at least 50-70 percent. Fire and fuels management strategy is based around CWHR types with accompanying guidelines including minimum canopy cover levels. These are some of the situations and objectives where canopy cover plays an important role in deciding management direction.

Unfortunately, management has had a hard time grappling with the implementation of canopy cover guidelines. Many silviculturalists in the Sierra Nevadas have privately admitted that they have had difficulty in translating canopy cover guidelines into timber marking prescriptions. Often these prescriptions roughly equate minimum canopy cover requirements to minimum basal area retention timber marking prescriptions. In theory canopy closure is associated with stand volume because it is an approximate indicator of stand density and trees per acre (Avery and Burkhart 2002). In reality, multi-tiered stands can have varying levels of canopy layers due to the multiple crown positions of individual trees. Crown closure and cover can have no relation to basal area and/or stand density. The challenge of using forest canopy characteristics goes beyond appropriate use of technical language. The application of canopy closure as prescribed by the SNF presents a unique problem to forest managers as well.

### **Canopy Cover**

A device called a sighting tube or densitometer often measures canopy cover. The device allows the observer to measure the vertical projection of canopy cover (see Figure 2). It is sometimes incorrectly referred to as a “moose horn”. Canopy closure is often measured with a



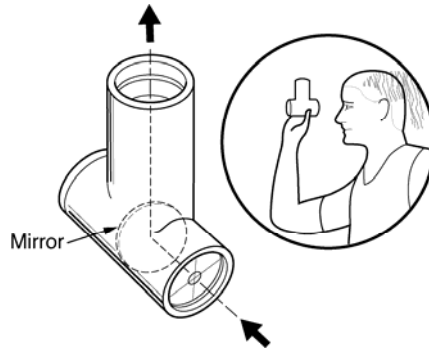


Figure 2. Canopy cover measuring device (GRS densitometer)

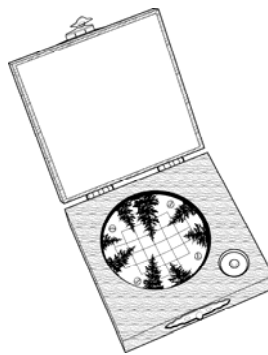
spherical densiometer or a moosehorn. These devices measure the hemispherical interception of the sky by a tree's canopy. A stand's canopy closure is affected by height of trees and base to live crown heights. As a stand grows, canopy closure can obscure the sky's hemisphere. A forest stand's canopy closure can increase over time, but its canopy cover remain the same. The before mentioned devices take this into consideration and measure the appropriate qualities of a forest canopy, either it being canopy closure or canopy cover. The use of these two terms synonymously is not only incorrect, but can lead to serious discrepancies in management.

Forest canopy is often measured by the GRS densiometer, spherical densiometer, or hemispherical photograph analysis. Many foresters also often employ the use of ocular estimation due to convenience and the hassle of using the previous mentioned tools. Despite many foresters and land managers using the different tools interchangeably, the tools vary in their application and emphasis. It is a common error to apply use of these tools and their measurements without realizing their differences. Each forest canopy measuring tool has its own inherent strengths, weaknesses, and application. It is important that the land manager understand this and choose appropriately. Remote sensing techniques such as photo interpretation or satellite imagery will not be discussed in this paper. The focus of this paper is to examine tools that can be used in the field by technicians and land managers. Although very valuable, remote

sensing requires expensive and sophisticated equipment that does not lend well to field application.

### *Spherical Densiometer*

The spherical densiometer is a compact device that fits in the palm of your hand is designed to measure forest canopy closure. Invented by Dr. Paul Lemmon in 1957 (Lemmon 1957), it is simply a convex mirror with a grid overlay (see Figure 3). Some models come with bubble levels to indicate whether the device is being held in a level position. It currently retails for approximately \$100.00 at most forestry suppliers ([www.forestry-suppliers.com](http://www.forestry-suppliers.com), [www.benmeadows.com](http://www.benmeadows.com)).



*Figure 3.* Spherical densiometer

The tool is relatively easy to use. The user holds the tool level and far enough away from the body such that the operator's head is just outside of the mirror's perspective. There is also the option of fixing the spherical densiometer onto a staff to increase the ease of use and precision. The user then counts the number of dots (maximum of 96 dots) that occupy openings in the forest canopy. Each dot is multiplied by 1.04 to obtain the percent of openings in the forest canopy giving a maximum canopy closure of 99.84% . This number is subtracted from 100% to determine the amount of canopy closure. If the amount of openings in the forest canopy greatly outnumber the canopy itself, the operator can count the number of canopy "hits" instead. The

number of dots is then multiplied by 1.04 to determine the amount of forest canopy closure. Lemmon (1957) recommends making a reading at each cardinal direction from a “reference tree”. A reference tree is assumed to represent a typical co-dominant or dominant tree in a stand. These four readings are then averaged. Statistical accuracy is dependent upon the four readings. Dealy (1960) recommends using a line transect sample design to measure low overstory crown foliage.

The spherical densiometer provides the land manager with a compact tool that can quickly assess canopy closure. Its use since the mid-1950's indicates its wide acceptance and application. It is a common tool that many forestry and land management students find themselves using while in college. Lemmon (1957) states in a study among four different users taking measurements in 28 different forests that there was little significant variation in results between the operators. Differences due to forest conditions did appear to have a significant impact. It was concluded that there was a 99% level of probability that forest conditions play the greatest role in spherical densiometer measurement variation. Under similar forest canopy conditions, differences in measurements varied at +/-3.1% at the 99% accuracy level (Lemmon 1957). Variability in measurements increased as the amount of forest overstory decreased. Stratifying the canopy closure to percent classes also increased the amount of variation in sampling.

The spherical densiometer has remained in use for a number of reasons. The relatively cheap cost of the tool allows wide access to agencies on tight budgets as well as private consulting companies. The affordability of the tool enhanced by its durable construction. With only one moving part - a hinge that protects the mirror- the spherical densiometer is extremely rugged and unaffected by any type of weather conditions. This allows the tool to be used for

many years before requiring replacement. The compact size and lightweight of the unit allows it to be carried at all times. The simplicity of application is an additional benefit. Use of the spherical densiometer requires little instruction. In addition, field calculations can be made with a calculator. Canopy closure can be assessed in the field with no lag time.

Like many tools, the spherical densiometer also has disadvantages. Despite claims by Lemmon (1957) of the reliability and low variation in sampling, the spherical densiometer has been cited by many as having low accuracy, low precision, and high variation among users (Ganey and Block 1994; Gill et al. 2000; Jennings et al. 1999). Many users have concurred with this claim with anecdotal stories of difficulty in using the device. Wind, unsteady hands, and the inability of most operators to hold their body in the same exact position compromise accurate and precise measurement of canopy closure, which contradicts Lemmon's (1957) claim of the spherical densiometer's accuracy and precision. As a result, users often times get different results of canopy closure from the same sample point. The lack of "field repeatability" can make use of the tool very frustrating and implementation of canopy closure guidelines somewhat difficult. Most foresters and land managers have actually professed dislike of the device, and even though the device is still sold, its actual use and application is decreasing. User bias, difficulty in attaining accurate and precise canopy closure estimates, and general mistrust of the tool are drawbacks that have lent to its decreased use by foresters and land managers.

### ***GRS Vertical Densitometer***

In the early 1990's, Geographic Resource Solutions (GRS) produced a device called the vertical densitometer that was capable of measuring canopy cover. At approximately \$100.00, it is sold at a variety of forestry supply companies ([www.forestry-suppliers.com](http://www.forestry-suppliers.com); [www.benmeadows.com](http://www.benmeadows.com)). Consisting of two pieces of PVC piping in the shape of a "T", it

allows the operator to measure the vertical projection and coverage of a forest's canopy. Inside of the vertical densitometer is a mirror set at an angle that gives a vertical view of the canopy above to the user holding the device on the ground. Two levels within the device ensure that the view is truly vertical to the ground. Inside the viewing tube is a set of crosshairs (see Figure 4).

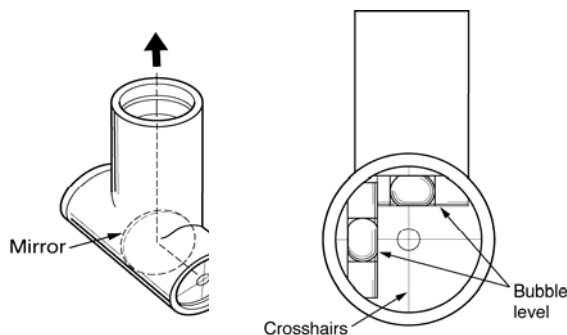


Figure 4. GRS Vertical densitometer and “inside” perspective

If the crosshairs are obscured by canopy, then it is recorded as a “hit”. The total number of “hits” divided by the total number of sample points taken is the percentage of crown cover within a forest. For example, if 23 out of 100 sample points were “hits”, then the crown cover for that particular stand would be 23%. When combined with a line-point transect, both vertical and surface vegetation sampling could be accomplished (Stumpf 1993).

The GRS vertical densitometer allows rapid and thorough canopy cover sampling. Ganey and Block (1994) found low variation of canopy cover estimates among different users. In their study, three observers made various estimates of canopy cover using a vertical densitometer. Within-plot variation among the different users averaged  $8.2 \pm 5.4\%$  standard deviation. Difference in average estimates among operators was 2.8%. Ganey and Block (1994) also recommend a minimum of 20 sample points per plot to minimize variation in sampling, although they made no reference to how many sample plots should be used to assess a stand. Jennings et al (1999) disagree with Ganey and Block (1994) and found that with 20 samples per

plot, at 95% confidence interval, there was a large amount of variation. Jennings et al (1999) conclude that a sample size of anything less than 100 samples per plot would prove to be meaningless in all but the stands with the grossest apparent difference in canopy cover. They failed to establish any guidelines regarding the minimum amount of plots required to assess a stand. Either way, the accuracy and precision of the vertical densitometer increases with the number of observations made.

Much like the spherical densiometer, the vertical densitometer is relatively inexpensive and very durable. With zero moving parts, the device can withstand a lot of punishment in the field before it breaks. In addition, its ease of use requires very little training time. Most of the sampling of canopy cover is done using point samples along a line transect and requires an operator to either record a “hit” or “miss” of forest canopy. Operation of the vertical densitometer requires the user to stand at the sample point, look through the device while ensuring that it is level using the level bubbles inside, and deciding whether the crosshairs inside intersect with the forest canopy. Another important advantage of the spherical densitometer is its consistency in canopy cover estimation. Unlike the spherical densiometer, the operators of the vertical densitometer can easily get the same results at the same sample point. The accuracy and precision of the device lends to its credibility as a scientific instrument. Although not required, WHR and CWHR both recommend use of the vertical densitometer as the primary forest canopy estimation instrument (CA Dept. Fish and Game). Use of the WHR and CWHR classification stratas have also provided land managers with valuable information regarding wildlife habitat. This appeal has led to greater application of the device. With more people using it, there will be a greater amount of users who are familiar and comfortable with the device. This fact has widened the application of the vertical densitometer.

The vertical densitometer is not without its drawbacks. Although very simple and fast to use, the large number of plots required for precise canopy cover estimation may not be cost efficient for all parties. Although Ganey and Block (1994) made a minimum recommendation of 20 sample points, the reality is that the minimum number of sample points should be much higher, 100 or more, if any type of precision is desired (Jennings et al 1999; Williams et al 2003). In addition, the nature of canopy cover versus canopy closure itself can be a drawback. Canopy cover only measures the vertical projection of the forest canopy. Peripheral views are excluded in its calculations. This can lead to misleading information regarding forest conditions, especially along the edges of forest stands. Use of the vertical densitometer may show a high percentage of forest cover while a spherical densiometer may conclude that along some parts of the forest, half of the overhead canopy is no longer present. This is not a drawback of the device, but the nature of canopy cover itself.

### ***Hemispherical Photographs***

Hemispherical photographs are a relatively new tool that is being used to measure both canopy cover and canopy closure. Although the various components can be expensive and bulky, cameras have the advantage of creating permanent records that can be stored and later re-analyzed. Using a fisheye lens, hemispherical photographs operate in much the same manner as a spherical densiometer. Since the camera needs to be level with the ground, they can also measure the vertical projection of forest canopy, thus estimating canopy cover as well. This ability to measure both canopy closure and canopy cover makes the use of hemispherical photographs attractive. Before the mass availability of digital cameras, film cameras were used. This required development of film and digitization of the image through a scanner. These extra steps added to the cost and inconvenience of using cameras to measure forest canopy conditions.

With digital cameras offering better resolution and becoming cheaper, the use of photographs to measure forest canopy is becoming increasingly feasible.

The application of cameras in the field is very similar in methodology to the spherical densiometer or the vertical densiometer. Depending upon the sample design, the camera can be employed either along transects or under reference trees as recommended by Lemmon (1957). Englund et al (2000) found that cameras were a viable alternative to spherical densiometers in assessing forest canopy. Images captured by the camera are then later analyzed by a computer program to determine canopy coverage or canopy closure. There were limitations that affected the accuracy and efficacy of cameras. Since cameras capture images, they are dependent upon lighting conditions. Manual tools such as the vertical densiometer rely upon human judgment and are less affected by environmental conditions. A camera's image quality and its resulting computer analysis are dependent upon a few site factors. The total site factor (TSF) is a function of above/below diffuse light and above/below direct light:

$$TSF = \frac{\text{below canopy diffuse PPFD}}{\text{above canopy diffuse PPFD}} (X) + \frac{\text{below canopy direct PPFD}}{\text{above canopy direct PPFD}} (Y)$$

where PPFD is photosynthetic photon flux density, X is the proportion of diffuse global PPFD and Y is the proportion of direct global PPFD (Englund et al 2000). The angle of the sun, cloud conditions, and color of the foliage are all factors that can affect image quality. This has later consequences in the computer analysis of the images.

The use of the camera produces a permanent record that can be stored and later re-analyzed if estimations of forest canopy come into question. The use of a camera can also be faster than conventional hand held tools. Properly set up on a tripod, application of the camera would require very little human judgment to determine canopy conditions. The tripod would



also stabilize the camera making it less prone to an unsteady hand such as the spherical densiometer or vertical densitometer. Uncertainty in bias or precision would be reduced. Digital cameras would further streamline the process by eliminating the need to develop film. Also, in-field analysis of images could occur, further reducing wait time and expense. Any recalibrations to camera sensitivity could also take place in the field.

There are drawbacks to the use of cameras and photographic analysis. The choice of media can be an important consideration in calculating canopy conditions. Although digital cameras can be cheaper and more efficient, they can have lower sharpness and resolution than film (Frazer 2001; Englund et al 2000). In addition, digital cameras consume batteries which may require spares to be brought into the field. Depending upon resolution and image size, additional memory cards may be a consideration. Cost and the relative fragility of the camera can become a drawback. Unlike a spherical densiometer or vertical densitometer, a camera has more moving parts. Accidental exposure to light in film cameras may destroy a day's work or unintentional contact with water may short a digital camera. Use of a camera will require more physical care than with other tools due its lower durability. The cost of the camera and the computers required for analysis can be cost prohibitive. Depending upon the amount of area to be covered, use of hemispherical photographs may not be an economical choice. Despite their apparent benefits, there are drawbacks that must be considered.

### ***Visual Assessment***

There are numerous tools available to the forester and land manager to assess forest canopy conditions, yet the most widely used tool is probably the human eye. Unaided visual estimates of forest canopy conditions are fast and free and the tool is obviously "carried" by the forester. The operator can also cover a lot of ground noting changes in canopy cover and closure

as she/he moves about. Most natural resource professionals use the eye to approximate canopy closure. Since canopy cover is the vertical projection of the overhead forest canopy, it is rather difficult to visually estimate. Land managers often look around and estimate how much canopy is present. Unfortunately, the statistical inferences regarding simple visual estimation lack are nonexistent. The human eye is also notoriously poor at making consistent estimations (Jennings et al 1999). Despite these drawbacks, visual estimation of canopy conditions will most likely continue. It provides a very generalized view of the forest and often informs land managers making local decisions.

Precision and accuracy in visual estimation usually increases with training and experience. The use of predesignated canopy classes is common and aids the precision in visually estimating canopy conditions (Bellow et al 2003; Jennings et al 1999). The human eye also has a difficult time in estimating canopy closure when it is extremely low or extremely high (Bellow et al 2003). In addition, many foresters have a hard time agreeing upon canopy closure thresholds. Some argue that it comprises of all the small gaps in the canopy while others contend that only larger gaps are of importance. These are some of the factors that prevent visual assessment to become something other than a quick estimating tool to guide land managers making local decisions.

## **Discussion**

The Sierra Nevada Forest Plan is an important guiding document that will affect all forests within the California Sierra Nevada ecosystem. Based upon information gathered by the Sierra Nevada Ecosystem Project in the mid-1990's, the SNFP outlines management objectives and guidelines for ecosystem management in the Sierras. Canopy cover plays an important role in the SNFP, providing direction on wildlife habitat, fire protection, and management for and

creation of structural old-growth stands (Sierra Nevada Forest Plan Amendment-Record of Decision 2004). One major reason for the challenge of using forest canopy guidelines is the inconsistencies in defining what variables of canopy cover should be measured. As mentioned earlier, the SNFP's Record of Decision's Glossary states that canopy cover is synonymous with canopy closure and that there are a variety of ways to measure it. According to Jennings et al (1999), canopy cover and closure are to explicitly different characteristics of forest canopy. This concern over definition and application is also stated in Appendix B of the draft Environmental Impact Statement of the draft SNFP (2003), where canopy cover is correctly defined and inconsistencies in measurement and application are brought up. Appendix B also states that there is approximately a 15% greater estimate in canopy cover when aerial photos are used in comparison to ground based techniques. The tools mentioned in this paper also produce canopy cover estimates that can produce highly divergent values. Despite this acknowledgement, there are no recommendations of standardized procedure. If canopy cover is to be used as a major guideline in Sierra Nevada forest management, its definition must be consistent and the tools used to measure it must produce accurate and precise results.

Like any tool, the devices mentioned in this paper have their specific applications, advantages, and drawbacks. The concern is that the SNF provides instruction and objectives to managing the Sierra's National Forests, but the lack of regularity from forest to forest and even from district to district within the same forest is destroying the purpose of consistent management and the principles of ecosystem management. The objectives of the SNF would be better met if land managers could agree on a single definition and interpretation of forest canopy and the same canopy-measuring tool was used. The preferred tool would have to meet the needs

and demands of field implementation. Factors such as cost, durability, ease of use, accuracy, and precision are important considerations in choosing which device is appropriate.

In terms of cost, the eye is the most economical tool available to the land manager. Obviously most individuals will come equipped with two. It is readily accessible and most operators probably already use it. Unfortunately, due to the lack of reliability and statistical confidence, visual assessment will most likely be used as an informal tool by land managers. The spherical densiometer and vertical densitometer are very comparable in terms of cost. Both retail for approximately \$100 and can be found at major forestry suppliers. The most expensive tool looked at in this paper is hemispherical photography. Digital cameras have brought the long-term cost of photography down, but the initial investment price is usually twice that of the spherical densiometer or vertical densitometer. The computer required to analyze the photos is an additional cost as well as the accompanying analysis software. The benefits of hemispherical photos may outweigh the cost. The ability to produce permanent and low-bias estimates might justify costs to organizations with interests in accurate and precise canopy estimates. Spherical densimeters and vertical densitometers are the most likely economical choices for measuring forest canopy.

Cost is not always the most important factor in deciding which tool to use. Fieldwork is physically demanding on the individual and the gear that they use. The human eye is the most durable tool used to estimate forest canopy. Without use of the eye, the other tools would be useless. Despite its limitations in estimation consistency, it still ranks high on available tools to foresters. Cameras and the computers and software required to analyze photos are the least durable of tools. Their fragility and cost require care that might not be possible under many conditions. If they do break, their higher costs may affect their replacement time. Spherical

densiometers and vertical densitometers are very durable devices. The spherical densiometer has only one moving part and the vertical densitometer has none. The bubble vials in both devices that are used to maintain their level position are sealed and well attached. These two devices are designed to withstand the rigors of field work.

With any tool, there is a learning curve associated with measuring canopy conditions with these tools. Until efficiency is attained, accuracy and precision will most likely be low. The human eye is grossly inaccurate at estimation of canopy closure and even more so at the extremes (Bellow et al 2003). Experience and training does lend to more accurate and precise estimates of canopy conditions. The spherical densiometer has been criticized by many users as being both inaccurate and imprecise. The nature of the tool makes it difficult for an operator to get similar readings in the exact same spot. Estimations also vary between users. However, it has been found that extensive training and experience do increase accuracy and precision (Englund et al 2000; Dealy 1960). The vertical densitometer requires relatively little training and experience to acquire accurate and precise results. The binomial nature of the sample method (“yes” or “no”) lends to ease of use and statistical analysis (Stumpf 1993).

Hemispherical photography is very simple to use once the thresholds in analysis have been adjusted. Once the analysis program and camera have been calibrated, it is a simple matter to place the camera on a sample point and capture an image of the canopy overhead. Photo analysis also has the advantage of producing permanent records and results that have high precision and accuracy. Photos can also be analyzed for either canopy cover or closure, increasing versatility of the device. For research purposes, they might prove to be an ideal tool. The vertical densitometer is probably the most pragmatic tool for management purposes. Its short learning curve, accuracy, and precision lends itself well for “everyday” field use.

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