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ESTIMATING PRODUCTIVITY ON SITES WITH A LOW STOCKING CAPACITY

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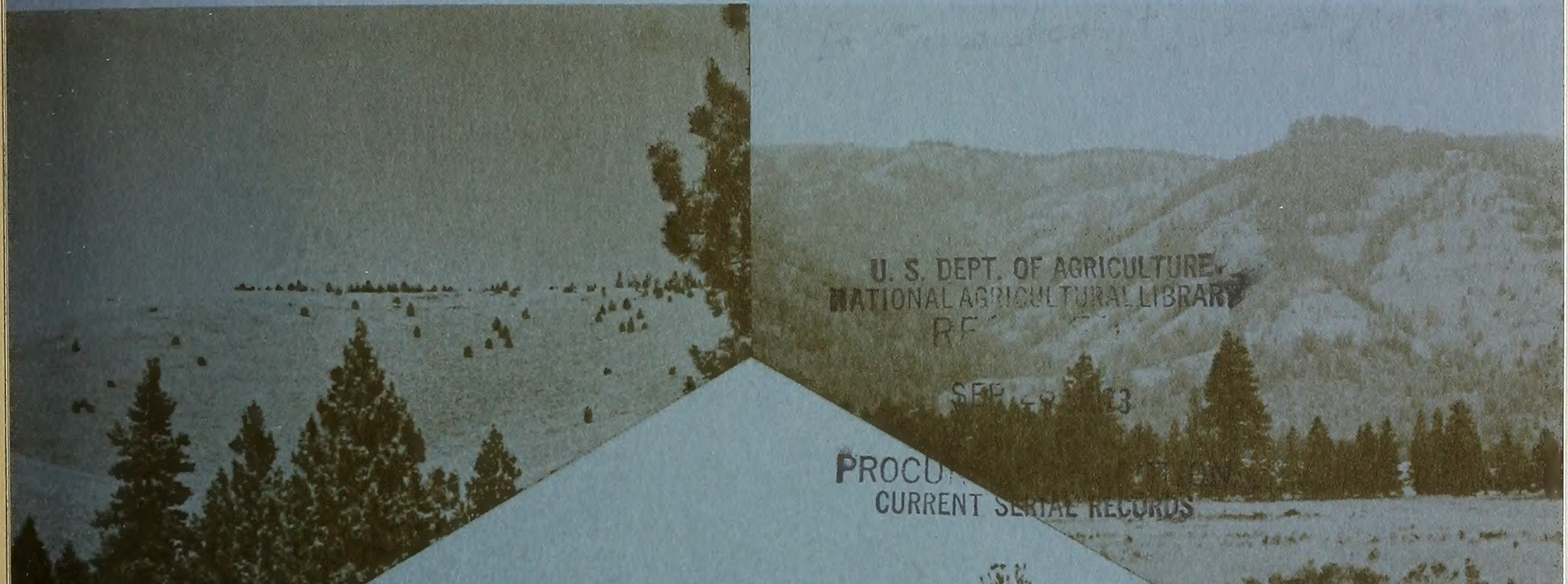

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ABSTRACT

In most areas, normal yield tables are the only tools available for estimating timber productivity and establishing stocking standards. However, the stocking capacity of naturally sparse stands in the arid West is often lower than was found in the stands sampled by the makers of normal yield tables. Normal yield table estimates, therefore, may indicate high productivity and understocking for stands that are really well stocked but not very productive.

About half of the commercial forest land in the areas studied--eastern Oregon and northern California--appears unable to support normal yield table stocking levels. Two methods are presented for identifying and quantifying this limitation. The first method is to develop factors to discount the normal yield tables in habitat types where a stocking limitation exists. The second method, for areas where habitat types have not been classified, is to predict stocking capacity from multiple regression equations based on site index, elevation, and the presence of certain indicator plants.

KEYWORDS: Stand density, indicator plants, productivity, stand yield tables.

CONTENTS

INTRODUCTION

In the arid West, stands of trees on the lower forest fringe are often surprisingly sparse, in spite of a moderately good site index and a history unmarked by either human disturbance or natural catastrophe (fig. 1). Such stands appear to have always been lightly stocked. Wikstrom and Hutchison (1971), commenting on this condition, observed that

> . . . the assumption that the area being evaluated can support as many trees as the land on which the yield table data were collected . . . is not always true and is not generally true on the more arid fringe of the forest. In areas of low rainfall, each tree requires more room than is "normal" to fulfill its moisture requirements.

Despite their understocked appearance, such stands are often fully utilizing the site's capacity to grow trees.

Naturally sparse stands may also occur where physical obstructions inhibit tree growth over part of an area. Trees may be growing in pockets of deep soil or cracks in the bedrock, interspersed with small areas where the soil is too shallow to grow trees. Such stands also often appear understocked when, in fact, the site may be fully occupied.

Figure 1.--*Ponderosa pine on the Colville Indian Reservation growing near the lower limits of tree occurrence. Stands such as this are naturally sparse.*

IMPACT OF LIMITED STOCKING CAPACITY ON FOREST PRODUCTIVITY

In areas where moisture is limited, shallow soil and rock outcrops common, or other extensive limitations on stocking capacity present, a corresponding reduction in forest productivity is likely--an effect often ignored in timber inventories (fig. 2). Forest management decisions are strongly influenced by the quality of available estimates of productive potential and of current stocking level--the degree of utilization of the potential productivity. Failure to recognize stands with limited stocking capacity may result in costly management errors. For example, if stands identified as poorly stocked are really sparse stands fully occupying sites with limited stocking capacity, then a planting program would fail.

In most areas, estimates of productive potential are based on normal yield tables--the only available sources of productivity information. One procedure used is to measure the site index, then refer to a normal yield table for the mean annual increment at the point of culmination for that site index. This estimate of the productive potential for well-stocked natural stands forms a basis for comparing the productivity of different areas. It is used in this manner by the nationwide Forest Survey of the U. S. Forest Service. Many others use site index as a means of ranking productivity without attempting to quantify the estimates. The soil vegetation maps of California,[1] for example, show Dunning's site class (Dunning 1942) for every commercial forest land type island. The tabulation or mapping of forest land into site classes is a widespread practice among forest managers.

Figure 2.--*These large rocks on the Warm Springs Indian Reservation severely restrict stocking capacity. The site index is 60 and the total basal area is 45 square feet per acre or 26 percent of "normal."*

Implicit in these approaches is the assumption that all acres having the same site index are equally productive. The widespread acceptance of this assumption is evidenced by the importance generally placed on site index information when making management decisions. However, the assumption that forest productivity depends on site index alone and can be measured by normal yield tables is valid only when the area of interest has environmental conditions that fall within the range of those sampled by the maker of the yield table.

Stocking standards also typically rest on the assumption that all acres with a given site index are equally productive--at least within a forest type. Present growing stock--usually expressed as basal area or number of trees per acre--is compared to a stocking standard that is often derived from normal yield tables. This comparison provides an indication

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[1] Compiled by the Soil-Vegetation Survey conducted by the Pacific Southwest Forest and Range Experiment Station in cooperation with the University of California for the California Division of Forestry.

of how well the productive potential of the site is being utilized. However, stocking estimates obtained in this manner are again only valid for areas that fall within the range of conditions sampled to develop the stocking standard.

Areas with patchy stands, nonforest inclusions, and sparse stands on the forest fringe are situations that evidently were not sampled by the makers of yield tables. Meyer's (1961) ponderosa pine (*Pinus ponderosa*)[2] yield table is based on a sample which excluded all plots with a stand density index of less than 250 (250 trees per acre when quadratic mean diameter is 10 inches). Data collected by Hall[3] in the Blue Mountains of eastern Oregon suggest that substantial areas of ponderosa pine type will not support this many trees.

Data gathered for this study suggest a similar situation in California. Stocking capacity also is obviously limited, possibly because of soil toxicity, in stands of Jeffrey pine (*Pinus jeffreyi*) growing on serpentine (peridotite and serpentinite soils) in southern Oregon and northern California (fig. 3). We have observed similar restrictions on stand density in stands of other species growing on dry sites, and Wikstrom and Hutchison (1971) report the condition to be widespread in the intermountain and Rocky Mountain regions.

The assumption, implicit in most yield tables, that stocking capacity is constant for a given site index has been questioned by several European authors. Assmann (1959) found substantial variation in Norway spruce (*Picea excelsa*) yields that he was unable to explain by site index. Bavarian spruce yield tables (Assmann and Franz 1965) reflect these findings by dividing each site index class into three production classes. Recent British tables (Bradley, Christie, and Johnston 1966) are similarly divided. Locally, data from Hall's (1971) ecological study of the Blue Mountain region of eastern Oregon indicate that basal area carrying capacity is more closely related to plant community than to site index.

Under what conditions are the procedures described above inappropriate? One such situation occurs when small patches of nonforest land, usually avoided by the makers of normal yield tables, are included in the forest land sample. Such patches may be deliberately combined with forest land because they fail to meet some previously defined minimum area standard, or they may be patches of scabland--nonforest inclusions incapable of growing trees--that have been mistaken

Figure 3.--*Jeffrey pine growing on serpentine (peridotite soil) north of Grants Pass, Oregon. The stocking capacity of this area is severely limited. Although the site index is 95, the basal area is only 24 square feet per acre--about 11 percent of "normal" stocking.*

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[2] Names of trees according to Little (1953).

[3] Frederick C. Hall, unpublished data on file at the Regional Office, U.S. Forest Service, Portland, Oreg.

for nonstocked forest land. In either case, conventional procedures based on site index and a normal yield table will lead to overestimation of potential productivity and underestimation of stocking. As previously pointed out, this combination of errors, in turn, may lead to the identification of an apparent treatment opportunity where none exists.

Conventional procedures are also inappropriate for assessing the potential productivity and stocking of sparse stands near the dry lower forest fringe--the sort of stands referred to by Wikstrom and Hutchison (1971). Such stands may have as few as 15 or 20 trees per acre and no evidence that stocking has ever been greater. They are often on deep soil and display a site index as good as that found in much denser stands at higher elevation. Ecologists, silviculturists, and other forest scientists that we talked to were in general agreement that such stands, if uncut and free from catastrophe, are in fact fully occupying the site even though stand density is far below that indicated by normal yield tables. This is a logical assumption if one accepts the premise implied by the normal yield tables and accepted by Franz (1967) that stands allowed to develop in an undisturbed condition tend toward an equilibrium at a ". . . natural basal area [that] is an expression of the productive capacity of the site."

A proper method for estimating productivity on sites with limited stocking capacity entails comprehensive site and yield studies. Since such data are years away, the urgent need for good productivity estimates encouraged us to develop some alternative solutions that would improve Forest Survey productivity estimates. Two such solutions are presented here--one for an area where considerable research data wer available and one for an area lacking such data.

A GENERAL APPROACH

Before examining specific localized procedures, let us first consider the general problem of identifying and quantifying restrictions on stocking capacity. The easiest part of the problem involves such obvious restrictions as rock outcrops. If half a plot is solid rock, then a 50-percent reduction in productive capacity seems logical. Likewise, the stocking standard for that particular plot should be only one-half that for a fully productive plot. If the plot is bisected by a creek, the answer is not so obvious since the trees may, to some extent, utilize the soil under the creek and the air space over it. Nevertheless, since creek bottoms are usually either very stony or saturated with water, it is probably more reasonable to assume that the creek is nonstockable than to assume that the potential productivity of the acre is unaffected (fig. 4).

Identifying small patches of land with soil too shallow to grow trees is more difficult. Fortunately, the plant communities growing on such scabland areas are usually distinctly different from those found on timber growing sites. On the Modoc plateau in northern California, for example, *Artemisia arbuscula* [4] is an indicator of nonforest land.[5] If, with the help of ecologists, we can learn to recognize the plant communities that occur only on nonforest land, then we can handle such areas in the same manner as rock outcrops and streambeds.

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[4] Names of grasses, herbs, and shrubs follow Munz and Keck (1970).

[5] Conversation with Frederick C. Hall, range ecologist, U. S. Forest Service, Portland, Oreg.

Figure 4.--*It is reasonable to assume that this creek bed is nonstockable.*

Learning to recognize sites that grow trees but are limited in stocking capacity is a complex problem. If we accept the premise that undisturbed stands tend toward equilibrium (Franz 1967), we can seek out such stands and compare their basal areas with those predicted by a normal yield table for the same stage of development. Those stands with less than "normal" stocking (including recent mortality) can be assumed to have a stocking restriction. By measuring such stands, we could build a new "normal yield table" for sites with restricted stocking capacity.

But how can we recognize restricted stocking capacity when disturbance has removed part or all of the tree cover? One way would be to study the effect on forest stocking of all the various physical factors which affect the environment: soil, microclimate, available moisture, slope, aspect, etc. Such an approach seems time consuming for an ecologist and probably hopeless for the average inventory crew. Even detailed soil information, although prospectively highly useful, is not easy to gather in most inventory situations.

Fortunately, the plants growing on a site offer an important alternate source of information. Plants or plant communities have often been used as indicators of environmental factors present, particularly those which are critical to plant growth on a particular location--e. g., moisture, temperature, fertility, etc. (Daubenmire and Daubenmire 1968, Dyrness and Youngberg 1966, Griffin 1967, Poulton 1970, Waring 1969, Youngberg and Dahms 1970). If plant communities representing various levels of forest productivity can be identified, then separate yield tables can be developed for each community, or in place of this, discount factors computed for existing yield tables.

A PROCEDURE FOR EASTERN OREGON

The first phase of this study was an effort to use plant community information to identify areas where stocking capacity is restricted and to improve productivity and stocking estimates on such areas. Fortunately, F. C. Hall, Range Ecologist for the U. S. Forest Service's Region 6, had recently developed a habitat type (plant community) classification scheme similar to Daubenmire and Daubenmire's (1968) for the Blue Mountain region of eastern Oregon, an area where a Forest Survey timber inventory was currently in progress.

Hall also developed a key (see

footnote 3) for determining plant community, even when disturbance has destroyed the climax vegetation. In addition, he estimated the average basal area and site index associated with each plant community from measurements in undisturbed stands. Hall's data indicated that six plant communities grew on sites incapable of supporting "normal" levels of stocking (fig. 5). The ratio of Hall's basal area data to equivalent normal yield table data provided a basis for discounting normal-yield-table-derived stocking standards and productivity estimates as follows:

Plant community	Percent of normal
Pine/wheatgrass	20
Pine/bitterbrush/fescue or sedge	54
Pine/bitterbrush/stipa	59
Pine/fescue	59
Pine/elk sedge	74
Pine/shrub/elk sedge	79

In addition, nonstockable land was treated as 0 percent of normal (fig. 6). Seven other plant communities were identified but not discounted as no stocking problem appeared to exist.

Forest Survey field plots sample approximately an acre with a cluster of 10 points. In eastern Oregon, each stockable point on each commercial forest plot was placed in one of the 13 plant communities. On spots where the soil was too shallow to support tree growth, we found grasses and herbs that identified nonforest habitat types in Hall's key. Points falling on such spots were classed as nonstockable, as were those falling on bare rock, water, or any other nonstockable condition. The 10 discount factors--one for each point in the 10-point cluster--were then averaged to provide a discount factor for the entire plot. Productivity was estimated for the plot by obtaining the mean annual

igure 5.--*This uncut ponderosa pine stand, near Bend, Oregon, is growing in a pine/bitterbrush/fescue plant community. Although the site index is 70, basal area per acre is only 85 square feet--about 42 percent of "normal." The growth rate has slowed from six rings per inch to 30 rings per inch, indicating that the stand is probably overstocked.*

Figure 6.--*Nonforest* (Poa-Danthonia) *scabland in Oregon's Blue Mountain area. The forest land in the background is a pine/wheatgrass community with a stocking capacity limited to about 20 percent of "normal" basal area.*

increment at culmination from an appropriate yield table and multiplying this amount by the plot discount factor. Plot stocking was assessed by comparing the basal area found on the plot with a basal area standard. This standard was derived from an appropriate normal yield table and discounted by the plot discount factor.

We were aware that several writers (Lynch 1958, Smithers 1961, Curtis and Reukema 1970) have reported that site index is sometimes correlated with stand density--especially in very dense stands. However, since our major interest in this study was in relatively low-density stands where the likelihood of site index-stand density correlations seemed least, we assumed that site index is independent of stand density.

Forest Survey inventoried all forest land in eight counties of eastern Oregon (Baker, Grant, Harney, Malheur, Morrow, Umatilla, Union, and Wallowa), except for the National Forests. The sample included 220 field plots distributed over the area on a rectangular grid. After discounting for limited stocking capacity, 15 percent of the land that had been classified as commercial forest was reclassified as noncommercial because it failed to meet the minimum productive capacity for commercial forest as defined by Forest Survey (20 cubic feet per acre per year). Half of the remaining commercial forest area was discounted because the plant community indicated that the site was not capable of carrying normal yield table levels of stocking. The total effect of the discount was to lower our estimate of the productive capacity of forest land in the eastern Oregon inventory unit by 21 percent including the loss due to change in land class.

The stocking capacity discount had a similar effect on the basal area by which plot stocking was judged. On 50 percent of the commercial forest plots, the basal area required for full stocking was reduced. As a result, those plots were judged to be somewhat better stocked than previously supposed. Although many of these stocking adjustments were small, the change was substantial for some plots. The stocking estimate for one plot in Wallowa County, Oregon, for example, was increased from 15 percent to 52 percent.

Did the discount factors that we developed from Hall's data fit the limited stocking conditions found on Forest Survey field plots? To test this, we selected 30 undisturbed or lightly cut plots in Harney, Grant, and Baker Counties--areas which appeared to have substantial limitations on stocking. On each plot, we tallied the total basal area in trees, stumps, and recent snags. If our tally represents the stocking capacity of the area sampled, then that area can support an average of 96 square feet of basal area per acre at the current stage of stand development. An estimate derived from a normal yield table suggests that the area should support 186 square feet of basal area--an overestimate of 94 percent. Our estimate based on discounted normal yield table values is 110 square feet per acre--still an overestimate, but by only 14 percent. The normal yield tables overestimated stocking capacity on each of the 30 plots--in many cases by a wide margin. On the seven plots with the most severe limitations, the stocking capacity averaged only 19 square feet of basal area per acre, yet the normal yield table estimate was 183 square feet per acre. After discounting by plant community, the yield table estimate was 47 square feet--again slightly high but much more reasonable.

A PROCEDURE FOR NORTHERN CALIFORNIA

The procedure used in eastern Oregon to identify and quantify restrictions on stocking capacity is applicable only to areas where ecologists have developed a plant community classification scheme. Such studies are still regrettably few. For other areas, some alternative procedure was needed. We undertook to develop such a procedure for Shasta and Trinity Counties in northern California where Forest Survey fieldwork was in progress.

There, productivity estimates proved more difficult than in eastern Oregon. The area is a complex mosaic of contrasting vegetation, geology, and climate. Plant communities in Shasta and Trinity County areas are as yet unclassified. Some indications of productivity are provided by the Soil-Vegetation Survey (see footnote 1). Where available, survey maps show soil characteristics, principal tree and shrub species present, and site class. Unfortunately for our purposes, these maps are limited in coverage and lack direct measure of limitations on tree stocking capacity. Although there is probably a strong relationship between soil characteristics and timber productivity, we concluded that this approach was too complex for our Forest Survey field assistants.

A POSSIBLE APPROACH

Plant indicators still seemed our best hope. Griffin (1967) had developed a vegetative drought index for use in the vicinity of Redding, California. His technique was to relate soil droughtiness to the presence or absence of 172 indicator plants. Since tree density is related to soil moisture, we reasoned that the plants used in Griffin's index might also be useful in estimating stocking capacity. However, rather than use vegetative drought index, we related the plant species growing on a site directly to its stocking capacity as measured by stand density index--that is, the trees per acre that a site can support when the quadratic mean diameter is 10 inches.

Our analysis rested on three assumptions. First, we accepted the premise (Franz 1967) that undisturbed stands tend toward equilibrium and that their natural basal area is an expression of the site's productivity. Accepting this, we were able to reasonably estimate stocking capacity on relatively undisturbed plots by tallying the trees and adding recent stumps and snags. Areas with an obvious history of severe fire or heavy cutting were not sampled. Second, we assumed that plant species associated with a given stocking capacity on undisturbed sites are likely to indicate a similar stocking capacity when found in heavily disturbed areas. This is in accordance with Daubenmire and Daubenmire's (1968) report that ground vegetation in the northern Rocky Mountains grew independent of the overstory, and with Dyrness'[6] observations of the persistence of most plant species even after clearcutting and burning. However, we took the advice of Waring and Major (1964) and Griffin (1967) and restricted our observations to plant occurrence, ignoring plant coverage, which they felt was more likely to be influenced by disturbance. Third, we assumed that stand density index (Reineke 1933) was a reasonable measure of stocking capacity that would enable us to directly compare

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[6] C. T. Dyrness. Early stages of plant succession in the western Cascades of Oregon. Unpublished manuscript on file at Pac. Northwest Forest & Range Exp. Stn., Corvallis, Oreg.

stands at different stages of development. In this we relied on the experience of others (Curtis 1971) who have found stand density index to have a wide application.

Stand density index--our choice as a dependent variable--is the number of trees per acre that a stand could be expected to have if it retained its present stocking (percent of normal trees per acre) and its quadratic mean diameter was 10 inches. The relationship between number of trees per acre and mean diameter, illustrated in figure 7, can be described mathematically as $N_e = a(\bar{D})^b$ (Curtis 1970) where N_e is the expected number of trees in a normal stand, $\bar{D}$ is the quadratic mean diameter of the stand, a varies with stand density index, and b is a constant power of D. For these study data, b approximated -1.6 for true fir and mixed conifer stands (as in figure 1), -1.8 for ponderosa pine stands (from Meyer's (1961) basic data), and -1.4 for hardwoods (from study data and the red alder (*Alnus rubra*) yield table (Worthington et al. 1960).

DEVELOPING A MULTIPLE REGRESSION EQUATION

Our sample consisted of 97 regular Forest Survey plots well distributed throughout the range of natural conditions found in the commercial forest zone. Although plots were, as much as possible, restricted to more or less homogeneous, relatively undisturbed stands, some reconstruction from stump counts proved necessary because of the area's long history of logging, mining, and fires. Each location was visited once during the growing season in order to measure the stand density index, measure site index on three or more dominant trees, and identify all recognizably mature plant specimens on Griffin's list. An area of about an acre was carefully searched to insure that all plant species were found. Slope, aspect, elevation, and physiographic class were also recorded. The only plant species not recorded were those occurring on small nonforest inclusions such as rock outcrops and roadbeds. The area of such inclusions was deducted from the plot area before calculating stand density index.

The next step was the multiple regression analysis. Since 172 variables were far too many, the plant list was reduced to 40 or 50 by hand screening. First, the list was shortened to include only those plants which were fairly easy to identify throughout the growing season. Then, hand plotting was employed to eliminate plants that were apparently unrelated to stand density index. Finally, plants that seemed to grow together under similar growing conditions were lumped together as single variables. The plant variables, the physiographic features, Dunning's site index (1942), and various squares and interactions were entered in a stepwise regression program. From this analysis we developed two equations for estimating stand density index capacity: One that included Dunning's site as a variable and one for use where suitable site trees are not available. The two equations follow. Elevation is recorded to the nearest 100 feet and site index to the nearest foot. All other variables have a value of 1 if present and 0 if absent. Plant combinations are considered present if any of the species in the combination is present.

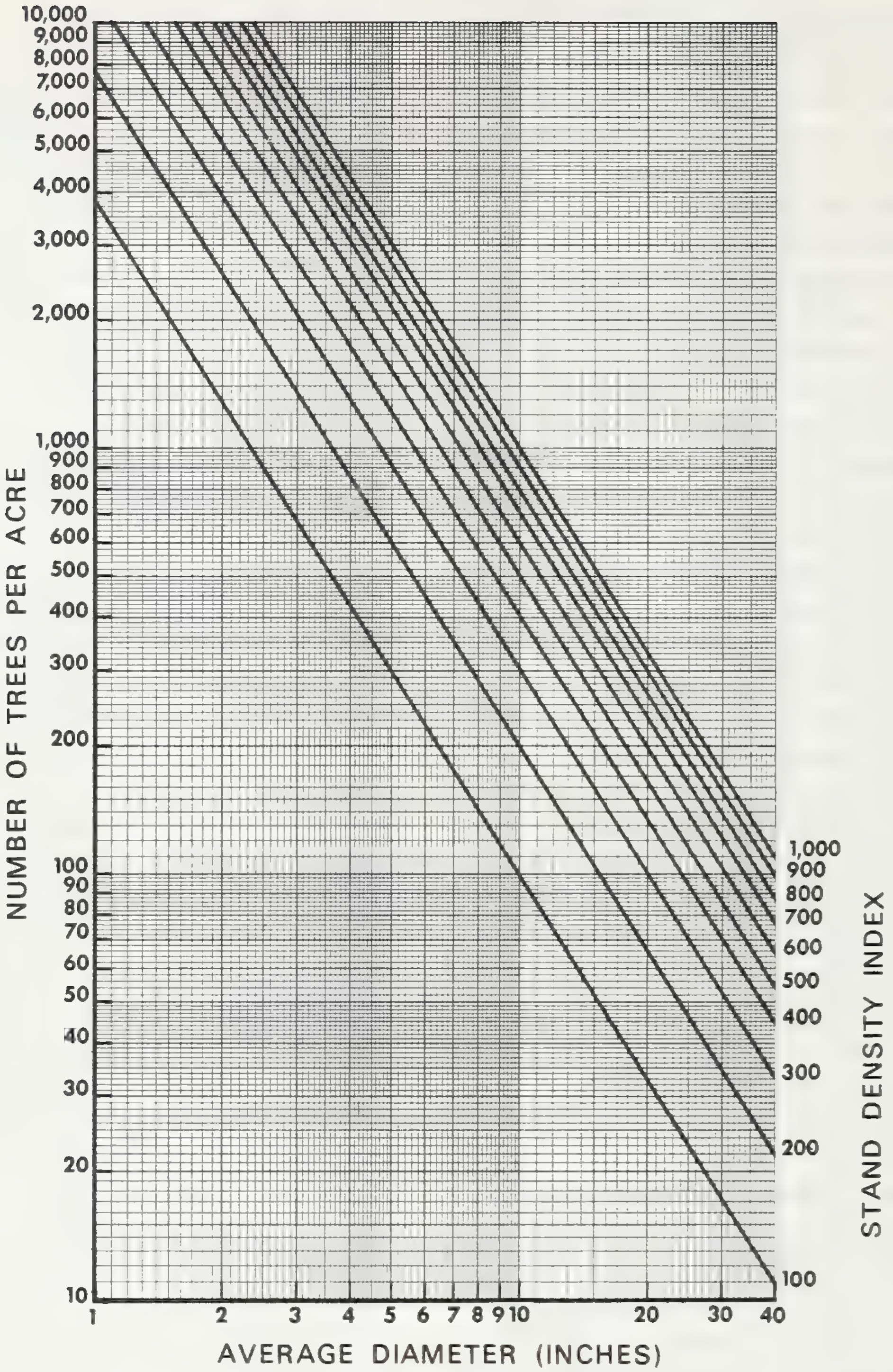

Figure 7.--*Stand density curves for true firs and* mixed conifer stands.

1. $$\text{Stand density index} = -2 - 47X_1 - 84X_2 + 62X_3 + 99X_5 + 39X_7 + 92X_8 + 64X_{10} + 33X_{11} + 61X_{12} + 32X_{13} - 44X_{14} + 0.0719X_{16} + 0.00045X_{17} - 0.0000082X_{18}$$

2. $$\text{Stand density index} = 230 - 105X_1 - 115X_2 + 54X_3 - 46X_4 + 50X_6 + 129X_8 + 60X_9 + 39X_{10} + 57X_{11} + 50X_{12} + 54X_{13} - 58X_{14} - 68X_{15}$$

When: X_1 = *Ceanothus cuneatus* (buckbrush), *Cercocarpus betuloides*, or *Cercocarpus ledifolius* (mountain mahogany)
X_2 = *Cercis occidentalis* (California redbud) or *Ceanothus lemmonii* (lemmon ceanothus)
X_3 = *Quercus garryana* (Oregon white oak), *Q. garryana* var. *breweri* (Brewer oak) or *Q. wislizenii* (interior live oak)
X_4 = *Rhamnus californica* ssp. *tomentella* (coffeeberry) or *Prunus subcordata* (sierra plum)
X_5 = *Abies magnifica* (California red fir)
X_6 = *Abies concolor* (white fir)
X_7 = *Pinus lambertiana* (sugar pine) or *Pseudotsuga menziesii* (Douglas-fir)
X_8 = *Castanopsis sempervirens* (bush chinquapin) or *Prunus emarginata* (bitter cherry)
X_9 = *Rosa gymnocarpa* (wood rose)
X_{10}= *Quercus kelloggii* (California black oak)
X_{11}= *Pyrola picta* (white vein shinleaf), *Trientalis latifolia* (star flower), or *Asarum* spp. (wild ginger)
X_{12}= *Chimaphila umbellatum* (prince's pine), *Pterospora andromedea* (pine drops), or *Smilacina* spp. (false solomon's seal)
X_{13}= *Pinus ponderosa* (ponderosa pine)
X_{14}= *Ceanothus prostratus* (squawcarpet)
X_{15}= *Berberis pumila* (dwarf barberry)
X_{16}= $(\text{elevation})^2$
X_{17}= $(\text{Dunning's site index})^2\ (\text{elevation})$
X_{18}= $(\text{Dunning's site index})^2\ (\text{elevation})^2$

HOW GOOD ARE THE EQUATIONS ?

The stepwise multiple regression programs used to develop the stand density index equations also provided estimates of the standard error of estimate for each equation and the variation it accounted for as follows:

Equation	R^2	**Standard error of estimate** (stand density index points)
With Dunning's site index	0.77	67
Without Dunning's site index	0.72	70

Since we were aware that stepwise regression analysis of large numbers of empirically chosen variables may give underestimates of variance and inflated R^2's, we also tested the equations against 70 plots that were from the study area but not used in constructing the equations. Although many of these plots had been heavily logged, we were able to reconstruct their stand density index capacity by means of stump counts. This gave us a measure of the equations' reliability on disturbed areas. The results of this test, on both disturbed and undisturbed sites, appear in table 1.

As expected, the equations, particularly the one without Dunning's site index, appear slightly less reliable than indicated by the stepwise regression analysis. Equation-based estimates of stand density index were neither significantly higher nor lower than field measured values. The small amounts of bias that show on table 1 are probably a result of sampling accident. However, standard errors of estimate obtained from the independent test were 5 to 20 percent larger than those obtained during the regression analysis. Despite this apparent crudity, the equations predict stand density index capacity with far greater precision than is possible from normal yield tables. When the stocking capacity of the test plots was estimated from these tables, the standard error of estimate was 127 stand density index points. Furthermore, the yield table estimates averaged 58 points higher than field measured stand density indices.

It might appear likely that logging would encourage the replacement of plants typical of a moist environment by plants adapted to a hotter, dryer site. If so, the equations would underestimate the stocking capacity of cutover land. We found no evidence of such underestimation. Plants that were present before logging seemed generally to have persisted in spite of heavy disturbance--possibly

Table 1.--*Reliability and bias of stand density equations for cut and uncut stands*

Type of disturbance	Number of plots	With Dunning's site[1]		Without Dunning's site	
		Standard error of estimate	Bias[2]	Standard error of estimate	Bias[2]
		Stand density index points			
Undisturbed stands	24	72	15	86	4
Logged within 10 years	21	75	-6	73	0
Logged more than 10 years ago	25	65	8	102	27
Total	70	70	6	88	11

[1] Dunning (1942).

[2] Average amount by which equation estimates exceeded or fell short of field measured stand density index.

because some undisturbed microsites usually remain. Although we were not able to test the performance of the equations in brushfields on old burns, we suspect that they may be less reliable for such areas. Areas that have been recently clearcut and broadcast-burned may be lacking plant indicators, although Dyrness (see footnote 6) found that slash fires did not destroy all vegetation--small unburned islands often retained their original cover.

DEVELOPING PLOT DISCOUNT FACTORS

Although the stand density index equation was developed from undisturbed stands, its usefulness is in predicting stocking capacity (expressed as stand density index) on all stands including those that have been heavily disturbed. For each stand, the stand density index capacity is estimated from the equation and compared to the appropriate "normal" stand density index (from a normal yield table). If the stand density index capacity is significantly below "normal," then productivity estimates and stocking standards based on normal yield tables are too high and should be discounted. The appropriate discount factor is the equation stand density index divided by the "normal" density index.

Normal yield table stocking is the average of the range of stocking conditions sampled by the builder of the table. Individual normal stands may exhibit stocking capacities that are somewhat less or greater than these tabular values. Such stands do not have a limited stocking capacity as defined in this paper and were not discounted. Since data on the range of stocking conditions sampled for normal yield tables are scanty, we more or less arbitrarily assumed that plots with a stand density index capacity of 80 percent or more of normal fell within this range. Plots with a lesser predicted stand density index capacity were appropriately discounted.

RESULTS IN SHASTA AND TRINITY COUNTIES

Productivity was estimated on each of 315 commercial forest plots in Shasta and Trinity Counties from appropriate normal yield tables. Where the predicted stand density index capacity was less than 80 percent of "normal," the estimate was appropriately discounted. Stocking was estimated by comparing the basal area found on each plot with a standard based on the appropriate normal yield table but again discounted where the equation indicated that stocking capacity was limited. Both productivity estimates and stocking standards were further discounted for small nonforest inclusions, when these occurred on the plot.

Study results indicate that 41 percent of the commercial forest land in the Shasta and Trinity inventory units (excluding National Forest) has a limited stocking capacity. Stocking estimates on these lands were adjusted upward to account for the limited stocking potential, and productivity estimates were revised downward. The productivity discounts reduced our estimates of total productive capacity by 12 percent, and of commercial forest land area by 1 percent (fig. 8).

DEVELOPING PLOT DISCOUNT FACTORS FOR THREE OTHER GEOGRAPHIC UNITS

Since completing the study unit, Forest Survey has developed equations for calculating stand density index capacity in three other areas in California. The procedure used was similar to that

igure 8.--*Natural sparse stand of Jeffrey pine near Weaverville, California. This is a serpentine area with a site index of 95. Although the stand has only about 28 percent of "normal" basal area, low growth rates indicate that the stocking level is at or near capacity.*

Figure 9.--*A low density stand of Jeffrey pine near Aden, California. Scattered stands such as this are common on the Modoc plateau in northeastern California. There is no evidence that they have ever supported "normal" stocking levels.*

used for the study except that the data were gathered from special temporary plots instead of the regular inventory field plots (fig. 9). Since lists of indicator species like that developed by Griffin (1967) did not exist for these areas, we recorded all the vascular plant species that were present and identifiable on each plot at the time of our visit. Since we were able to visit each plot only once, species that were not generally identifiable throughout the growing season were subsequently dropped from our list of potential indicators. Development of equations for the three areas prior to regular fieldwork made plant identification much easier for Forest Survey field crews, since they needed to identify only the relatively few plants appearing in the final equation--a much easier task than identifying the 172 plants required for Shasta and Trinity Counties.

Estimates of the reliability of the three equations appear in table 2. In addition, independent tests of reliability were made in the central Sierra and in the Modoc plateau-northeast Sierra units. The standard error of estimate was 88 stand density index points for the central Sierra test and 113 points for the Modoc unit when site index was one of the independent variables in the equation. When site index was deleted, results were substantially poorer. Although the Modoc test results were somewhat disappointing, the equation was still a much better predictor of stocking capacity than was the normal yield table. Still, we were dissatisfied with the result. We suspect that the equations would have proved more reliable if we had separated the area into two or more nearly homogeneous units. Anyway, it points up the advisability of making an independent test of each equation before putting it to use.

Table 2.--*Standard error of estimate and variation accounted for by stand density index equations developed for northern California*

Unit and county	Dunning's[1] site included		Dunning's site deleted	
	R^2	Standard error of estimate	R^2	Standard error of estimate
West Sacramento (Tehama, Colusa, Glenn, and Lake)	0.72	75	0.70	78
Modoc Plateau - Northeast Sierra (Modoc and eastern portions of Lassen, Plumas, Sierra, Nevada, Placer, and El Dorado)	.69	91	.66	94
Central Sierra (Yuba and western portions of Sierra, Nevada, Placer, and El Dorado)	.72	106	.71	106
Shasta and Trinity	.77	67	.72	70

[1] Dunning (1942).

CONCLUSIONS

During the course of this study, field crews visited 535 plots spread over eight counties in eastern Oregon and two counties in northern California, all capable of producing at least 20 cubic feet per acre per year according to the normal yield tables. After field examination, we concluded that 255 of these plots were incapable of carrying normal yield table levels of stocking. In other words, normal yield table based estimates of productivity were too high and similar stocking estimates were too low on almost half of the study area. Clearly, a forest manager with funds to invest in silvicultural treatment needs better information if he is to spend his money wisely.

Long-range studies may, someday, result in yield tables that are stratified by plant community. Development of such yield tables over large areas would require a massive effort, since they would, of necessity, be quite local in nature. Because such a massive effort is not likely to be undertaken soon, cruder approximations of yield will have to suffice. The method tested in eastern Oregon--developing yield table discount factors for plant communities--is relatively simple to apply and yields much more realistic estimates of productivity on problem areas than does the undiscounted normal yield table. Unfortunately, its use depends upon the existence of an ecological study of the plant communities in the area to be inventoried. Although such studies are still comparatively few in number, their potential usefulness extends well beyond the scope of this study.

Even where long range studies are lacking, continued use of undiscounted normal yield table values to estimate the productivity and stocking level of stands with limited stocking capacity seems unacceptable. For areas where plant community information is not available, the regression approach developed in northern California is an alternative. Although admittedly crude, we believe it will yield a substantially closer approximation of true productivity than the use of an undiscounted normal yield table.

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Two methods are proposed for discounting normal yield tables for limited stocking capacity: one based on habitat types and the other on identification of certain indicator plants and other variables.

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