Site productivity and soil conditions on terraced ponderosa pine stands on the Bitterroot National Forest

Elena J. Zlatnik

The University of Montana

Follow this and additional works at: https://scholarworks.umt.edu/etd

Let us know how access to this document benefits you.

Recommended Citation


This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.
Permission is granted by the author to reproduce this material in its entirety, provided that this material is used for scholarly purposes and is properly cited in published works and reports.

** Please check "Yes" or "No" and provide signature **

Yes, I grant permission [X]
No, I do not grant permission [ ]

Author's Signature [Signature]

Date [6 Dec. '96]

Any copying for commercial purposes or financial gain may be undertaken only with the author's explicit consent.
SITE PRODUCTIVITY AND SOIL CONDITIONS ON TERRACED PONDEROSA PINE STANDS ON THE BITTERROOT NATIONAL FOREST

by

Elena J. Zlatnik

B.A., Reed College, 1991

presented in partial fulfillment of the requirements

for the degree of

Master of Science

The University of Montana

1996

Approved by:

Chairperson

Dean, Graduate School

Date
Terraces were built by the U.S. Forest Service on the West Fork District of the Bitterroot National Forest (BNF) from 1964-1971 as a method of mechanical site preparation prior to machine-planting ponderosa pine in recent clearcuts. The terraces were intended to reduce site competition for planted seedlings and to allow machine-planting. Political and institutional pressure forced the practiced to be abandoned, and decades later, the regenerating stands have not been evaluated for the long-term effects of terracing on tree productivity and soil characteristics. This study was undertaken to determine the influence of terracing on planted ponderosa pine and understory productivity, and to investigate differences in soil characteristics between terraced and non-terraced sites of similar age, slope, aspect, and soil and habitat characteristics.

Three paired study sites were established, with 5 terraced and 5 non-terraced plots each, on the West Fork District, BNF. Trees on the plots were measured for dbh and height, and understory biomass samples were taken. Soils were sampled at each site and analyzed for P, K, C, pH, water-holding capacity, and particle size distribution in the lab. Site volumes for planted ponderosa pine (*Pinus Ponderosa*) were significantly higher on the plots of the three terraced study sites, when compared to the non-terraced plots. Understory vegetation biomass was significantly lower on two of the three terraced sites. Soil characteristics differed little between terraced and non-terraced sites. All terraced sites had significantly higher silt content than the non-terraced sites, and available K was different between terraced and non-terraced pairs on two of the three sites.

Concerns relating to the possible negative effects of terracing on soil structure and nutrient status, and their influence, in turn, on productivity, include compaction and erosion. However, neither compaction nor significant nutrient loss appears thus far to affect tree productivity on the terraced sites, nor is there chemical evidence of current erosion.

Water retention and slower snowmelt on the terraces, positively altered nutrient relations due to piling of organic matter in terrace risers, and changes in site temperature regimes are discussed as possible factors in the significant differences in site productivity.
ACKNOWLEDGEMENTS

I would like to thank my committee members, Don Potts, John Donahue, and Kelsey Milner for their advice, ideas and encouragement. I am especially grateful to my committee chair and advisor Tom DeLuca for his patience, unflagging enthusiasm, and field assistance. Thanks also for field assistance to Jenny Newland, Jennifer Ferenstein, and David Claman. Thanks to Sam Stier and Tammy Mildenstein for their careful reading of and comments on early drafts.

Special thanks go to Don King and Linda Reiche on the West Fork District for showing me the terraces and helping me out again and again during my field work.
# TABLE OF CONTENTS

ABSTRACT ......................................................................................................................... ii
ACKNOWLEDGEMENTS ..................................................................................................... iii
TABLE OF CONTENTS ....................................................................................................... iv
LIST OF TABLES, FIGURES AND PHOTOGRAPHS ......................................................... v

CHAPTER 1: INTRODUCTION .......................................................................................... 1
  Study Objectives ............................................................................................................ 1
    Terrace construction .................................................................................................... 3
    Literature review ........................................................................................................ 4
  Problem Background ................................................................................................... 9
    Methods of site preparation ....................................................................................... 11
    Potential problems associated with terracing ......................................................... 14
  Materials and methods ............................................................................................... 19

CHAPTER 2: RESULTS ..................................................................................................... 23
  Vegetation Data
    Tree data .................................................................................................................. 23
    Understory vegetation ............................................................................................. 29
  Soils Data
    Physical characteristics ............................................................................................ 30
    Chemical characteristics .......................................................................................... 32

CHAPTER 3: DISCUSSION ............................................................................................... 33
  Effects of terracing on vegetation .............................................................................. 33
  Effects of terracing on soil ......................................................................................... 35
  Other possible explanations for productivity differences ......................................... 39
  Other considerations .................................................................................................. 42
  Conclusion .................................................................................................................. 43

LITERATURE CITED ....................................................................................................... 45
LIST OF TABLES, FIGURES, AND PHOTOGRAPHS

TABLES

Table 1. Study site characteristics of paired terraced and non-terraced sites on the West Fork District, Bitterroot National Forest ........................................................... 20

Table 2. Volume and biomass data, paired non-terraced (A) and terraced (B) sites, West Fork District, Bitterroot National Forest ................................................. 24

Table 3. Types of understory vegetation on non-terraced (A) and terraced (B) sites ............................................................................................................ 29

Table 4. Soil water-holding capacity and percent sand, silt, and clay in surface soils (0-10 cm) of non-terraced (A) and terraced (B) ponderosa pine stands, Bitterroot National Forest ......................................................... 31

Table 5. Soil pH, extractable P, exchangeable K, and total organic C in soils of non-terraced (A) and terraced (B) ponderosa pine stands, Bitterroot National Forest .......... 32

FIGURES

Figure 1. Standard terrace with bench, riser and planted tree ........................................... 10

Figure 2. Mean diameters at breast height of planted ponderosa pine, terraced vs. non-terraced sites, Bitterroot National Forest ................................................. 25

Figure 3. Mean planted ponderosa pine heights, in meters, terraced vs. non-terraced sites, Bitterroot National Forest ................................................................. 25

Figure 4. Diameter distributions, planted ponderosa pine, Coal Creek non-terraced (A) and terraced (B) plots ................................................................................. 26

Figure 5. Diameter distributions, planted ponderosa pine, Spruce Creek non-terraced (A) and terraced (B) plots ................................................................................. 27

Figure 6. Diameter distributions, planted ponderosa pine, Thunder Mt. non-terraced (A) and terraced (B) plots ................................................................................. 28

Figure 7. Percent sand, silt, and clay in surface soils (0-10 cm) of non-terraced (A) and terraced (B) stands, Bitterroot National Forest ................................................. 31

PHOTOGRAPHS

Photograph 1. East Coal Creek terrace, West Fork District, Bitterroot National Forest ...... 5
Photograph 2. East Coal Creek terrace, West Fork District, Bitterroot National Forest……6

Photograph 3. Lookout Mountain terraces, West Fork District, Bitterroot National Forest.6
CHAPTER 1: INTRODUCTION

Study Objectives

U.S. Senate S. Doc. 115, "A University View of the Forest Service," also known as the Bolle Report, reads in its introduction: "The management sequence of clearcutting-terracing-planting cannot be justified as an investment for producing timber on the B[itterroot] N[ational] F[orest]... The practices of terracing on the BNF should be stopped. Existing terraced areas should be dedicated for research." (Bolle et al. 1970)

The Bolle Report, originally titled "A Select Committee of the University of Montana Presents its Report on the Bitterroot National Forest," was a culminating blow in a several year-long conflict embroiling BNF managers, the Forest Service Regional Office in Missoula, Bitterroot Valley natives of both conservationist and logging sympathies, and faculty members of the University of Montana and its School of Forestry (Bolle 1989). The Bolle Report was critical of many aspects of the BNF’s management of timber resources, and it eyed terracing, used since 1964 as site preparation prior to planting in clearcuts, as emblematic of the Forest’s short-sighted, extractionist planning.

The Forest Service had issued its own internal review of BNF practices in April of 1970, in "Management Practices on the Bitterroot National Forest: A Task Force Appraisal," at the request of regional forester Neal Rahm (Worf et al. 1970). Although it was encouragingly straightforward about management failures on the Forest and critical of excessive clearcutting and road building, poor regeneration successes, and lack of attention to non-timber values, the Task Force Report did not condemn terracing out of hand. In the chapter "Is Terracing Justified?,” the task force argued that it was an
effective and, indeed, justified practice but concluded the chapter with seven recommendations that significantly circumscribed the situations in which terracing should be used.

In any case, within a year of the release of the Bolle Report, terracing screeched to a halt on the BNF. The Bolle Report and the Task Force Report drove a deep wedge into generally cordial relations between the local Forest Service and the University School of Forestry. Public outcry and dissent within its own ranks forced the Forest Service to review its practices and acknowledge public opinion in forest planning, particularly in terms of multiple use, recreation, and aesthetic requirements. People complained bitterly of the terraces’ “foreign appearance,” and Senator Dale McGee of Wyoming garnered national media coverage for his declaration, at Took Creek on the West Fork District (WFD), that trees would never grow again on the devastated landscape (Popovich 1975). Despite the Forest Service’s internal acceptance of the limited use of terracing, the public and academic outrage shut the practice down completely. Although the Bolle Report urged that the sites be “dedicated to research,” they have been entirely ignored in the BNF’s research agendas. For years, workers on the Forest have kept an eye on the regeneration of these sites, and though many have observed impressive productivity on terraced hillsides, the fate, thirty years later, of the BNF’s most notorious and criticized management strategy has gone unreviewed. This study was undertaken to examine some of these terraced stands and to investigate how well they have regenerated over the last thirty years. The purpose of this study was to evaluate the effects of terracing on tree and site productivity and site soil characteristics, with the following objectives:
A) to assess differences in site planted tree and site productivity and understory biomass between terraced and non-terraced sites.

B) to evaluate the effectiveness of terracing as a method of reducing site competition by assessing differences in current tree growth and in understory biomass between non-terraced and terraced sites.

C) to assess differences in nutrient and soil characteristics that may be a result of terracing and may affect tree productivity.

**Terrace construction**

Terracing was quickly embraced by the West Fork District (WFD) of the BNF, and almost every stand harvested from 1964-1971 was terraced prior to planting, resulting in thousands of acres of terraced land. According to the Bitterroot Task Force Report (Worf et al. 1970), 5,113 acres were terraced on the BNF from 1965-1969 alone. Over the roughly seven years of terracing on the district, terracing techniques changed considerably. The earliest terracing on the Bitterroot National Forest took place on the Sula district, where mules and plows carved the first terraces in the late 1950s. The standard procedure on the West Fork was as follows. The stand to be terraced was clearcut and the slash piled and burnt. Occasionally seed trees were left in the later stands. The WFD used two Caterpillars, a D-6 or D-7 with a twelve foot wide blade, and a smaller TD-340 or TD-9 pulling a planting machine and a planter. After the slash was burnt, the large Cat drove back and forth from the top of the stand, along the contours, down to the bottom of the stand, cutting about 3-6 feet into the hillside and redepositing that material as fill along the downhill side. The terraces had to be at least ten feet wide to
accommodate the tracks of the Caterpillar, and the spacing of terraces up and down the hillside was determined by the steepness of the slope. On steep slopes, a lower terrace had to be far enough down the hillside not to undercut the integrity of the terrace above it. Any debris or slash left on the hillside was incorporated into the construction of the terrace, resulting in stumps, logs, and rootballs being completely buried. Known areas of problematic geology, especially shale, were avoided.

The second and smaller Cat followed the first along the terraces, with one person driving and another on the back, putting trees into the planting machine. The planting machine sliced open a furrow, into which the worker riding the planter dropped a tree seedling, and then two small wheels under the machine pushed the slit closed. A third worker walked behind to correct any obvious misplants. Trees were spaced as close as six feet apart, in order to reach the same stocking rate per acre as on non-terraced sites, which were not constrained by the greater than 12 ft. lateral spacing imposed by the terraces and machine planting. The mechanization of planting meant that three workers could plant more than 8,000 trees in a day (pers. comm., King 1996), the work of a twenty-five person hand-planting crew. The resulting plantations feature very straight lines of trees on the benches, which are roughly 8-10 feet wide, separated by terrace risers from 3 to 8 ft. tall, depending on hill slope or other factors.

**Literature Review**

Terracing has been common globally and historically as a way of making marginal lands available to agricultural production and, more recently, as a method of protection against soil erosion (Tato & Hurni 1992; Morgan 1986b). Steep lands in
Photograph 1: East Coal Creek terrace, West Fork District, Bitterroot National Forest.
Top, photograph 1: East Coal Creek terrace; bottom, photograph 2: Lookout Mountain terraces.
Africa, South America, Europe, and Southeast Asia have been terraced to allow crop cultivation and to minimize soil erosion (Lewis 1992; Bell 1981; Lal 1994; Morgan 1986a, 1986b). The forms, underlying geologies, and cultivation practices of these terraces vary widely, and the few published studies focusing on steep land terracing provide a scattered image of the effects of terraces and their usefulness.

Many studies have evaluated the effectiveness of terraces in slowing erosion or in harvesting water (Williams et al. 1995, Lewis 1992; Prochazkova and Seda 1992). Luft and Morgenschweis (1984a) studied large-scale terracing of vineyards in the East Kaiserstuhl Mountains of southern Germany and identified increased peak floods, reduced base run-off, and increased mean areal soil moisture as results of terracing (Luft et al. 1981; Luft and Morgenschweis 1984a, 1984b). Williams et al. (1995) used rainfall simulation and gully-level monitoring to compare run-off volume and sedimentation rates on bench terraces in Spain, planted in 12 year-old *Pinus* with mature *Pinus* and *Cistus* plots. They concluded that the terraces showed the highest sedimentation rates, volumetric soil moisture contents, and clay content. Contrary to much of the literature, Williams et al. (1995) concluded that bench terracing contributed to erosion on seasonally arid, steep lands, due to high levels of soil moisture that facilitated sediment transport for a longer period in the spring. Most studies have focused on physical or hydrological effects of terracing, rather than its effects on site productivity. An exception is the study of Veeck et al. (1995), who found mean crop yields to be higher on machine terraced lands than hand- or non-terraced slope lands in Northern China, primarily because of high water and fertilizer retention on broad benches.
In the U.S., more subtle terracing has been common on the low slope agricultural lands of the Midwest and the Southeast, where it often accompanies drainage tiling for routing run-off and abating erosion (Lal 1994). In the Great Plains, terracing has been used for erosion control and water conservation (Schwab et al. 1996, Finnell 1930). The Soil Conservation Society has identified terracing as a suggested “best management practice” to control erosion and harvest water for southeastern Idaho (Michalson, et al. 1983).

Forest lands terracing is less common than annual crop agricultural terracing. Foresters in southern Russia (Poliakov 1972) and Scandinavia (Örlander et al. 1990) in particular have terraced extensively and machine-planted trees on forested lands. The literature addressing forest terracing in the U.S. is scarce, since terracing is uncommon in the forested lands of the western United States. The Forest Service’s Region Four used the related practice of contour trenching from the 1930s through the early 1970s in Utah’s Wasatch Mountains and elsewhere to counter severe erosion problems resulting from years of intensive over-grazing and flooding (Doty 1971.) Doty (1970, 1972) concluded that trenching did not significantly alter the hydrological characteristics of a watershed in terms of water yield and soil moisture, but that snow accumulation on the trenches may have affected revegetation. Elsewhere in Region Four, on the Boise and Payette National Forests, terracing was and is still used to control erosion, particularly on rangelands and foothills (pers. comm., C. Lesch 1996). On the Idaho City district, terracing was used extensively in the 1950s and 1960s to prepare stands for plantations, especially on twenty to fifty year-old burned sites after they had been completely taken over by mountain maple, ninebark, chokecherry, and other brushy species (pers. comm., R. Ecklund 1996).
Herbaceous competition was not deemed as significant a factor on the Boise as on the Bitterroot. On the Idaho City District, terraced trees do not necessarily appear to be larger but survivability is estimated to be much higher in terraced than non-terraced stands, 20-30 years later (pers. comm., R. Ecklund 1996). In any case, none of these terracing projects have been evaluated in refereed literature, and the effects of terracing on tree volume productivity, soil moisture, sedimentation, and nutrient transport in western conifer forests are unknown.

Newton et al. (1974) conducted a study of a Douglas fir \textit{(Pseudotsuga menziesii)} plantation over nine years following terracing and planting in the Oregon Coast Range. They found planting survival and growth to be higher on terraced than non-terraced sites, and machine-planted seedlings slightly edged out hand-planted seedlings under the same planting conditions. However, these terraces were only up to nine feet wide, were thirty feet apart, and were cut into a salal \textit{(Gaultheria shallon)} dominated site that had not been clearcut immediately prior to planting, so this study reflects less complete disturbance than occurred on the BNF sites. Also, the hydrological and habitat characteristics of this wet, coastal site are too different from the Bitterroot to make a valid comparison.

**Problem background**

A terrace consists of a bench, which can be of varying widths, and a riser, which can be unconsolidated earth or held in place by rocks or other methods (Figure 1). Terraces are built either by hand, where machines are unavailable or impractical, or with bulldozers, as the WFD did in the ‘60s. Terraces are built along the elevational contours of a hillside and are either flat or slightly graded--into the hillside in arid environments to
trap water, or outward toward water routing channels in areas of high rainfall or where irrigation water is needed elsewhere.

The explicit justifications for terracing on the BNF were to: 1) reduce site competition for ponderosa pine seedlings, particularly from elk sedge (*Carex geyeri*) and pinegrass (*Calamagrostis rubescens*); 2) allow machine planting of seedlings on steep slopes, a time and money saving practice in the Forest Service of the 1960s (Worf 1970). Reducing site competition from other vegetation is considered a necessary and difficult step for successful ponderosa pine seedling establishment in fire-suppressed environments (Ross et al. 1986; Wellner 1970; Worf 1970).

Figure 1: Standard terrace with bench, riser and planted tree

Lanini and Radosevich (1986) found ponderosa pine to be the most sensitive of three conifer species, including sugar pine (*Pinus lambertiana*) and white fir (*Abies concolor*),
to competition from shrubs. Ponderosa pine dominates on harsh, dry sites, and can easily be out-competed on the more mesic Douglas-fir type sites (Steele 1988) characteristic of the WFD, where lower elevation ponderosa pine seedlings were frequently planted on mid-elevation Douglas-fir sites. Competition either from grasses and forbs or shrub species can reduce survival of seedlings or severely impact their growth (Miller 1988) and is a primary cause of regeneration failure (McNabb et al. 1993), as pine seedlings compete poorly for soil moisture and nutrients with the root mats of established understory vegetation (Chang et al. 1996; Miller 1988; Elliot and White 1987).

**Methods of site preparation**

Numerous techniques are available for minimizing site competition, including chemical (herbicide) options (Eckert 1979) and a range of mechanical practices (Prevost 1995, McNabb et al. 1993; Lanini and Radosevich 1986), such as ripping, tilling, scarifying, brush blading, soil removal, chaining, fire, and combinations of chemical and mechanical. Investigations continue into the best techniques for reducing site competition without unwanted additional impacts. Herbicides are often very effective for complete control of unwanted vegetation in the year of application but may need re-application in following years, an expensive, time-consuming, or impractical complication. Dense brush may be difficult to kill because of inaccessible roots. Herbicides applied on steep ground may drain to subsurface flow and end up in streams (Heidmann 1988). Herbicides may have unforeseen additive or synergistic effects, either positive or negative (Boyd 1982). They may affect soil fauna, disrupting their roll in the detrital food web and their ability to aid in N mineralization or perform other nutrient cycling functions (McColl and Powers...
The positive nutrient-cycling and soil structure effects of beneficial forbs may also be seriously reduced.

Limited mechanical site preparation may be less expensive than chemical methods and less hazardous to workers and unintended environmental targets (Pritchett 1979), but thorough reduction of competition, in the year of treatment and especially in following years, has proven difficult with less intensive mechanical practices (Foiles and Curtis 1973). Established grasses and brush may take advantage of the newly opened canopy and increased soil moisture following clearcutting to establish in the scalps or clear places created for the seedlings. Removal of surface vegetation alone leaves soil seed banks and vegetative (root) propagules intact, allowing second year regrowth (Foiles and Curtis 1973). Steele and Geier-Hayes (1987) found contour terracing to provide the highest ponderosa pine survival percentage of three site preparation methods, including burning and scalping, on Idaho Douglas-fir/elk sedge sites. A number of investigators have studied site productivity and nutrient relations following different types of mechanical site preparation, other than terracing, that remove top layers of soil, such as scalping or blading. Stransky et al. (1981) found pines to grow bigger on bulldozed and bladed sites, due to reduced competition. Prevost (1995) concluded that scarification controlled ericaceous shrub competition for three years and improved black spruce regeneration in Quebec, but that light scarification was as effective as severe perturbation. McNabb et al. (1993) concluded that severe preparation techniques, despite their effectiveness in controlling competition, generally had negative long-term impacts on soil productivity, as did Powers et al. (1988). Ross et al. (1986) attributed lower ponderosa pine growth on mechanically treated plots to the loss of surface soil and increase in soil bulk density.
following brush-blading. Clayton et al. (1987) found lateral soil displacement to decrease ponderosa pine diameter at breast height (dbh), and radial and height growth on planted Idaho clearcuts. Volume of pine seedlings decreased by 40-53%. They equated the effects of localized soil displacement to the loss of productivity associated with soil erosion.

Tuttle et al. (1985) found a combination of surface scarification or soil removal and herbicide application to be most effective in reducing competition and concluded that non-pine competition was decreased most in their “heavy” soil removal treatment of 7 62 cm. These levels of treatment, however, do not compare in intensity with the BNF’s terracing practices, where soil was disturbed up to several feet in some stands. Most studies conclude that mechanical site preparation does, to varying degrees, increase ponderosa pine growth and biomass (Lanini and Radosevich 1986; McNabb et al. 1993) by eliminating site competition, improving water and nutrient relations, and exposing mineral soil, thus encouraging net mineralization/mobilization (Pritchett 1979), but serious concerns remain regarding possible negative effects on soil and site quality (MacKinnon and McMinn 1988; McColl and Powers 1984). Literature cited below regarding loss of topsoil due to erosion and its effect on productivity may also apply here.

Terracing seemed like a viable option to the Forest Service in the early 1960s because it disturbed vegetation on up to 12 foot wide benches and pushed surface debris and soil away from the planting area, giving seedlings a mineral bed free of seed competitors and plenty of room and growing resources. Such thorough site preparation guaranteed planted seedlings several growing seasons of freedom from competition but entailed severe site disruption and may also have had unforeseen negative effects on the
soil. There are no published studies evaluating the effects of the Forest Service’s terracing on soil properties or productivity.

**Potential problems associated with terracing**

*Compaction*

A particular concern is the degree of soil compaction that results from the combination of clearcutting and terracing. Ponderosa pine is highly vulnerable to the effects of compaction, since it sends deep roots to garner low available soil moisture. Also, in low organic matter soils, ponderosa pine uses extensive ectomycorrhizal short roots to access relatively nutrient-rich, organic subsurface layers (Harvey et al. 1988). Root elongation depends on root water potential and soil strength, and in a low-moisture, high evaporative demand soil environment, root development may be particularly impeded by the high strength of compacted soils (Sands 1983). Restricted root development reduces uptake of nutrients (Sands 1983) and also, because of reduced saturated and unsaturated hydraulic conductivity and lower available moisture, may stimulate stomatal closure, and hence, lower photosynthetic rates (Running 1982). Compaction related to clearcutting is well-documented (Greacen and Sands 1980), especially in forest practices of the 1960s. Terraces were built from spring until fall on the WFD, with little concern for soil moisture levels (pers. comm., King 1996). Frozen or dry soils are less subject to compaction than soils near field capacity (Pritchett 1979; Grier et al. 1989). Soil compaction can result in reduced infiltration rates and surface puddling, reduced spring recharge of soil moisture, disruption of soil aeration, restriction of plant root development, frost-heaving of planted seedlings, decreased saturated and unsaturated hydraulic
conductivity, and soil erosion (Conlin and van den Driessche 1996; Huang et al. 1996). Compaction occurs most readily on fine-textured soils (Pritchett 1979) or those with low organic matter (Sands 1983). Soils that are well-graded or contain an even mix of gravels, sands, and silts are least subject to compaction. The specific concern regarding terraces is not merely the increased number of passes, because most of the compaction related to forest harvesting is caused with the first several passes of heavy machinery (Shetron et al. 1988). Froehlich (1979) estimated the compacted area of a tractor logged site to be 25-35% of the cutting unit. The concern with terracing is that the entire cutting unit was deliberately treated in the construction of the terraces, and the percentage of compacted area may be very much higher. Also, the trees were planted directly in the most compacted area of the stand, the benches. Aside from the nutrient and water supply effects of soil compaction, long-term effects can include odd shaped or stunted roots (Haines and Pritchett 1965) and reductions in seedling growth rates (Froehlich 1979).

Erosion

The interterrace risers, on the other hand, were unconsolidated fill soil and more likely to suffer immediately from erosion than compaction. In fact, recently constructed terraces are essentially a dense series of road cut and fill slopes, and roads are a primary source of erosion on forested lands (Megahan 1991), particularly if high intensity or frequency precipitation occurs soon after construction. While terraces are used extensively as erosion abatement, they are not understood to halt particle detachment itself—dense vegetation best provides that function (Stocking 1994)—but only to decrease sediment transportation (Morgan 1986) by slowing runoff, decreasing the flow’s erosivity and sediment carrying capacity (Foster and Highfill 1983). Terraces disrupt and shorten the
runs of steep slopes (Lal 1994) and redeposit sediment from an upper terrace or riser onto the lower.

Erosion depletes surface soil horizons of nutrients and alters soil structure as the finer, more transportable, soil components leave the profile. Extensive research has shown the effects of erosion on agricultural soils, where decreases have been found in organic carbon content, soil pH, and depth to carbonates (Cihacek and Swan 1994). Frye et al. (1982) found that erosion increases bulk density and the clay percentage and decreases plant available water content in their study of Kentucky agricultural soils. These studies have often focused on the soil A horizon found in agricultural soils, which differ from ponderosa pine forests that are characterized by a relatively thin O horizon, directly above a weak or very thin A.

Undisturbed forest soils are rarely eroded, due to vegetative cover, a protective litter layer, and high infiltration and transpiration rates (Morgan 1986). However, forests are particularly susceptible to accelerated erosion following any disturbance (Clayton et al. 1987). The effects of erosion on the nutrient characteristics of forest soils have received little attention (Powers 1991) due to the relatively low or short-term erodibility of forest soils, in the period between harvest and revegetation (Pritchett 1979), and the length between harvests. McColl and Powers (1984) identified soil erosion as the main means of P loss on forested lands. The nutrient losses caused by soil erosion on agricultural lands are readily evident in declining annual yields, whereas the diminishing productivity of forests due to nutrient depletion may not be revealed for several harvest cycles over hundreds of years. Lal (1994) points out the difficulty in these soil erosion studies in relating soil nutrient levels (eroded or uneroded) and production values, since so many
variables are involved in any one year’s crop production. Similar difficulties may constrain evaluating the effect of forest soil erosion on tree volume production. The National Soil Erosion-Soil Productivity Research Planning Committee (1981) concluded that the loss of agricultural productivity is primarily related to the loss of plant-available soil water-holding capacity, more than to nutrient losses. Megahan (1991) also suggested that the effect of erosion on forest productivity is a function of reduced soil depth and its effect on available water capacity and nutrient pools. Eroded topsoils leave plants with shallower rooting depths to subsurface fragipans, clay pans, and bedrock, and therefore a net decrease in available soil moisture, and in turn, nutrients. Also, soil organic matter, which provides nutrient storage, water-holding capacity, and cation exchange capacity to soils, is easily eroded, reducing soil productivity.

A few points should be made regarding the construction of the terraces, its placement of soil materials, and possible effects on erodibility and nutrient and water relations of the soil. Construction of the terraces on the BNF haphazardly incorporated any debris or slash left on the hillside into the bench or riser, completely burying stumps, logs, and rootballs, and mixing organic matter (OM) throughout the soil profile, especially in the terrace risers. Any soil strata that had developed in these shallow, rocky, nutrient poor soils were completely disrupted. Such total movement of OM has several implications. In general, increased OM in moist soils decreases pH as the material decomposes, increases soil water-holding and transport capacities, and increases nutrient storage, especially of nitrogen, phosphorus, and sulfur. On seasonally dry sites like those on the WFD, decomposition may be too slow to have a short-term effect on pH, but woody material in the soil profile holds substantial moisture (Harvey et al. 1987) and may
affect productivity (Harmon et al. 1986.) On the other hand, since loss of organic matter and soil C is usually considered a primary result of erosion (Brady 1974), the benches may suffer from reduced water-holding capacity and increased bulk density. Lal (1994) concluded that available water capacity (AWC) might be the forest soil productivity characteristic most affected by soil erosion, which corresponds with the agricultural findings of Frye et al. (1982) and Megahan (1991). Also, after incorporated woody material decomposes, loss of soil shear resistance and slumping may occur, ultimately resulting in mass movement of soils (Morgan 1986; McColl and Powers 1984).

The soils of the WFD are shallow and have a naturally low OM content. Ponderosa pine is relatively well adapted to low OM soils (Harvey et al. 1988; Page-Dumroese 1991), so the construction of the terraces may not reduce the ability of pines to grow on the benches. (Although small changes in OM may result in disproportionately large changes in AWC (Hudson 1994), and ponderosa pine responds well to increases in OM with increased volume (Harvey et al. 1988).) However, the terrace risers, as unconsolidated soils, drain and dry more quickly than the terrace benches, which led Foiles and Curtis (1973) to conclude that planting success and site quality were worst on Idaho terraces towards the outside edge due to rapid draining. This finding coincides with Williams et al. (1995) who found soil moisture to be lowest on the riser (6%) and highest at the inner edge of the bench (31%). Investigations into the soil productivity of these sites is difficult, because the terracing operation so severely disrupted original conditions. While erosion is cited as a primary cause of loss of OM and nutrients from a soil (Garcia et al. 1996), observed losses on the terraced sites may in fact simply represent the displacement associated with terrace construction. The question becomes whether it is
possible to determine if nutrients were permanently lost from the system through leaching or merely redistributed, through trapped sediment and plant uptake of leached nutrients.

If the OM, and therefore nutrient bank, of the terraced site, is concentrated and mineralized in the riser, it is possible that one would observe down-slope evidence of leaching, including increased nutrient levels on down-slope terraces, higher nutrient levels on terrace benches than non-terraced sites, and lower pH values on the benches. The combined effects of soil compaction and erosion may detrimentally affect tree productivity on the terraced sites, but the alterations of the natural conditions of these stands were so complete that predictions of response are difficult to make.

MATERIALS AND METHODS

Study sites, consisting of pairs of terraced and non-terraced stands, were chosen on the West Fork District (WFD) of the Bitterroot National Forest in southwestern Montana through a combination of database searches, aerial photograph reviews, and ground-truthing. The primary factors for consideration in selection of the paired sites were: 1) no management activity since the original clearcut, site preparation, and planting; 2) similar stand age, aspect, elevation, soil, and habitat characteristics between paired stands. Of more than 150 terraced stands on the WFD, only three were finally deemed appropriate for this study. Two obstacles prevailed. First, most stands have either been thinned or treated in some other manner since the original planting, up to thirty-five years ago. Second, the WFD used terracing so extensively during the late sixties/early seventies that clearcut non-terraced stands are very difficult to find, especially stands that were not terraced for reasons other than extreme geological fragility or other concerns that would
make them inappropriate for a paired comparison. Also, some stands are virtually inaccessible at present due to permanent road closures. And a final, pervasive difficulty in finding sites was the number of database errors, including misidentification of stand types, omissions of thinning or other treatments, and unrecorded wildfires in stand records.

The three paired sites were in the East Coal Creek drainage, on Thunder Mountain, and on Lookout Mountain. Site characteristics are found in Table 1.

<table>
<thead>
<tr>
<th>Site name</th>
<th>slope</th>
<th>aspect</th>
<th>elevation</th>
<th>soil subgroup</th>
<th>soil texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Coal Creek</td>
<td>30-55%</td>
<td>N-NE</td>
<td>1585 m</td>
<td>glossic Eutroboralfs;</td>
<td>sandy clay loam</td>
</tr>
<tr>
<td>Lookout Mountain/Spruce</td>
<td>40-55%</td>
<td>S-SE</td>
<td>1890 m</td>
<td>Typic Ustochrepts-Typic Eutroboralfs complex;</td>
<td>gravelly clay loam</td>
</tr>
<tr>
<td>Creek</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thunder Mountain</td>
<td>35-50%</td>
<td>SW-WSW</td>
<td>1645 m</td>
<td>Typic Ustochrepts</td>
<td>gravelly loam</td>
</tr>
</tbody>
</table>

Table 1: Study site characteristics of paired terraced and non-terraced plots on the West Fork District, Bitterroot National Forest

Each pair consists of one terraced and one non-terraced site, both of which were clearcut and planted at the same or close to the same time. On each site, five 0.25 hectare square plots were established, using a stand map and random number table, making sure that slope and aspect on all plots were similar. A plot of this size usually covered two or three terrace bench-riser rows. The heights and diameters of all trees on the plots were measured using a dbh tape and clinometer (Curtis 1983). Whether the trees were natural regeneration or planted was also recorded, easily determined on the terraced sites by
placement within the plot, and determined by placement, species, and size on the non-terraced plots. Many of these sites are not naturally ponderosa pine sites, although they were planted in ponderosa pine, and natural regeneration is usually Douglas-fir or lodgepole pine (*Pinus contorta*).

On these same 0.25 hectare plots, 10 soil subsamples were taken, either in five pairs of two on the non-terraced plots, or divided equally on the benches (planting surface) of the terraced plots. These subsamples were taken to a 15 cm depth, either by a 2.5 cm diameter soil core or a trowel, mixed in a bucket, and lumped into a single plot sample, resulting in five soil samples per site, and ten per pair.

Also on each plot, five randomized understory vegetation samples were taken on square subplots of 30 cm\(^2\) by clipping all vegetation down to the soil surface. Five samples per plot resulted in twenty-five vegetation samples per site. These understory vegetation samples were then dried for >48 hrs. at 105° C and weighed.

Soil pH was determined by Orion 810 meter on dried and sieved (2 mm) soils. 10g (dry weight) soil samples were mixed with .01M CaCl\(_2\) in a 2:1 ratio, let sit for at least five minutes, and then analyzed. Particle size distribution was measured by hydrometer as described by Jury et al. (1991). Water potential was measured by placing saturated samples under -1/3 bar pressure for 2.5 hrs, weighing the wet soils, oven drying them for 48 hrs, and then weighing again. Plant available phosphorus was determined colormetrically, following extraction by the Bray-Kurtz dilute acid flouride method (Olsen and Sommers 1982). Soluble and exchangeable potassium was assayed by ammonium acetate extraction and analysis by atomic absorption spectrophotometry (AA): 5g of soil in 50 ml of 1.0M NH\(_4\)OAc was shaken vigorously for thirty minutes, filtered through a
Whatman #42 and analyzed for K⁺ by AA. Organic C was assayed by the Walkley-Black procedure: soil was ground and passed through a 0.147 mm (#100) sieve, and 0.5 g samples were reacted with acid potassium dichromate and measured colorimetrically against glucose standards (Nelson and Sommers 1982).

Statistical analyses were one- and two-tailed t-tests assuming unequal variances, using Microsoft Excel.
CHAPTER 2: RESULTS

A comparison of current site productivity was made in terms of tree stem volume (m³/ha) and understory biomass (kg/ha). Productivity in this case refers to the silvicultural aim of producing timber, not the ecological sense of net primary productivity.

Vegetation data

Trees

On all three paired sites, the terraced plots showed higher tree volume/hectare (Table 2). The Coal Creek pair has the most favorable site conditions of the three pairs in this study, with north and northeastern exposures, available water, relatively deeper, more nutrient rich soil, and moderate elevations. Predictably, the Coal Creek plots have the highest planted tree productivity, yielding 162 m³/hectare on the non-terraced plots, vs. 252 m³/hectare on the terraced plots, significantly different at p<0.01. The terraces had higher volume/hectare despite the non-terraced plots having 886 planted trees/hectare to the terraced plots’ 420 (also significant at p<0.01). The difference between mean tree volume is also significant, with 0.18 m³/hectare on the non-terraced site and 0.60 m³/hectare on the terraces. The second pair, at Spruce Cr., includes the least productive plots of the study. Both sites are south facing, with dry, rocky, and steep slopes. The terraced site is slightly higher in elevation, but both are above 1830m (6000 ft). The non-terraced plots held only 213 total planted trees, with a volume of 11.9 m³/hectare and a mean tree volume of 0.06 m³. The terraced site had more planted trees per hectare, at
425, with 33.2 m³/hectare and a mean tree volume of 0.08 m³. The difference between total planted volume per hectare is significant at p<.05, but the difference between mean tree volumes is not significant.

<table>
<thead>
<tr>
<th>Site</th>
<th>total # trees/hectare</th>
<th>total volume m³/hectare</th>
<th># planted trees/hectare</th>
<th>Mean vol./planted tree m³</th>
<th>planted volume m³/hectare</th>
<th>understory biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Creek A↑</td>
<td>1097</td>
<td>172.52</td>
<td>886</td>
<td>.184</td>
<td>162.56</td>
<td>2451</td>
</tr>
<tr>
<td></td>
<td>**</td>
<td>***</td>
<td>***</td>
<td>**</td>
<td>***</td>
<td>*</td>
</tr>
<tr>
<td>Coal Creek B</td>
<td>830</td>
<td>266.89</td>
<td>420</td>
<td>.601</td>
<td>252.45</td>
<td>1491</td>
</tr>
<tr>
<td></td>
<td>**</td>
<td>***</td>
<td>***</td>
<td>**</td>
<td>***</td>
<td>*</td>
</tr>
<tr>
<td>Spruce Creek A</td>
<td>321</td>
<td>16.27</td>
<td>213</td>
<td>.056</td>
<td>11.88</td>
<td>1281</td>
</tr>
<tr>
<td></td>
<td>**</td>
<td>***</td>
<td>***</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Spruce Creek B</td>
<td>469</td>
<td>33.62</td>
<td>425</td>
<td>.078</td>
<td>33.22</td>
<td>784</td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>**</td>
<td>***</td>
<td>**</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Thunder Mountain A</td>
<td>425</td>
<td>37.67</td>
<td>366</td>
<td>.061</td>
<td>37.61</td>
<td>1206</td>
</tr>
<tr>
<td></td>
<td>**</td>
<td>***</td>
<td>*</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Thunder Mountain B</td>
<td>642</td>
<td>108.77</td>
<td>499</td>
<td>.215</td>
<td>105.76</td>
<td>1639</td>
</tr>
<tr>
<td></td>
<td>**</td>
<td>***</td>
<td>*</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

†A=non-terraced sites; B=terraced sites
‡p values: one-tail t-test: *= statistically significant within pair at p<0.1; **=p<0.05; ***=p<0.01.

Table 2: Current density, volume and biomass data for paired non-terraced (A) and terraced (B) sites, West Fork District, Bitterroot National Forest.

The Thunder Mt. pair is intermediate. It is dry and south facing, with rocky soils.

Again, the terraced sites had significantly greater planted volume (106 m³/hectare to 38 m³/hectare, p<0.01) and also had more planted trees/hectare, at 499 vs.366, significant at p<0.10. Mean tree volume was higher on the terraced sites, at 0.22 m³, compared to 0.06
on the non-terraced sites (p<0.01). Mean diameter and height measurements on all three terraced sites significantly (p<0.01) exceeded those of the non-terraced (Figures 2,3).

Figure 2: Mean diameters at breast height of planted ponderosa pine, terraced vs. non-terraced sites, Bitterroot National Forest. All differences significant at p<0.01.

Figure 3: Mean planted ponderosa pine heights, in meters, terraced vs. non-terraced sites, Bitterroot National Forest. All differences significant at p<0.01.
Likewise, frequency distributions for mean dbhs show higher frequencies for larger diameters on the terraced plots (figures 4-6).

Figure 4: Diameter distributions of planted ponderosa pine on Coal Creek non-terraced (A) and terraced (B) plots.
Figure 5: Diameter distributions of planted ponderosa pine on Spruce Creek non-terraced (A) and terraced (B) plots.
Figure 6: Diameter distributions of planted ponderosa pine on Thunder Mountain non-terraced (A) and terraced (B) plots.
**Understory vegetation**

Biomass of understory vegetation was measured to indicate whether terracing appeared to inhibit the growth of understory species. Dominant understory species identified in the site understory biomass subsamples are given in Table 3.

<table>
<thead>
<tr>
<th>Site name</th>
<th>Vegetation types</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coal Creek</strong></td>
<td></td>
</tr>
<tr>
<td>A†</td>
<td>Calamagrostis rubescens (pinegrass) Linnea borealis (twinflower) Berberis repens (Oregon grape) Arctostaphylos uva-ursi (kinnikinnik) Symphoricarpus albus (snowberry) Rubus spp.</td>
</tr>
<tr>
<td>B</td>
<td>Berberis repens (Oregon grape) Achillea millefolium (yarrow) Fragaria spp. Arctostaphylos uva-ursi (kinnikinnik) Calamagrostis rubescens (pinegrass) Linnea borealis (twinflower) Antennaria rosea (pussytoes)</td>
</tr>
<tr>
<td><strong>Spruce Creek</strong></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Festuca idahoensis (Idaho fescue) Carex geyeri (elk sedge) Balsamorhiza sagittata (balsam root) Xerophyllum tenax (beargrass) Agropyron spicatum (blue-bunch wheatgrass) Achillea millefolium (yarrow) Symphoricarpus albus (snowberry)</td>
</tr>
<tr>
<td>B</td>
<td>Physocarpus malvaceus (ninebark) Spirea species Berberis repens (Oregon grape) Achillea millefolium (yarrow) Fragaria spp. Festuca idahoensis (Idaho fescue) Carex geyeri (elk sedge) Agropyron spicatum (blue-bunch wheatgrass)</td>
</tr>
<tr>
<td><strong>Thunder Mt. A</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Festuca idahoensis (Idaho fescue) Carex geyeri (elk sedge) Berberis repens (Oregon grape) Arctostaphylos uva-ursi (kinnikinnik) Achillea millefolium (yarrow) Symphoricarpus albus (snowberry) Centaurea maculosa (knapweed)</td>
</tr>
<tr>
<td><strong>Thunder Mt. B</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Berberis repens (Oregon grape) Arctostaphylos uva-ursi (kinnikinnik) Achillea millefolium (yarrow) Symphoricarpus albus (snowberry) Centaurea maculosa (knapweed) Xerophyllum tenax (beargrass) Festuca idahoensis (Idaho fescue)</td>
</tr>
</tbody>
</table>

†A = non-terraced, B = terraced

**Table 3: Dominant understory vegetation on non-terraced (A) and terraced (B) sites**
Understory productivity on the Coal Cr. and Spruce Cr. terraced sites was significantly lower than on the corresponding non-terraced sites (Table 2). At Coal Cr., understory biomass on the non-terraced sites exceeded that on the terraced plots, with 2451 kg/hectare compared to 1491 kg/hectare. At Spruce Cr., the terraced site had less understory vegetation (784 kg/hectare) than the non-terraced site (1281 kg/hectare). Although biomass/hectare differed significantly on two of the three pairs of terraced and non-terraced sites, species composition of the understory did not.

Soils Data

Physical characteristics

Particle size distributions differed significantly between the terraced and non-terraced sites. All terraced sites contained much higher percentages of silt than the non-terraced sites (Table 4). However, each initial (non-terraced) soil has a different texture, with Coal Cr. primarily sandy, Spruce Cr., high in clays, and Thunder Mt. more intermediate, with almost equal amounts of sand and silt (Figure 7).

Water-holding capacity was significantly different (p<.05) only between Coal Creek sites A and B. On neither of the other two sites was the difference in water-holding significant. Spruce Creek differed between terraced and non-terraced in clay content, significant at p<.05.
<table>
<thead>
<tr>
<th>Site</th>
<th>% sand</th>
<th>% silt</th>
<th>% clay</th>
<th>water-holding capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Creek A†</td>
<td>53.48</td>
<td>26.12</td>
<td>20.4</td>
<td>31.722</td>
</tr>
<tr>
<td>Coal Creek B</td>
<td>39.44</td>
<td>44.66</td>
<td>15.9</td>
<td>21.64</td>
</tr>
<tr>
<td>Spruce Creek A</td>
<td>39.52</td>
<td>26.68</td>
<td>33.8</td>
<td>28.398</td>
</tr>
<tr>
<td>Spruce Creek B</td>
<td>38.4</td>
<td>53.6</td>
<td>8</td>
<td>27.63</td>
</tr>
<tr>
<td>Thunder Mt. A</td>
<td>45.4</td>
<td>39.8</td>
<td>14.8</td>
<td>37.276</td>
</tr>
<tr>
<td>Thunder Mt. B</td>
<td>35.88</td>
<td>53.72</td>
<td>12.4</td>
<td>33.906</td>
</tr>
</tbody>
</table>

†A=non-terraced; B=terraced. † two-tailed t-test, significance within pair * = p < 0.1; ** = p < 0.05; *** = p < 0.01

Table 4: Soil water-holding capacity and percent sand, silt, and clay in surface soils (0-10 cm) of non-terraced (A) and terraced (B) ponderosa pine stands, Bitterroot National Forest.

Figure 7: Percent sand, silt, and clay in surface soils (0-10 cm) of non-terraced (A) and terraced (B) stands, Bitterroot National Forest.
Chemical characteristics

The soil chemistry figures of the three sites were only moderately influenced by terracing. Exchangeable K\(^+\) was significantly different only on the Coal Creek and Spruce Creek sites (Table 5). However, the figures for Spruce Creek are problematic due to extreme variance on Spruce Creek A (non-terraced). (Plot values are 27.70, 40.99, 435.8, 512.6, 360.7 ppm and 33.79, 46.99, 49.39, 48.19, 27.79, non-terraced and terraced, respectively.)

<table>
<thead>
<tr>
<th>Site</th>
<th>pH</th>
<th>P ppm</th>
<th>K ppm</th>
<th>g organic C/g soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Creek A†</td>
<td>5.21</td>
<td>21.7</td>
<td>82.4</td>
<td>.0052</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Coal Creek B</td>
<td>5.04</td>
<td>15.3</td>
<td>27.6</td>
<td>.0062</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Spruce Creek A</td>
<td>5.38</td>
<td>43.5</td>
<td>275.6</td>
<td>.0068</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Spruce Creek B</td>
<td>5.14</td>
<td>37.6</td>
<td>41.2</td>
<td>.00575</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Thunder Mt. A</td>
<td>4.99</td>
<td>36.0</td>
<td>72.9</td>
<td>.0074</td>
</tr>
<tr>
<td>Thunder Mt. B</td>
<td>4.96</td>
<td>35.9</td>
<td>70.5</td>
<td>.007</td>
</tr>
</tbody>
</table>

†=non-terraced, b=terraced

two-tailed t-test, p= significance within pairs at 0.1=*, 0.05=**, 0.01=***

Table 5: Soil pH, extractable P, exchangeable K, and organic C in soils of non-terraced (A) and terraced (B) ponderosa pine stands, Bitterroot National Forest.
CHAPTER 3: DISCUSSION

Effects of terracing on vegetation

The tree volume data clearly show greater tree volume per hectare on the terraced plots than on the non-terraced. There are, however, a number of difficulties in drawing the conclusion that terracing is the primary reason for these differences or in generalizing that terracing would always grow larger trees.

One of the first caveats to consider is the extensive variation among these plots, among treatment techniques, and among the stands on the district. The requirements of the study, particularly that the stands to be included could not have been treated since the original planting, may have excluded most of the similar aged stands that either did very well, and therefore demanded prompt thinning, or those that did very poorly and were therefore repeatedly planted or managed in some other aggressive way. Therefore, theoretical conclusions drawn in this study must be limited to some conceptual median of stand quality.

For example, if 90% of terraced sites failed to regenerate, but the 10% that did grew tremendous trees, the study design would positively bias assumptions about terracing’s effects on regeneration. Likewise, figures are unavailable to compare survival rates on terraced versus non-terraced sites of the same age/historical period. District silviculturists maintain that the terrace survival was very high and failures were almost entirely due to outplanting low elevation ponderosa pine on high Douglas-fir or subalpine...
fir sites (pers. comm, D. King, 1996). The predominate seed source for ponderosa pine seedlings on the WFD came from ponderosa pine stands along the West Fork of the Bitterroot River. However, these statements have not been verified.

Keeping these concerns in mind, conjectures can be made regarding the effects of terracing on tree production on these study sites. In terms of the Forest Service's initial objectives, to reduce site competition and allow machine-planting, terracing seems to have succeeded on these sites. Two of the terraced sites have significantly lower understory vegetation, and most of the understory biomass, on those sites and on the third, where the numbers are more equivocal, is concentrated on the risers. The terrace benches themselves are very low in understory biomass, possibly due to the exposure of less nutrient-rich subsurface layers. The distinction between risers and terraces is particularly clear at Coal Creek, but the tree canopy is closed on that site, confounding the reason for the lack of understory vegetation by sunlight, nutrient and water competition between understory plants and trees. However, the Spruce Creek and Thunder Mt. terraces are not as uniformly closed, yet the same pattern of sparsely vegetated benches and more heavily vegetated risers is evident. Given the severe disruption of the sites during terracing and their current understory characteristics, it appears that the planted trees did not have to compete immediately or as vigorously with other vegetation on the terraces and therefore may have experienced higher initial growth rates than trees on non-terraced sites.

Unfortunately, no records of stocking rates are available for the original plantings on the sites, so no comparison can be made of survivability. However, stocking exams performed on the WFD terraces in the years following planting suggested survival rates above 90% (pers. comm, D. King, 1996). In this study, two of the study pairs showed
more planted trees/hectare on the terraced plots than on the non-terraced plots. These two pairs were the rockier, harsher of the three sites, and the higher numbers of trees may be a result of machine-planting. One possibility is that in rockier, difficult soils, a hand-planter would be more selective and less likely to plant at regular and frequent intervals. A worker on a machine-planter does not determine plantability, since the weight of the machine itself slits a planting trench into the terrace. Also, the construction of the terraces themselves provides a more uniform substrate and systematic approach to planting frequency and order than the subjective unleashing of hand-planters on a hillside. (Keep in mind that these terraces were constructed in the 1960s and early 1970s, and planting technology and theory have changed since then.) Survival may also have been improved by the consistent rooting depth created by the machine. Planting by machine may also decrease the likelihood of frost heaving (pers. comm., King 1996). Handplanting creates a circular area of loosened soil directly around the seedling, where water may collect and, upon freezing, push the seedling roots above the soil surface. Machine planting, with its continuous furrow down the center of the terrace bench, may provide a channel of looser soil down that spreads out collected water, reducing the likelihood of localized frost-heaving at the base of the seedling.

Effects of terracing on soil characteristics

Unfortunately, whether or not terracing was a successful practice in terms of its effects on soil properties is a much more difficult question to answer. It is impossible now to reconstruct the immediate impacts at the time of the terracing. Workers building the terraces expected some slumping of the risers as they came to the angle of repose, and
anecdotal evidence (pers. comm., D.King 1996) suggests that sedimentation was high for the first few seasons following terracing. This is also true of standard non-terraced clearcuts (Morgan 1986a), and no figures are available comparing erosion rates of the two treatments. The Bitterroot Task Force Report denies significant sedimentation following terracing (Worf 1970). However, terracing combined the effects of the loss of anchoring vegetation with massive, if not total, soil structural disruption and extensive compaction, and it seems likely the sedimentation rates immediately following treatment would have been higher than standard clearcutting and planting.

The only distinct, significant soil difference (p=.001-.01) on all three sites is the significant increase in silt content in the soils of the terraced plots. Silt is the most transportable of the soil constituents and therefore a good indicator of soil erosion (Lal 1994). The higher silt values on the terraces are definitely a sign of erosion, but the silt may only reflect trapped sediment from the time of construction, which would have concentrated the silt on the bench where it would be uniformly spread out on, or lost from, a non-terraced clearcut site. Part of the difficulty in assessing erosion rates is the usually non-uniform rates of sedimentation across a landscape (Megahan 1991). The terraces, in effect, tell us where to look for soil deposition.

Even on clearcuts, sedimentation rates usually returns to normal within several years, provided that vegetation is established and roads are stabilized. Megahan (1991) found road erosion rates to decrease by 90% by the second year following construction. In this case, the terrace risers could effectively be considered roads, and as they revegetated and stabilized, sedimentation probably decreased. However, soils like those now found on the terrace benches, high in silt, low in clay, and low in base minerals, tend
to be the most erodible, so one concern would be the possibility of current erosion.

Nutrient data can be used to assess current sedimentation rates (Morgan 1986a). Current nutrient differences between the terraced and non-terraced sites, in the form of higher K, P, and C on the benches, would suggest current erosion from the relatively nutrient-rich risers collecting on the bench below—possibly benefiting the trees and contributing to the greater productivity evident on the terraced sites.

However, the nutrient data of this study do not point in this direction. On all three sites, concentrations of P and K were lower on the terraced than on the non-terraced plots, which could suggest either an unrecuperated loss of nutrients from the terraced sites or current vegetative uptake. The differences in exchangeable K⁺ are statistically significant at Coal Creek and Spruce Creek. The difference at Coal Creek between the terraced and non-terraced sites is also greatest in terms of tree volume/hectare, so the low terrace K numbers are complicated by the effect of potentially high plant uptake. The differences in K in the Spruce Creek pair may reflect the low vegetative demand at Spruce Cr. A, where the three plots with unusually high K values had the fewest trees per plot of all plots in the study. Organic C concentrations were not significantly different within any of the pairs. The lack of difference in total C suggests that the intense disturbance during terracing had little long-term impact on soil C levels, even though initial levels were probably greatly reduced due to burial of the thin O and A horizons at these sites. It is also possible that the clearcut non-terraced sites experienced extensive erosion and loss of soil C post-harvest, making the two treatments equally detrimental on total C levels in these low C soils.
The chemical differences were least at Thunder Mt., where the terraced and non-terraced plots are right next to each other, unlike the other two pairs where the two sets of plots are on separate hillsides. To put it simply, on the plots most likely to have been similar prior to treatment, no discernible difference in P, K, and C can be seen 25 years after treatment, and the soil data of this study suggest neither significant current sedimentation nor nutrient differences sufficient to explain differences in productivity.

No other soil characteristics measured in this study seem to be affected by terracing. There was no significant difference in pH. Water-holding capacity is significantly different on at Coal Creek, where the non-terraced site has higher water-holding capacity than the terraced site. Clay content is also higher on the non-terraced site, but not significantly. Soil compaction and erosion may have been responsible for the increased silt on the terraces, decreasing the high percentage of clay found on the non-terraced site.

Given the lack of distinct current soil chemistry differences between terraced and non-terraced sites, one possibility is that any evidence of leaching or nutrient transport related to the original terracing is obscured by current nutrient relations. In a low nutrient, dry environment, nutrient losses due to harvesting may no longer be evident 25-30 years following harvesting because of resumed nutrient cycling, and accumulation of atmospheric and biologic inputs (Miller 1984). The current nutrient figures for these six sites do not present a picture of current erosion, although sediment collection studies would be needed to verify this conclusion.

Negative effects on tree growth due to excessive compaction of terraced sites are not evident in the data of this study. While compaction still may have occurred and decreased the potential growth of the planted seedlings, the typical effects of puddling,
rooting difficulty, and loss of infiltration and saturated hydraulic conductivity, do not seem to have severely curtailed the productivity of the terraces. However, since the time of year when these terraces were built is unknown, we cannot determine whether these terraces were more or less compacted than the average on the district, and whether compaction may have negatively effected other terraced stands.

**Other possible factors in productivity differences**

Terrace benches do not appear to be nutrient-enriched by sedimentation or leaching, yet there may still be nutrient differences between terraced and non-terraced sites. Mounding, or bedding, a site preparation technique used commonly in the humid southeastern United States, may be an illustrative corollary to the building of terrace risers and may suggest some of the nutrient effects of piling the displaced soil and organic material. Mounding was used at first primarily to aid drainage on Piedmont pine plantations and other wet sites but has since been used in northern Idaho (Page-Dumroese et al. 1989). Mounding increases seedling growth (Attiwill et al. 1985), by increasing soil OM, and thereby lowering bulk density, and increasing net mineralization rates, temperature, aeration and nutrient availability of mounded soils. While parallels cannot be drawn too directly, because most of the mounding studies took place on flat or low slope lands, similar effects of piling soil and organic matter may be evident in the terrace risers. Of particular interest is the finding of Attiwill et al. (1985) that after 9 years, the gutters between mounds—originally subsurface soil—had been enriched to the control’s original surface nutrient levels. Page-Dumroese et al. (1990) attributed higher Douglas-fir and western white pine biomass in Idaho to better nutrient availability on mounded soils. They
concluded that most of the nitrogen on N-limited Idaho sites was immobilized in organic matter, and mounding speeds decomposition rates of woody debris and mobilizes nutrients. Mounded sites in Idaho also had higher cation exchange capacities than scalped sites (Page-Dumroese 1991) and higher numbers of ectomychorrhizal short roots (Harvey et al. 1991), both characteristics associated with increased seedling growth.

The implication of these mounding studies may be that the terrace risers are areas of enriched nutrients. As they stabilized and revegetated, slowing any sedimentation or leaching, they may have become nutrient banks for the elongating roots of the growing seedlings. A serious flaw in the design of this study was sampling only bench soil, rather than both bench and riser. This study’s soil figures reveal the lack of nutrient enrichment on the benches, which is important for an assessment of erosion, but the possibility that the risers have significantly higher available nutrients than those found on non-terraced slopes was not investigated.

Another possible factor in productivity is suggested by the work of Doty (1972), who suggests that snow melts more slowly on the terraces due to piling effects and sun angle deflection, perhaps saving soil moisture later into the spring. Southern slopes of greater than 30% slope receive significantly greater solar radiation than other slopes and aspects (Running 1982). In light of the equivocal soils data of this study, to monitor water content and transport throughout the growing season seems to be a logical next step in investigating the cause of differences between terraced and non-terraced productivity. Foiles and Curtis (1973) argue that tree growth in the Intermountain forests depends primarily on snowmelt, which not only provides water but also precipitation/atmospheric nutrient inputs into the growing season (Miller 1984). Ponderosa pine, in particular, has a
long growing season and may be particularly adept at taking advantage of soil moisture further into the summer.

Forest canopy removal in small areas affects snowmelt distribution and ablation rates of the snowpack. Snowpack manipulation has been investigated as a way of increasing or redistributing snowmelt run-off, either to augment on-site soil moisture or increase watershed baseflows (Baker 1988). While terraces may currently augment water availability due to decreased insolation, particularly on south-facing slopes, as trees reach mature size, canopy interception and understory re-radiation of longwave radiation may have an opposite effect on snowpack ablation and soil moisture. The south-facing slopes of this study, where terracing appears to have facilitated higher tree numbers per hectare, may suffer as the stand ages from overstocking, which can result in drought as larger trees compete for lower available water (Klock 1983).

The shape of the terraces may also affect soil temperature regime. The BNF Task Force report suggested that the angle of the terraces disrupts the intensity of solar influx on south-facing slopes and may help seedlings to survive their first summers (Worf 1970). But in contrast, Prevost (1995) found more rapid warming of scalped, exposed mineral soils in the spring, compared to untreated soils whose OM layer acted as insulation. Morris and Pritchett (1983) also recorded soil temperature increases of 2-5°C following shear/pile/disc site preparation. Decreased insulation but also decreased insolation on the terraced sites may alter the temperature regime of the soil and affect the length of the growing season and biological activity within the soil.
Other considerations

Another pertinent question regarding the WFD terraces is whether there is evidence of increased mortality due to weak root structure or growth stalling as roots cannot provide sufficiently for larger trees. As mentioned earlier, soil compaction and machine planting are both blamed for root deformities or weaknesses. There is no apparent evidence of such problems yet, but the possibility remains open as the trees increase in volume. Shallower depths to underlying rock or subsurface soil weakness due to the construction of the terraces may result in instability as the trees reach mature size.

None of these terraced forests in Montana has been harvested at the end of its prescribed 150-year rotation, and there are some concerns about the feasibility of removing large trees from the terraces and what effects that might have on terrace structure. The high silt soils on the benches might be subject to tremendous erosion if disrupted by harvesting. Any method of tree removal would involve maneuvering trees over the humps of the terraces, and damage to the risers and release of sediment seems likely. Considerable study will have to precede any action. Helicopter or other expensive aerial means of removing the trees might have the least impact, but economics usually determines harvesting methods.

On another level, the aesthetic and cultural concerns that spurred the controversy of the 1960s and early 1970s have not disappeared; they’ve merely been ignored. Before terracing could again be considered as a management technique on western American forests, the public would have to be informed about the tradeoffs involved. If terracing turned out to produce higher timber volume per hectare, would Americans be willing to devote smaller areas to more intense silvicultural practices in order to save others from
being cut at all? The answer to that question is beyond the scope of this study, but the cultural implications of this forestry technique form significant constraints to its applicability, regardless of its economic potential.

CONCLUSION

There is physical evidence of soil erosion on the terrace benches, in the form of higher silt content. However, any chemical advantage due to leaching of nutrients after the construction of the terraces is no longer evident, either having been taken up into the standing biomass or obscured by the development, over thirty years, of sufficient nutrients on both terraced and non-terraced sites. The results of this study do show significantly and distinctly higher tree volume, both per acre and per tree, associated with terracing on the study sites of the West Fork District. Another important area for research would be the current nutrient status of the risers and the tree roots’ access to them. The trees on these sites are less than a quarter of the way through their prescribed rotations, and the length of rotation affects the long-term nutrient and productivity impacts of management practices (Powers 1991). Also, young trees depend on soil nutrient capital more heavily during initial stages of regeneration than do mature trees in later stages (Grier et al. 1989). If nutrient differences are contributing to volume differences between terraced and non-terraced sites, these advantages may not continue to affect productivity significantly as the trees age.

Given the lack of evident soil effects, one might return to the conclusion of Lal (1994) that available water is the primary factor affecting the productivity of forest sites. There is no doubt that the West Fork District is a water-limited district, with a mean
annual precipitation of 89 cm (pers. comm., Bradstorm 1996). Since none of the soil factors evaluated provides a sufficient explanation for the observed differences in site productivity and tree regeneration, plant available water would be a good next step in evaluating the effects of terracing on tree volume. Research should continue to assess whether the observed increases in site tree productivity continue throughout the length of the rotation.
LITERATURE CITED


