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Utah State University is committed to a policy of equal opportunity in student admission, student financial assistance, and faculty and staff employment and advancement, without regard to race, color, religion, sex, age, national origin, or handicap.
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1988 UTAH SCIENCE INDEX AND NEW PUBLICATIONS
Forests are the most important natural resource in Utah. Few would question my veracity if I said the same thing about Oregon or Idaho or Montana, but everyone "knows" that Utah is salt flats and slick rock—the state is not a major wood-producing state. But the importance of forests in Utah is apparent when we consider what supports the state's major industries.

The leading industries in Utah are agriculture and tourism, both of which are strongly dependent upon forests. The majority of our agricultural production would not be possible without the plentiful irrigation water from the state's forest lands. Many people visit the National Parks of Southern Utah, but the biggest share of the tourist dollars that flow into Utah come from skiing, and skiing occurs on forest lands.

Approximately 16 million acres or one-third of Utah is forested. Only 3.4 million acres are classed as commercial timberland. These
lands are dominated by spruce-fir (25 percent), aspen (21 percent), Douglas-fir (16 percent) and lodgepole and ponderosa pine (13 percent). This timberland is administered largely by government agencies: U.S. Forest Service (72 percent), Bureau of Land Management (6 percent) and state and local agencies (6 percent). The only appreciable acreage of private commercial forest land is in the aspen type.

Timber

Obviously timber production is not the predominate use of Utah's forest land. Only about 13 million cubic ft of wood is harvested annually. The majority (85 percent) of this is removed as sawlogs, largely ponderosa and lodgepole pine. In the past Utah's forests produced large quantities of poles, post, mine timbers and railroad ties, but these products now only account for 6 percent of the annual harvest. Fuelwood gathering is a major activity in the forests of Utah, but it is more of a recreational activity than a form of timber harvest and accounts for only 3 percent of the wood removed from the forest each year.

Water

Water is clearly the most important and valuable product generated from our forest land. All 16 million acres of forest catch, retain, and gradually release the water that is vital to Utahns. Utah is a dry state with over two-thirds of the state receiving less than 20 inches of precipitation annually. Utah's forest lands, however, receive 30, 50, even 70 inches of precipitation. Nearly all of this arrives as snow or rain on snow. This water gradually enters the soil and even more gradually leaves the soil to enter streams and lakes. Most of the water flowing down Utah's streams has been "resident" in the mountains for 1 to 2 years. As snow melts in spring a large "flush" of water cascades down Utah's mountains, little...
of which is from new snowmelt. The majority is stored water that is forced out as new water enters storage. The slow release of this stored water allows Utah to have a large number of perennial streams in arid areas and to irrigate millions of acres of agricultural and urban land.

Utah produces 8 million acre-ft of water annually. Two-thirds of this water is used in Utah; over half of it is used for irrigation. Utah water is also important to Arizona, California, Nevada, Wyoming and Mexico. On average Utah is an arid state, but its forested mountains are an important water source for much of southwestern North America.

Tourism
Tourism is very important to the state’s economy, and recreation is the second most important product of Utah’s forest land. The Wasatch-Cache National Forest ranks first among the national forests in recreation use with 7-8 million visitor-days annually. The state’s forests produce nearly 20 million visitor-days of recreation each year, the majority involving winter sports.

The concentration of population along the Wasatch Front and the large ski industry in the same area create many recreation-related management problems. The most heavily used forest land is also a major source of culinary water. As both population and recreational use grow, the conflicts between recreational uses and the need to protect areas to ensure sources of plentiful, clean water will also increase.

Hunting and Fishing
Hunting, fishing and other forms of recreation are very popular in our forests. Big game hunting alone produces over a million visitor-days per year. Much of the timber management activity in the state’s forests is directed toward improving wildlife habitat. Both harvesting and prescribed fire are used to create openings and alter tree age class distri-
butions to favor wildlife populations. In recent years a great deal of work has concerned the improvement and protection of the riparian zone along streams and lakes to improve fish habitat in forests.

Grazing
Grazing is another major use of forest land. Over 90 percent of the state’s forest area is classed as grazing land. These lands produce nearly a million animal unit months of grazing annually. Most of Utah’s cattle and sheep graze mountain ranges in the summer. Sheep outnumber cattle 2 to 1 on the state’s forested range, but cattle consume nearly two-thirds of the forage harvested each year from forest lands. Nearly 80 percent of the forest in Utah is actively managed for grazing. These lands contribute significantly to the state’s cattle and wool economy.

Minerals
Because the major forested area of the state coincides with the overthrust belt, minerals have long been important products of forest lands. The importance of gold, silver and copper mining has declined in recent years, but exploration for and extraction of oil, gas and coal have more than offset hard rock mining as forest uses. Conflicts between recreational users and minerals interests present some of the most difficult problems for forest managers.

Not much lumber is produced from forests in Utah, but other products of the forest—water, wildlife, recreation, range—are vitally important to the state’s economy. The wise management of Utah’s forests is extremely important to the state’s citizens. The concentration of population and forest use along the Wasatch Front creates many unique problems for the state’s forest managers. It also provides the impetus for the Forest Resources Department of the Agricultural Experiment Station to undertake such important research projects as silviculture for elk, fire management for recreation, impacts of forest insect and disease outbreaks on visual quality, and minerals management.

ABOUT THE AUTHOR

R. F. Fisher is professor of wildland soils and head of the Department of Forest Resources at USU. His research interests include soil-plant interactions and agroforestry systems.
USING COMPUTER GRAPHICS TO ASSESS THE VISUAL IMPACT OF LIMB RUST IN PONDEROSA PINE

F. A. BAKER and D. RABIN
Recreational use of forests has increased steadily for many years. Hof and Kaiser (1983) recently predicted that recreational use will continue to increase well into the 21st century. The large number of recreation-oriented forest visitors means that the visual quality of forests is an increasingly important resource.

The public's concern for the aesthetic qualities of our forests prompted Congress to enact legislation mandating the management of visual and other amenities. The Multiple Use-Sustained Yield Act of 1960 and the National Environmental Policy Act of 1969 required land managers to protect intangible forest resources, including aesthetics, wilderness, non-consumptive uses of wildlife and recreation. The Federal Land Policy and Management Act of 1976 further compelled land managers to consider scenic resources in management decisions involving public lands.

The management of any resource, including visual quality, requires a method to measure how changes will affect that resource. Techniques are available to measure the impact of changes on water, timber or other resources, but it is much more difficult to quantify the impacts on visual quality.

Most attempts to assess visual impacts on forests and other wildlands have involved changes associated with proposed timber harvests, the construction of roads, dams, and power lines, or other man-caused alterations or developments. A wide range of graphic techniques have been employed to simulate proposed landscape changes, including free-hand sketches, special-effect photography, three-dimensional models and computer-modified images (USDI Bureau of Land Management 1980b; Orland 1986a, 1986b). The artistic skills, expense, and realism of the resulting images varies considerably (Orland 1986b). These simulation techniques have been applied almost exclusively to human-directed changes to landscapes. However, visual resources are also changed by natural forces, which can dramatically alter the appearance of forest landscapes.

Insects and diseases kill, deform, defoliate, or otherwise alter the appearance of trees. Forest pests can affect a few trees or trees on hundreds of acres. In either case, these natural changes have a visual impact.

Land managers must have a functional method to measure visual impacts due to forest pests in order to consider visual quality when managing pest-infested forests. They now must rely on intuition, perceived public sentiment or professional judgement (e.g., the opinions of landscape architects) if they consider visual resources. Along road corridors or trails in parks, campgrounds or other areas receiving heavy public use, a more reliable method must be developed to assess how pest infestation affects visual resources.

Many variables affect the scenic value of an area. It is very difficult not to alter other visual elements while varying the parameter of interest—damage due to pest infestation—when using slides of representative areas or when exercising the best professional judgement. Artists' sketches often lack the detail needed to show pest damage, and can be a very expensive way of showing several degrees of damage. Recent technological developments have made computer graphic systems available at relatively low cost. These systems make it possible to produce and manipulate very detailed images, and could be very useful in the visual assessment of damage due to pests.

We evaluated several graphics systems to find one with the desirable features. We required a system which would allow us to "grab" and store images in a file in order to interchange parts of images. The first system we used, designed by Wasatch Computer Graphics in Salt Lake City, had a limited ability to perform this "cut-and-paste" function and created images very slowly (> 8 hours).¹ This system was expensive and did not produce acceptable results. Several other systems were evaluated before we selected the Artronics PC 2000 system Version 3.1 manufactured by Artronics, Inc. of South Plainfield, N.J. This system slowly (at least on our computer) converts images from the video camera to a computer image ("grabbing" the image), but its ability to work with the images offset other deficiencies.

Rating Visual Impact

A preliminary experiment determined the visual impact of limb rust resulting from different "types of infection" and examined the relationship between visual impact ratings and the proposed six-class limb rust rating

¹ Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the authors or the Utah Agricultural Experiment Station, and does not imply its approval to the exclusion of other products that may also be suitable.
Figure 2. Original and computer altered images of near-view ponderosa pine scenes. A) original slide; B) one tree infected, rust rating of 4; C) two trees infected, rust ratings of 4 and 2 (rust in tree with rust rating of 2 is obscured by foreground tree); D) two trees infected, rust ratings of 6 and 6.
Figure 1. Linear ranking of viewer preference of limb rust infected ponderosa pines. The numbers refer to the ranking for a particular slide. The distance between lines reflects the degree of difference in viewer preference.

system (Baker et al. 1986). Of special interest was the question of whether trees of different appearances but with the same ratings for limb rust would receive equal ratings for visual impact.

Twelve computer images that were examples of the six-class rating system (from uninfected to class six trees) were shown to two groups of student observers. In the paired comparison test, each student was asked to select the least attractive slide. All possible pairs of slides were shown so it was possible to rank visual attractiveness of all of the images.

The visual rankings derived from this test were consistent with the six-class rating system at the extremes of the scale, although rankings did not conform as closely with the middle rust rating classes (Fig. 1).

A second experiment measured viewer response to different levels (percent) and severity (extent) of infection in closeup views of ponderosa pines. Images selected for the visual assessment experiment represented rust rating classes of 0, 2, 4 and 6. Four scenes were chosen, and two trees were removed from each scene and altered to show varying degrees of rust infection. These trees were then added back to the scene (Fig. 2a-d). A total of 10 separate images per scene were tested, which represented all combinations of rust infections. Thirty-seven viewers were instructed to rate the beauty of each scene on a scale from 1 to 10. Limb rust was not mentioned or explained to the viewers.

Because viewers used the scale differently, their scores were transformed using the Z distribution (Snedecor and Cochran 1974). These Z-scores were then used to compute the variance for each viewer for a particular slide. The four viewers with the largest variance were dropped from the study. The Z-scores for the four scenes with the same incidence and severity of limb rust were then averaged. Means were multiplied by 100, and the value of the lowest mean was added to all scores to make all values positive. One-way analysis of variance and contrasts were used to determine statistical differences between means. Kendall’s Tau was used to test the hypothesis that a viewer’s ratings of scenes decreased with increasing disease incidence and severity (Kendall 1955).

Viewers Rated Damage

The analysis of the sums of ratings for each scene showed that viewer ratings decreased with increasing incidence and severity of limb rust (Fig. 3). Kendall’s Tau value was 0.876, indicating that it is very unlikely that this result was due to chance alone. In Figure 3, it appears that there are three levels of visual impact. Total rust ratings of 0 and 2 are distinct from those of 4 and 6, and ratings of 4 and 6 are distinct from total ratings of 8 or more.

Unfortunately, these findings are not of much use to forest managers. We know that the average user of a forest sees and reacts negatively to limb rust in scenes typical of those surrounding Bryce Canyon National...
Explaining the value of dead trees could make viewers more receptive to the scenic beauty of these trees.

Explanation Alters Perceptions

We altered the computer image and removed the diseased trees. Another group of viewers were then asked to rate the slides. A few slides of diseased trees were included for reference. This time viewers received an explanation of the value of dead trees for wildlife. As before, limb rust disease was not mentioned. As shown in Figure 4, viewers found that diseased trees had desirable visual qualities and gave disease-free scenes lower ratings, whether the scenes showed only uninfected trees or scenes in which the diseased trees had been removed.

These findings help forest managers determine the visual impact of certain management activities. If desired, the forest manager can employ the traditional approach and remove dead trees. An alternative strategy involves educating users about the value of dead trees, thus turning a potential liability into an asset. Dead trees can enhance scenic beauty, and the insects that they harbor and the snags on dead trees used for perches and nesting sites benefit wildlife.

Results of this study will help forest managers consider other alternatives for managing dead and dying trees in our scenic landscape. Using computer graphics to explore the impacts of changes to landscape before making changes will be a valuable tool for the intelligent management of our natural resources.

ACKNOWLEDGMENTS

This study was conducted under and supported by Cooperative Agreement No. 28-C6-388 with the Rocky Mountain Forest and Ranger Experiment Station, USDA Forest Service, and was a contribution to Regional Research project W-110, Interactions Between Bark Beetles and Pathogens and Their Influence on Forest Productivity.

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LITERATURE CITED


SAVINGS POSSIBLE WITH CONSOLIDATION OF DAIRY PLANTS

R. A. CHRISTENSEN

Grade A milk markets in Utah and surrounding states were once local, i.e., milk was assembled, processed and distributed within relatively small geographic areas. Technological advances, economies of size, and competitive forces led to fewer but larger, more centrally located dairy plants. These plants now serve an integrated regional market that includes Utah and surrounding states.

Has the structure of the dairy industry stabilized, or will there be further centralization of processing and manufacturing facilities to take advantage of plant economies of size? Or will there be a decentralization of plants to minimize assembly and distribution costs, especially if energy costs increase significantly during the next decade? A study was made to help answer these questions.

This study determined the number, size and location of dairy plants that would minimize total assembly, processing and distribution costs. Two scenarios were examined—minimize total costs at current plant
and transportation operating costs levels, and how to minimize costs if energy prices increased by 100 percent. The study included plants in the Black Hills, Eastern Colorado, Great Basin, Lake Mead and Southwest Idaho-Eastern Oregon federal milk orders. These five federal milk orders make up the Intermountain area, a region in which there has been considerable coordination and integration of milk supplies, plant operations and distribution of finished dairy products. All of the fluid milk and cream, ice cream, cottage cheese and cheese manufacturing plants that used milk pooled in one or more of the five federal orders were included. Manufacturing plants and their Grade B milk supplies were included because they utilize surplus Grade A milk, thus helping to balance the market.

The system that would minimize total costs was simulated using a linear programming model. The model was based on milk production and consumption in December 1983, and plant and transportation costs in 1985. The study simulated the assembly of 227 million lb of Grade A milk from producers in 120 counties, and the processing and distribution of 134 million lb of fluid milk and cream, 5 million lb of cottage cheese and 7 million lb of ice cream to consumers in 157 counties. Surplus Grade A milk was made into cheese as was 105 million lb of Grade B milk received by manufacturing plants.

1For additional information, see "Optimum Number, Size and Location of Dairy Plants in the Intermountain Area," Research Bulletin 511, Utah Agricultural Experiment Station, Utah State University.

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Figure 1. Current number, size and location of fluid milk plants.

Figure 2. Optimum number, size and location of fluid milk plants.
Fluid Milk Plants

Thirty-six widely dispersed fluid milk processing plants were operating in the study area. Twenty-six of these plants were small (5.0 million lb or less of product per month), two were large (10.1 to 15.0 million lb) and eight were medium (5.1 to 10.0 million lb).

Using current costs, the computer model indicated that minimizing total costs would involve a reduction in the number of fluid milk processing plants from 36 to 10 (Figs. 1 and 2). The larger remaining plants would be located primarily near the larger consumption centers. Plants would be as large as warranted by consumption. In the Ogden-Salt Lake City area, for example, there would be two plants: one extra-large plant (15.1 to 20.0 million lb) operating at maximum capacity and one large plant. Optimal marketing areas for each fluid milk plant are indicated by the circles in Figure 2.

When the costs of energy required for transportation and plant operations increased 100 percent, total marketing costs increased; there was no change in the optimum number, size and location of plants.

Cottage Cheese Plants

There were nine cottage cheese plants in the study area—six small (160,000 to 450,000 lb of product per month), two medium (460,000 to 750,000 lb) and one large (760,000 to 1,050,000 lb). At current energy costs, the optimal solution involved the operation of only two extra-large plants (1,060,000 to 1,350,000 lb), one in Greeley, Colorado, and one in Ogden, Utah. Both of these plants would operate near maximum capacity (Figs. 3 and 4). Optimal marketing areas for each plant are indicated by the circles in Figure 4.

According to the computer model, costs would be minimized by reducing the number of milk processing, cottage cheese, ice cream and cheese manufacturing plants.
As with fluid milk plants, a 100-percent increase in energy costs would increase total marketing costs but would not affect the optimum number, size and location of cottage cheese plants.

Ice Cream Plants

There were 14 ice cream plants in the study area—11 small (as much as 1 million lb of product per month) and three medium-sized (1.1 to 2.0 million lb). The optimum solution involved two plants: an extra-large plant (3.1 to 4.0 million lb) operating at maximum capacity in Greeley, Colorado, and a large plant (2.1 to 3.0 million lb) located in Salt Lake City (Figs. 5 and 6). Optimal marketing areas for each plant are indicated by the circles in Figure 6. An increase in energy costs involved a reduction in volume at the Greeley plant and an increase in volume at the Salt Lake City plant.

Manufacturing Plants

Seventeen manufacturing plants used some surplus Grade A milk from the federal order pools. Most of these plants were located in Utah and Idaho (Fig. 7). There were two extra-large plants (4.6 to 5.5 million lb of product per month) and one medium plant (2.6 to 3.5 million lb) in Northern Utah, one extra-large plant in Western Idaho and one large plant (3.6 to 4.5 million lb) in Nebraska. The rest of the plants were small (no more than 1.5 million lb).

At current and increased energy costs, the optimal movement and manufacture of surplus supplies of Grade A milk involved four manufacturing plants, which would serve as
the primary balance plants for surplus Grade A milk. These four plants would operate at capacity (Fig. 8). Three would be located on the western side of the supply area (one in Northern Utah, one in Southcentral Idaho and one in Southwestern Idaho) and the fourth would be located in Nebraska (Fig. 8).

Six of the 17 existing manufacturing plants would continue operating, using mainly Grade B milk when milk was in short supply and some surplus Grade A milk during months of high milk production.

Assembly, Processing and Distribution Costs

Total estimated assembly, processing and distribution costs of existing plants for one month were $13,229,000 (Table 1). This underestimates actual costs because plants do not necessarily receive milk from the least-cost sources nor do they distribute finished products to the least-cost markets, as would occur if all plants were coordinated and operated by one firm. There is considerable duplication and overlapping of routes. Nevertheless, this estimate is useful in determining how changes in the number, size and location of plants would affect costs.

According to the computer model, the optimum number, size and location of plants would decrease assembly, processing and distribution costs by $2,740,000, a savings of $1.21 per hundredweight of Grade A milk, or about 10 cents per gallon.

The optimal solution reduced assembly, processing, manufacturing and distribution costs. The greatest reduction ($1,990,000) occurred in the processing of fluid milk and cream, cottage cheese and ice cream. Savings
TABLE 1. Total current and optimum costs of assembling, processing, and distributing milk and dairy products in the Intermountain area.

<table>
<thead>
<tr>
<th>Item</th>
<th>Current costs and number, size and location of plants</th>
<th>Optimum number, size and location of plants with:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Current costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thousands of dollars</td>
</tr>
<tr>
<td>Assemble milk from producers to processing plants</td>
<td>482</td>
<td>455</td>
</tr>
<tr>
<td>Process fluid milk and cream, cottage cheese and ice cream</td>
<td>9,022</td>
<td>7,032</td>
</tr>
<tr>
<td>Manufacture surplus Grade A and Grade B milk into cheese</td>
<td>3,166</td>
<td>2,497</td>
</tr>
<tr>
<td>Distribute fluid milk and cream, ice cream and cottage cheese</td>
<td>559</td>
<td>505</td>
</tr>
<tr>
<td>Total</td>
<td>13,229</td>
<td>10,489</td>
</tr>
</tbody>
</table>

were achieved by economies of size. Average cost per unit decreased when there were fewer but larger plants. Almost $700,000 was saved in a similar manner by reducing the number of cheese manufacturing plants.

Modest savings were possible in assembling milk ($27,000) and in distributing finished products ($54,000) when fewer, larger plants were more strategically located.

Under the optimal solution, a 100-percent increase in energy costs would result in an 8.6 percent increase in total costs. Assembly costs would increase 19.6 percent; costs of processing fluid milk and cream, cottage cheese and ice cream would increase by 6.7 percent; costs of manufacturing cheese would increase by 10.7 percent; and costs of distributing fluid milk and cream, cottage cheese and ice cream would increase by 15.6 percent.

**Further Consolidation Likely**

The optimum economies of scale may be difficult to achieve because there are many independently owned and operated milk marketing firms in the study area. However, competitive market forces will probably continue to encourage the operation of larger, more centrally located plants. Several plant closures and consolidations have already occurred since this study was initiated. Firms building new plants should carefully consider how they can achieve the greatest efficiencies, thereby remaining competitive. They should also consider whether joint ownership or operation of plants in cooperation with other firms might more fully capture potential economies of size and reduce costs. In the long run, processors, producers and consumers will benefit from these savings.

**ABOUT THE AUTHOR**

R. A. Christensen is a professor in the USU Economics Department, Extension dairy economist, and does marketing research with the Utah Agricultural Experiment Station.
Utah's 52.5 million acres include landscapes of remarkable physical and biological diversity. Natural vegetation ranges from desert to alpine tundra. Approximately one-third of the state is occupied by forests. These forests are diverse, ranging from those dominated by pinyon, juniper or Gamble oak, which mark the transition from nonforested low-elevation lands, to the conifer and aspen forests at higher, more moist, elevations.

Forests are not static; natural succession results in shifts in species composition and gradual, but inexorable, changes in forested landscapes. These changes are often inconsistent with management objectives and in many cases, natural disturbance alone will not accomplish management goals, such as maintaining a particular type of forested landscape in high-use recreation areas. In such cases, intervention is necessary in order to create or maintain the desired forest vegetation.

To be successful, foresters must have clearly defined management objectives. Appropriate management objectives, of course, vary from one forest to another; e.g., objectives in wilderness areas differ substantially from those in forests where timber production is emphasized. Silviculture is the active manipulation (in contrast to a more custodial role in wilderness areas and some parks) of forest stands in order to accomplish

SILVICULTURE: SHAPING FUTURE FORESTS

J. N. LONG
Figure 1. Modification of predicted change in stand composition through silvicultural treatments. (Note: This is from Daniel et al. 1979)

Figure 2. Left unthinned, a 70-year-old lodgepole pine is too dense for use by elk.

Figure 3. Early thinning has left these young lodgepole pines with room to grow. This stand will continue to provide elk hiding cover for many years.

Figure 4. Though the same age as the stand in Figure 2, the trees in this thinned stand are much larger.

the desired objectives. In other words, silviculture is the theory and practice of predicting and controlling the composition and development of forests.

Anticipating Natural Changes

Succession and periodic natural disturbance mean that forests are seldom static and are constantly changing. An important part of silviculture is to anticipate the direction and rate of natural change in forests and, if necessary, speed up, slow down or even change the direction of succession and stand development in a manner consistent with management objectives (Fig. 1). In some cases, these silviculturally-induced changes may involve

Predicted future composition

Desired stand composition to meet management objectives

Present stand composition

Succession

Past stand composition

Treatments necessary

Figure 1.
replacing one type of forest community with another. More commonly they involve subtle but nevertheless important changes. For example, changes may provide a slight competitive advantage to one set of species or modify stand structure without changing species composition.

Silviculture and forest land management are similar to agriculture but there are some fundamental differences. For example, unlike the typical agricultural situation, forest management often involves several different objectives relating to multiple resources. Forest management does not involve annual crops; indeed, management of a single stand may involve rotations of 100 years or more. This sort of time frame requires careful planning for the timely replacement of maturing stands.

This paper reviews some recent silvicultural research supported by the Utah Agricultural Experiment Station and illustrates how this research affects the management of the state's forests. The management of our forests is the concern and responsibility of many people and many organizations; similarly, the silvicultural research discussed has been supported by several organizations in addition to the Experiment Station, including the timber and wildlife management staffs of the USDA Forest Service's Rocky Mountain and Intermountain Regions.

The role of silviculture in the management of forests for specific objectives is illustrated by the following hypothetical situation concerning the management of forests for wildlife habitat in which the primary, but not exclusive, land management objective is to create and maintain quality elk summer range.
Habitat for Elk

Quality habitat for elk must include both forage and cover. While not mutually exclusive, these two elements of quality habitat generally occur in different areas. The forbs, grasses and shrubs generally used as forage do not usually grow well under the relatively dense stands of trees that provide the best cover. Thus, quality habitat depends largely on how the cover and forage are distributed across the summer range of the animals. For example, some wildlife biologists have suggested that 40 percent of the total area should be vegetation providing cover and 60 percent should be vegetation providing forage.

Wildlife biologists typically characterize cover as either thermal or hiding cover. Thermal cover provides protection from extreme heat or cold and is assumed to minimize the energy that animals require for thermoregulation. Hiding cover provides security from predators, including humans. Of these two types of cover, hiding cover is undoubtedly more important for quality elk habitat in the central Rocky Mountains. Research by wildlife biologists suggests that optimum elk hiding cover is provided by a stand of trees sufficiently dense to hide, on average, 90 percent of an adult standing elk at a distance of 200 ft.

One of our recent research projects involved methods to help silviculturists apply these cover guidelines. The first step was to
assess the cover provided by existing stands and to plan for its eventual replacement by younger stands. We developed a computer model that simulated hiding cover, which we tested by comparing results with measurements of hiding cover in many different forest stands.

The model is based on several characteristics of stands, including the number, size (a common measure of tree size is diameter at a height of 4.5 ft or DBH for diameter at breast height) and spatial distribution (i.e., uniformly distributed or in clumps) of trees. The amount of hiding cover is largely a trigonometric problem. The hiding cover provided by a tree stem is equal to an arc whose length is proportional to the diameter of the stem, the distance between the tree and the observer, and the distance from the observer to the arc. Thus, how much of an arc (or elk) will be hidden depends on the number, size and position of trees between the observer and the arc. Because tree crowns are not completely solid, more than one crown is necessary to completely conceal an arc segment. The model considers partial transparency of the bases of live crowns that are lower than the body of a simulated elk. The model has been tested with each of the important tree species for elk summer range in Utah.

**Forecasting Cover for Elk**

The model lets foresters and wildlife biologists determine whether stand structures (e.g., combinations of average size and trees per acre) meet or exceed the guidelines for cover. Of course, stand structure changes in predictable ways as trees mature. Average height, DBH and crown size increase as trees grow. At a certain average size and density, lower branches begin to die and the live crowns are farther above the ground. In unmanaged stands, self-thinning (the death of smaller, suppressed trees) eventually reduces the number of trees per acre. Cover characteristics change with the structure of a stand. The model we developed can predict and provide information to control, if necessary, these changes.

The following examples illustrate how the model can be used to manage the hiding cover for elk. Two alternative management strategies will be considered for a young stand of lodgepole pine of the USU Experimental Forest that has about 1,450 trees per acre and an average DBH and height of about 1 inch and 6 ft, respectively. These short trees do not provide enough cover to hide a standing adult elk.

A “no-thinning” option would allow the unthinned stand to grow until it is about 70 years old. The model makes it possible to estimate when the stand would provide adequate hiding cover. At about 10 years of age, average tree height is about 7 ft and the stand begins to provide hiding cover. At about 15 years, however, the death of many lower branches means that the stand no longer meets the hiding cover guidelines. At about 25 years of age, the average DBH and trees per acre again provide adequate cover. In an unthinned stand, adequate hiding cover would be provided for approximately 50 years.
years of the 70-year rotation. Large animals are not likely to use a stand as dense as that during the latter half of the rotation (Fig. 2).

The alternative management option is one of many possible thinning options. This alternative involves thinning the stand to about 300 trees per acre, corresponding to an average spacing between trees of about 12 ft (Fig. 3). Thinning increases the growth rate of remaining trees and trees would be substantially larger at the end of the 70-year rotation; e.g., the predicted average DBH of 10.8 inches compared to only 8.5 inches in an unthinned stand (Fig. 4). Even at this DBH, 300 trees per acre will not provide adequate cover. On the other hand, low branches on trees in the thinned stand remain alive longer than in the unthinned stand. Thus, the thinned stand provides adequate cover about 25 years of the 70-year rotation (i.e., until the low branches die).

This analysis has considered only one management objective—the creation of elk hiding cover. Forests, however, are usually managed for more than one resource. Even when one resource (such as elk) has the highest priority, management and utilization of other, secondary, resources may be compatible with management of the dominant resource. To determine whether either of the alternative management strategies is compatible with a timber management, we must evaluate how the alternative stand structures affect the quality of logs at the end of the rotation.

Stand Density and Log Quality

Quality, and therefore value, of logs depends on many characteristics, one of the most important of which is size. When all other factors are equal, the larger the diameter, the more valuable the logs. On this basis, the logs produced by trees in a thinned stand would be more valuable. Branch diameters also affect log quality. The diameter of knots in boards from trees with large diameter branches are larger than knots in boards from trees with smaller diameter branches. In general, the lower branches of trees in sparser stands live longer and have larger diameters than the lowest branches of trees in denser stands, which means that not thinning trees would be preferable to thinning trees.

To determine how stand density affects log quality, the relationship between stand density and branch diameter must be quantified. Results of another research project supported by the Utah Agricultural Experiment Station allow foresters to predict the diameter of the branches of lodgepole pine trees at various stand densities (Fig. 5). The average of the five largest branches more accurately determines the value of a board than the number or average size of all knots; the bottom 16 ft of the log typically represents as much as 75 percent of the total timber value of a tree.

As illustrated in Figure 5, the average diameter of the five largest branches on the butt log would be about 0.8 inches in an unthinned stand and 1.3 inches in the thinned stand. Even the larger of these average branch diameters would probably not reduce the value of lodgepole pine logs. Nevertheless, this is an example of how foresters evaluate the potential effects of alternative management strategies on management objectives.

Creating a Desirable Forest Environment

Basically, silviculture is a tool foresters use to create a certain desirable kind of forest development. What is "desirable" varies from one forest to another and ultimately depends on the objectives of the forest owners. The management objectives for most of the publicly owned forests in Utah are diverse and complicated, and so are the silvicultural strategies that must be employed. Research sponsored by the Utah Agricultural Experiment Station is helping foresters design silvicultural systems for forest management objectives as diverse as quality timber production and hiding cover for elk.

ABOUT THE AUTHOR

J. N. Long is an associate professor in the Department of Forest Resources at USU. He received his PhD in forest ecology and silviculture from the University of Washington in 1976. He conducted silvicultural research for Weyerhaeuser Company from 1977 to 1980. His research deals primarily with the influence of stand structure and density on the growth of both stands and individual trees.

REFERENCES

THE EFFECTS OF TRADE LIBERALIZATION ON THE DAIRY AND BEEF INDUSTRIES IN UTAH

B. BISWAS, T. BOWLES and A. BHATTACHARYYA

The agricultural sector of the U.S. economy is very dependent on foreign trade. Even though agriculture's share of total U.S. exports has declined during the past decades, the agricultural sector continues to generate a trade surplus, which helps cover deficits in the balance of payments. However, a country's long-term capacity to export also depends on its ability and willingness to import.

We now import many agricultural products that compete with domestic products. High tariff barriers and quota restrictions, which are often used to protect domestic producers from foreign competition, are designed to help domestic producers cope with the changes in the international economy. Even though agriculture and other sectors have enjoyed special protection from foreign competition for a long time, these protective...
Liberalizing global trade could solve many of the problems confronting U.S. agriculture.

barriers have not prevented a decrease in the competitiveness of the agricultural sector. Between 1978 and 1986, the volume of competitive agricultural imports (imported agricultural products which are also produced domestically) increased from 53 percent to 63 percent. On the other hand, more agricultural products have been accorded special protection, mainly because major exporting countries such as the European Economic Community (EEC) subsidize domestic production to remain competitive in world markets. Hufbauer et al. (1986) estimated that the value of imports under special protection increased from $3.4 billion in 1960 to $67.6 billion in 1984—an increase from 5 percent to 21 percent of total U.S. imports. This protection increases the costs of imports, diverts scarce resources to less efficient industries, and creates quotas whose benefits may accrue to foreign producers. Large, politically powerful industries generally reap more benefits from special protection than smaller industries. These factors have emphasized the benefits associated with trade liberalization.

Increased Exports and Imports

Many of the problems confronting U.S. agriculture could be solved by liberalizing global trade, which would increase exports as well as imports. The intraindustry trade index indicates the degree of trade involving similar commodities. The intraindustry trade index for agricultural products is very high (0.885 in 1986). Cline et al. (1986) reported that high intraindustry trade between the United States and its major trading partners, Japan and the EEC, means multilateral trade liberalization would be a boon to the American economy.

How would trade liberalization affect the agricultural sector in Utah? The state is self-sufficient in only a few commodities, including milk and beef (Snyder 1985). Beef and dairy products are the most important agricultural products exported from Utah; these products account for about 80 percent of the state’s agricultural production (Biswa and Tribedy 1982). Despite the special protection granted to beef and dairy production, the United States is a net importer of meat and dairy products. Therefore, global trade liberalization could have a major (and perhaps adverse) impact on agriculture in Utah. This paper analyzes how complete trade liberalization among the United States, Japan and the EEC might affect the dairy and meat industries of Utah, and the overall economy of the state.

This analysis concerns three dairy products (nonfat dry milk, butter and cheese) and two meat products (beef and veal). Because it was extremely difficult to determine the amounts exported directly from Utah to the EEC and Japan, exports from Utah were assumed to equal the state’s proportion of national output of these commodities. In 1986, Utah produced 0.76 percent of the nation’s dairy products and 0.55 percent of the nation’s meat products. Utah produced 0.76 percent of the total U.S. output of nonfat dry milk, 0.67 percent of the butter and 1.42 percent of the cheese. These percentages were used to calculate the following values for exports of these products from Utah: $1.67 million, nonfat dry milk; $0.27 million, butter; $0.37 million, cheese; and $0.3 million, beef.

Mutual abolition of tariffs and other import restrictions would reduce the prices of imported goods and would increase the demand for imported goods. The increase in demand equals the percentage change in the price multiplied by the price elasticity of demand. The percentage change in price is based on the increase in domestic prices that can be attributed to trade restrictions. The price elasticity of demand for imported goods reflects the change in demand when the price changes by 1 percent. As noted above, trade liberalization could increase both exports and imports in the trading countries. The extent of that increase depends on elasticities of demand and import restrictions. The net gain in production depends on the difference between exports and imports. If the value of increased exports exceeds the decline in the production of imported goods, trade liberalization will result in a gain in production. A decrease in prices due to trade liberalization will increase the consumers’

1See Foreign Agricultural Trade of the U.S., 1986, Supplement, USDA.

2Intraindustry trade index:

\[ I = 1 - \frac{|X - M|}{X + M} \]

where \( X \) = value of exports, \( M \) = value of imports and \( |X - M| \) is the absolute difference between \( X \) and \( M \).

3See Agricultural Statistics, 1968, USDA.

<table>
<thead>
<tr>
<th></th>
<th>Nonagricultural</th>
<th>Agricultural</th>
<th>Meat</th>
<th>Milk</th>
<th>Butter</th>
<th>Cheese</th>
<th>Total dairy</th>
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</thead>
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<td><strong>Exports ($1,000)</strong></td>
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<td>11,130</td>
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<td>1,154</td>
<td>202,154</td>
<td>345,481</td>
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</table>

Source: Foreign Agricultural Trade of the U.S., 1986 (Supplement). USDA.

TABLE 2. Effects of trade liberalization on U.S. exports.

<table>
<thead>
<tr>
<th></th>
<th>U.S. exports (1986) ($1,000)</th>
<th>Tariff equivalent (%)</th>
<th>Change in price of imports (%)</th>
<th>Absolute value of elasticity of demand for importing countries</th>
<th>Changes in imports from U.S. ($1,000)</th>
<th>Total change in exports from U.S. ($1,000)</th>
<th>Utah's share of total U.S. exports</th>
<th>Utah's production gain ($1,000)</th>
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<tr>
<td><strong>Meat</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Japan</td>
<td>426,379</td>
<td>130</td>
<td>57</td>
<td>0.98</td>
<td>238,175.31</td>
<td>239,386.64</td>
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<td>EEC</td>
<td>6,674</td>
<td>50</td>
<td>33</td>
<td>0.55</td>
<td>1,211.33</td>
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<tr>
<td>Total meat</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nonfat dry milk</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>Japan</td>
<td>NIL</td>
<td>120</td>
<td>55</td>
<td>1.94</td>
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<td>67</td>
<td>0.55</td>
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<td></td>
<td>0.0076</td>
<td>25.371</td>
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<tr>
<td>Total nonfat dry milk</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td><strong>Butter</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>NIL</td>
<td></td>
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<td>—</td>
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<td>257.49</td>
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<td>330</td>
<td>77</td>
<td>0.55</td>
<td></td>
<td></td>
<td></td>
<td>1.725</td>
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<tr>
<td>Total butter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cheese</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>4,598</td>
<td>167</td>
<td>63</td>
<td>1.94</td>
<td>5,619.68</td>
<td>5,812.98</td>
<td>0.014</td>
<td>81.382</td>
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<tr>
<td>EEC</td>
<td>639</td>
<td>121</td>
<td>55</td>
<td>0.55</td>
<td>193.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cheese</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total dairy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14,904</td>
<td>647,957</td>
<td></td>
<td></td>
<td>248,795.352</td>
<td>1,544.798</td>
<td></td>
<td></td>
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</tbody>
</table>

Sources: Table 1 and Hufbauer et al.

surplus (i.e., net benefits to consumers) as consumption of imported goods increases; this decrease in the consumption of domestic substitutes lowers the producers’ surplus (i.e., net benefits to producers). Trade liberalization also reduces tariff revenue. On the whole, trade liberalization increases production efficiency through better utilization of scarce resources.

Costs of Import Restrictions

Hufbauer et al. (1986) estimated the costs and benefits of special restrictions for 31 U.S. industries. The total estimated cost of special protection associated with the dairy industry was $7.12 billion: a $5.5 billion reduction in consumer surplus, a $1.37 billion loss in efficiency and quota rent of $0.25 billion (quota
Trade liberalization would mean a slight decline in income in the state, but an increase in net output and employment in the dairy and beef industries.

Restrictions reduce imports and increase the domestic price of the imported item. In the case of the voluntary export restraint quotas, foreign producers receive this additional gain (rent) due to increased prices. Special restrictions on imports of dairy products result in a gain of $5.034 billion: a $5 billion increase in producer surplus and a $0.034 billion increase in tariff revenue. Thus, special trade restrictions on dairy products result in a net loss of $2.086 billion to the U.S. economy.

The net loss associated with special protection for the meat industry is about $0.436 billion. If these costs are distributed in proportion to state population, Utah consumers pay $1.57 million annually due to import controls on dairy and meat products ($1.3 million for dairy products and $0.27 for meat products). "Special protection" means producers gain at the expense of consumers and the U.S. economy.

Table 2 shows how trade liberalization among the United States, Japan and the EEC would affect U.S. exports of dairy and meat products and Utah's share of these increased exports. The impact of trade liberalization on U.S. imports of these products is shown in Table 3. Trade liberalization would increase U.S. exports of beef by about $240 million and reduce imports by $0.8 million, resulting in a net gain in production. Estimated exports from Utah would increase by $1.4 million.

Net Benefits of Trade Liberalization

Complete trade liberalization in the dairy industry would increase exports by $9.41 million and increase imports by $48.16 million, a net loss for the U.S. economy. The dairy industry in Utah would lose approximately $560,000. Some aspects of the dairy industry would benefit from trade liberalization. For example, exports of nonfat dry milk from the state would increase by $22,500. The cheese industry in Utah would experience a net loss of $590,000. Trade liberalization would have little effect on butter production.

The net gain for beef production in Utah would exceed losses in the dairy industry, which suggests that trade liberalization would benefit the country and Utah. Beef production would probably expand and there would be adjustments in the dairy industry—an increase in nonfat dry milk and a decrease in cheese and butter production.

Trade liberalization would also have multiplier effects on output, employment and income. A change in demand is associated with a change in income and with changes in the consumption of other goods. Thus, a change in the output of a sector also affects the output and employment in other sectors. Multipliers from the input-output models developed for Utah by Keith et al. (1985) were used to determine the overall effects of trade liberalization. The total output, employment and income multipliers for the dairy industry in Utah are 2.16, 2.63 and 2.38, respectively. Based on the job-output ratio and the income-job ratio in the dairy and beef industries, these multipliers can be used to determine how trade liberalization will affect employment and income. Keith et al. (1985) calculated that the dairy industry generates 14 jobs per million dollars of output and that $8,400 in income was generated for each job created. The beef industry generates

<table>
<thead>
<tr>
<th>Product</th>
<th>Change in U.S. imports ($1,000)</th>
<th>Utah's share of U.S. production ($1,000)</th>
<th>Utah's production loss ($1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meat</td>
<td>832.5</td>
<td>0.006</td>
<td>4.995</td>
</tr>
<tr>
<td>Nonfat dry milk</td>
<td>378.4</td>
<td>0.0076</td>
<td>2.876</td>
</tr>
<tr>
<td>Butter</td>
<td>271.2</td>
<td>0.0067</td>
<td>1.817</td>
</tr>
<tr>
<td>Cheese</td>
<td>47,506.19</td>
<td>0.014</td>
<td>665.09</td>
</tr>
<tr>
<td>Total dairy</td>
<td>48,155.79</td>
<td>669.783</td>
<td>674.778</td>
</tr>
<tr>
<td>Total</td>
<td>48,988.29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sources: Table 1 and Hofbauer et al. (1986).
TABLE 4. Net effect of trade liberalization on production of selected agricultural commodities.

<table>
<thead>
<tr>
<th></th>
<th>U.S. ($1,000)</th>
<th>Utah ($1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meat</td>
<td>238,554.1</td>
<td>1,431,330</td>
</tr>
<tr>
<td>Nonfat dry milk</td>
<td>2,959.8</td>
<td>22,495</td>
</tr>
<tr>
<td>Butter</td>
<td>-13.7</td>
<td>-0.092</td>
</tr>
<tr>
<td>Cheese</td>
<td>-41.693.2</td>
<td>-583.708</td>
</tr>
<tr>
<td>Dairy industry</td>
<td>-38,747.08</td>
<td>-561.305</td>
</tr>
<tr>
<td>Total</td>
<td>199,807.06</td>
<td>870.025</td>
</tr>
</tbody>
</table>

Sources: Based on Tables 2 and 3.

Thus, eight jobs would be lost in the dairy industry in Utah due to trade liberalization ($0.561 \times 14$). The multiplier effect of this would mean the loss of 21 jobs in Utah. The income lost in the dairy industry due to trade liberalization amounts to $67,000 (8,400 \times 8), which has a multiplier effect of approximately $159,500 ($67,000 \times 2.38). The total output effect (the net production loss multiplied by the output multiplier) would be $1,214 million.

Similar calculations for the beef industry.

TABLE 5. Multiplier effects of trade liberalization on output, employment, and income in Utah.

<table>
<thead>
<tr>
<th>Multipliers</th>
<th>Job/output ratio (jobs per million dollars of output)</th>
<th>Income/job ratio (income per job)</th>
<th>Employment effect</th>
<th>Output effect ($1,000)</th>
<th>Income effect ($1,000)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Employment</td>
<td>Income</td>
<td>Industry</td>
<td>State</td>
<td>Industry</td>
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<tr>
<td>Meat</td>
<td>2.65</td>
<td>4.97</td>
<td>4.96</td>
<td>7</td>
<td>4,200</td>
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<tr>
<td>Dairy</td>
<td>2.16</td>
<td>2.63</td>
<td>2.38</td>
<td>14</td>
<td>8,400</td>
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<tr>
<td>Total</td>
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<td>14</td>
</tr>
</tbody>
</table>

Sources: Tables 2-4 and Keith et al. (1985).
are more encouraging. Trade liberalization would result in 10 new jobs, whose multiplier effect would result in the creation of 50 new jobs. The income gain of $42,000 for the industry would mean an increase of $208,000 for the state. With an output multiplier of 2.65, the $1.431 million increase in output in the beef industry would increase total output by $3.79 million.

Table 4 shows that trade liberalization would directly create only two jobs in the beef and dairy industries, but that 29 more jobs would be created in the state. Total output in the two industries would increase by $890,000, resulting in a total increase in output of $2.6 million for the state. Trade liberalization would reduce income in the two industries by $24,000, but would increase income in the state by $51,000.

Consumers Benefit from Lower Prices
Liberalization of trade in meat and dairy products among the EEC, Japan and the United States would not have any deleterious effects for Utah. Income in the state would decline slightly, but the net output and employment in the two industries would increase. There would be some adjustments as resources were diverted from dairy to beef production and as less butter and cheese and more non-fat dry milk were produced. The most important gain from trade liberalization would be associated with the elimination of higher prices due to tariff and/or quota restrictions, which now cost Utah consumers an estimated $48.5 million annually. The state would also share in the $1.8 billion savings in the United States associated with increased efficiency.

Agricultural sectors in the major trading nations are generally highly protected. Domestic price supports result in prices that are higher than world prices, thereby leading to overproduction. Many countries subsidize exports to dispose of surpluses. Thus, export subsidies are introduced to alleviate the adverse effects of another market distortion (domestic price supports). To realize the benefits of trade liberalization, trading nations must eliminate their agricultural price support programs.

ABOUT THE AUTHORS
Basudeb Biswas is an associate professor in the Department of Economics at USU. He received his PhD from the University of Chicago. His research concerns international trade, development and production efficiency.

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LITERATURE CITED


CONTROLLING EROSION ON WESTERN PHOSPHATE MINE EMBANKMENTS

G. HART and C. WHITSON

Phosphate ore is surface-mined in most of the western phosphate region, primarily in Southeastern Idaho, northeast of Soda Springs. Overburden is removed and dumped onto nearby valleys or hill slopes. The dumps are then graded to about 3:1 slope, deep harrowed, drill-seeded to grasses and forbs, and fertilized with nitrogen.

Grading usually creates long embankment slopes, some as long as 800 ft. Theoretically, long slopes generate more erosion than a series of short segments. For this reason, agencies concerned with water quality have wondered whether installing contour terraces or trenches might reduce erosion from rainstorms.

Figure 1. Rainfall simulator on site 1. This embankment with 3 years growth of grasses and forbs and 56 percent surface coverage of gravel produced under 0.2 tons/acre of erosion during this rainfall.

Figure 2. Rainfall simulator on freshly constructed embankment of alluvial fill. This bank had 64 percent bare soil and yielded about 25 tons/acre of erosion during this event.
Rainfall Simulated to Create Erosion

A study supported by the U.S. Forest Service and the Conda Mining Company was conducted to compare erosion on plots on representative embankments ranging in length from 50 to 200 ft (Whitson 1987). A very large rainfall simulator was used (Fig. 1) that could deliver rain at a rate of about 1.6 in/hr for roughly 45 minutes, an amount which exceeded the 100-year rainfall for the region. Temporary runoff plots, 10 ft wide and of varying lengths (50, 73, 90, 100, 150 and 20 ft), were installed. Runoff water was directed through a small flume at the bottom of the plot. During “rainfalls,” samples of the water/suspended sediment mixture were collected at about 2 minute intervals. Flow rate was measured by the flume and sediment concentration was determined by weighing the dried sediments in the laboratory. Erosion was computed by multiplying the flow rate by sediment concentration and was adjusted to tons/acre.

Three embankments were studied. On the first, which had been graded and seeded 3 years previously, 56 percent of the surface was covered with partly weathered shales, chert and mudstones. The slope was 27 percent. The surface of the second embankment consisted almost entirely (93 percent) of unweathered shales and cherts; it also had a slope of 27 percent and was seeded the previous autumn. The third site was also constructed and seeded the previous fall. Because it was located in a valley bottom, it consisted primarily of alluvial sediments; only 32 percent of the surface was covered with unweathered rocks and gravel. The slope ranged from 30 to 33 percent.

Results

The average erosion losses on plots of various lengths on the three embankments are given in Table 1. There were variations in the rainfall applied but the results clearly show that erosion differed on the three types of embankments. There was little erosion (less than 0.2 ton/acre) on the embankment with 3 years of revegetation. Living plants occupied 9 percent of the surface area of this embankment and 27 percent of the surface was covered with dead litter; only 8 percent of the soil was bare. The mulch-like effect of litter and gravel evidently prevented raindrops from detaching soil and reduced the velocity of surface runoff to limit erosion (on most farms, soil losses of 2 to 5 tons/acre/year are considered tolerable).

On the second site, which was almost completely covered with gravel and rocks, only 2 percent of the surface was covered with plants and litter the first year but rainfall rapidly infiltrated the porous surface, thus preventing excessive surface runoff and erosion.

There was extensive erosion (20 to 35 tons/acre for “rainfalls” of 1.4 to 1.8 inches) on the

<table>
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<th>TABLE 1. Average erosion from plots of various lengths on three embankments.</th>
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<td>Slope length (ft)</td>
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<tr>
<td><strong>Site 1.</strong> Three year rehabilitated, partly weathered, gravelly surface.</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>73</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td><strong>Site 2.</strong> Newly rehabilitated, much coarse, unweathered gravel surface.</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td><strong>Site 3.</strong> Newly rehabilitated, alluvial soil dominates surface.</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>73</td>
</tr>
<tr>
<td>90</td>
</tr>
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</table>
third type of embankment (Fig. 2). Live plants covered only 3 percent of the surface; bare soil occupied 64 percent. Obviously, the seeding had not yet effectively controlled erosion and the small amounts of gravel and rock cover were not an adequate mulch. Comparison of erosion on sites 2 and 3 after only 9 months of rehabilitation (October to June) indicates the importance of incorporating high amounts of gravel and rock in the overburden material in freshly-constructed embankments to control erosion. As illustrated at site 1, grasses and forbs provide longer term protection against erosion.

**Erosion Did Not Increase With Slope Length**
Results of this study show that erosion per unit area need not be higher on longer slopes than on shorter slopes. According to classical erosion theory (Zingg 1940; Smith and Wischmeier 1957), the longer the slope, the greater the erosion, as the velocity of runoff water increases enough to detach and transport soil particles. However, the relationship between slope length and erosion per unit area on phosphate mine embankments does not support this theory. Although there is considerable scatter, erosion clearly did not increase with slope length. The trend line shows a slight but insignificant decrease in erosion with increase in slope length.

Results indicate that it is not necessary to break up slopes into shorter segments with contour terraces or small trenches to reduce erosion. Rather, erosion can be reduced by incorporating more than 60-70 percent coarse rock or gravel into the embankment surface and rough grading to create a gently rolling surface containing mounds and depressions. These features divert and slow down any surface runoff and create areas to temporarily detain runoff. As the rock weathers to soil, the seeded plants and the organic litter they produce then provide longer-term erosion control.

**ABOUT THE AUTHORS**
G. Hart is associate professor of watershed management in the Forest Resources Department. He is interested in methods of quantifying and controlling erosion and sedimentation in wildlands.

C. R. Whitson is a former graduate student who now works as a hydrological consultant in California.

**LITERATURE CITED**


Zingg, A. W. 1940. Degree and length of slope as it affects soil loss runoff. Agricultural Engineering. 21:59-64.

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*There was relatively little erosion on the site that was almost completely covered with gravel and rocks.*

---

**Figure 3.** Relation between slope length and erosion at site 1. The trend line is not significant.
There are thousands of acres of commercial ponderosa pine (Pinus ponderosa) forests in southern Utah. The potential for timber production on these forests varies widely and ranges from low on harsh sites that support a few slow-growing pine trees per acre to high on prime sites that are among the most productive in the Rocky Mountains. Intensive forest management for timber production is economically feasible only on these prime sites. The objective of this research was to develop a method that could be used to identify prime sites for ponderosa pine production in southern Utah.

The USDA Forest Service has developed a habitat type land classification system for southern Utah (Table 1), which is based on the fact that different plants grow on different types of sites. For example, manzanita usually
grows on shallow, alkaline soils, while snowberry usually grows on deeper, neutral pH soils. Because the species composition reflects environmental factors, growth rates should differ in different types of ponderosa pine habitats. Therefore, one would expect the snowberry habitat type to be associated with sites better suited for pine production than the manzanita habitat type.

To test this hypothesis, we randomly located 172 sample plots within the ponderosa pine zone of the Dixie National Forest. Within each plot, the dominant pine tree with greatest initial 25-year diameter growth was selected as a “site tree.” Site tree height growth for 25 years (called site index 25 or SI$_{25}$) was measured by boring an increment core at breast height; the site tree was then climbed and increment cores were bored until the location corresponding to 25 years less than breast height age was located. SI$_{25}$ was then measured with a steel tape to the nearest meter. Habitat type was determined by using keys and descriptions published by Youngblood and Mauck (1985). To avoid bias in habitat identification, habitat type was determined before the site index was measured.

We found that mean SI$_{25}$ differed significantly among habitat types. However, there was also considerable variation in SI$_{25}$ within the habitat types (Fig. 1). This variation meant that no habitat type consistently contained good or poor sites.

### Model Developed

Although there was considerable variation in SI$_{25}$ within the habitat types, the best sites occurred only in the cool-moist habitat types. Therefore, we felt that including additional site factors would help identify prime sites. We then developed a model to predict prime and non-prime sites according to habitat type, soil and topographic properties. A prime site was defined as one on which the SI$_{25}$ of dominant ponderosa pine trees exceeded 25 ft (a tree at least 25 ft tall at 25 years of age).

We then randomly established 75 plots within the ponderosa pine zone in the Dixie National Forest, only two of which were prime sites. We also randomly established 44 plots at areas identified as prime sites for ponderosa by Dixie National Forest silviculturists. Within each of these plots, the SI$_{25}$ was

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**TABLE 1. Description of ponderosa pine habitat types.**

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<th>Habitat type</th>
<th>Dominant understory species</th>
<th>Typical site</th>
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<tbody>
<tr>
<td><strong>Hot-Dry Habitat Types</strong></td>
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<td></td>
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<tr>
<td>Ponderosa pine/manzanita (Pinus ponderosa/Arctostaphylos patula)</td>
<td>Arctostaphylos patula</td>
<td>Shallow limestone soils; south and west facing slopes</td>
</tr>
<tr>
<td>Ponderosa pine/black sagebrush (Pinus ponderosa/Artemisa nova)</td>
<td>Artemisa nova</td>
<td>Deep sandy plains at low elevations</td>
</tr>
<tr>
<td>Ponderosa pine/bitterbrush (Pinus ponderosa/Purshia tridentata)</td>
<td>Purshia tridentata</td>
<td>Shallow basaltic or sandstone slopes</td>
</tr>
<tr>
<td><strong>Cool-Moist Habitat Types</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ponderosa pine/gambel oak (Pinus ponderosa/Quercus gambelii)</td>
<td>Quercus gambelii</td>
<td>Wide variety of sites; most common on non-limestone soils</td>
</tr>
<tr>
<td>Ponderosa pine/snowberry (Pinus ponderosa/Symphoricarpos oreophilus)</td>
<td>Symphoricarpos oreophilus</td>
<td>Moist benches; north and east facing slopes</td>
</tr>
<tr>
<td>Douglas-Fir series (Pseudotsuga mensiesii)</td>
<td>Symphoricarpos oreophilus</td>
<td>Cool slopes above ponderosa pine</td>
</tr>
<tr>
<td>White Firs series (Abies concolor)</td>
<td>Symphoricarpos oreophilus</td>
<td>Cool slopes and benches above ponderosa pine series</td>
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</table>
The prime sites for ponderosa pine had cool-moist habitats, and soil with a low pH containing large amounts of sand.

measured on the tree with the best initial 25-year diameter growth (based on increment cores). Soil samples under this tree were analyzed for pH, organic matter, mineralizable nitrogen, extractable phosphorus and percent sand, silt and clay. Elevation, slope, slope aspect, and habitat type were also recorded for each plot.

Our previous study of habitat type indicated that prime sites occurred only on cool-moist habitat types, so we only included plots with these habitat types. Classification tree analysis (Breiman et al. 1984) was used to develop a model to predict whether sites were prime or non-prime. The classification tree correctly classified 71 of the 77 sample cases (Fig. 2), an accuracy of 88 percent.

Prime sites were associated with cool-moist habitats with a high sand content and low pH. Short-duration thunderstorms in the study area are common during the summer, and those deep sandy sites may have more water available for root extraction (due to high infiltration and low runoff). Root extraction may be more rapid on these sites due to high soil hydraulic conductivity. A low soil pH could affect many of the biological and chemical soil properties that influence tree growth. For example, there was a negative correlation between extractable phosphorus and pH ($r = -0.89$, $P < 0.001$).

Many of the potential predictor variables were closely related and therefore were not included in the model, even though they may be useful predictors. For example, the percentage of sand was negatively correlated with the percentage of clay ($r = -0.89$, $p < 0.001$), so after the percentage of sand was included in the model, including the percentage of clay would explain little of the remaining variation.

The key of Youngblood and Mauk (1985) can be used to determine habitat type by anyone who can identify a few common plants. A soil scientist can teach someone how to feel the soil to estimate its sand content, and simple kits are available for the colorimetric determination of soil pH. Thus, after less than a week of specialized training, a forester can use our simple model to identify the relatively rare prime sites that can be intensively managed for the economical production of valuable ponderosa pine timber. This is extremely important during an era when we must make the wisest use of every acre of our public lands.
**ABOUT THE AUTHORS**

**D. L. Verbyla** completed his PhD in Forest Resources at USU. This paper was part of his dissertation research. His current research interests include computer applications in natural resources, predictive statistical models and internal validation of models.

**R. F. Fisher** is professor of wildland soils and head of the Department of Forest Resources at USU. His research interests include soil-plant interactions and agroforestry systems.

**Figure 2.** Classification tree developed to predict prime ponderosa pine sites.

```
Is the habitat type PIPO/ARPA, PIPO/ARNO or PIPO/PUTR?

Yes

Predicted nonprime site

No

Is the soil pH at 15 cm greater than 6.55?

Yes

Predicted nonprime site

No

Is the percent sand at 45 cm greater than 34%?

Yes

Predicted prime site

No

Predicted nonprime site
```
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