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Working Paper

99

Washington's Sawmilling Sector Analysis: Capacity Utilization Rates and Timber Outlook

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EXECUTIVE SUMMARY

The study produced an assessment of the lumber manufacturing sector. It analyzed the changes in this sector and its relation to timber harvest levels. The study's objective was to determine whether Washington's sawmilling sector can expand or not, given a projection of future timber harvest levels.

We analyzed the Washington State Department of Natural Resources mill surveys from 1968 to 2002. The analysis first defined five timbersheds in western Washington and two timbersheds in eastern Washington. The study then focused on an analysis of capacity utilization by the sawmilling sector. We produced trends of utilization rates and discussed potential reasons why the rates have changed over time and among timbersheds. Periods of high prices were related with periods of high utilization rates, with exception. During the 1980's, there occurred a shut down of capacity that improved the average utilization rate for the sector following a collapse of high lumber prices in 1979. Currently, the average utilization rate is at historically high levels as one might expect given the strong U.S. housing sector. Lumber prices have recovered from a short period of lower prices, and they are currently at near-high levels providing impetus to the high capacity utilization in the sawmilling sector. We also found differences in the utilization rates among the timbersheds, and they are presented in the body of the report.

We followed the capacity utilization analysis with an assessment of log consumption. Log use by the sawmilling sector within respective timbersheds was compared with the timber harvest level. Except for the South Coast, Southwest and eastern Washington timbersheds, sawmills were now, by far, the main consumer of the harvest level. Substantial amounts of saw logs continue to move from one timbershed to another. In 2002 approximately 600,000 mbf of timber was transported across timbershed boundaries to be used by sawmills in other timbersheds. Timber heading to Oregon continued to be significant, and logs imported from British Columbia were now occurring.

We examined the potential supply of timber for western Washington timbersheds. The complexity of projecting uneven-aged stands found in eastern Washington limited the analysis to western timbersheds. While the projection was considered preliminary, it was a useful first step to gauge the wood availability required to maintain or expand the sawmilling capacity in western Washington. Further sensitivity analysis is required but was beyond the scope of this phase of the research. The projections indicated that current harvest levels can be sustained, and in the South Coast timbershed, the harvest level can be increased over the next several decades. There did not appear to be any indication that the harvest level will fall below the current level of 2.8 billion board feet. Timber inventories in all timbersheds revealed a significant growth in volume in older age classes given the projected harvest level suggesting there exists the potential for a higher, future harvest level if these forested lands were made available for timber production.

Our projections assumed current harvesting conditions will continue to exist into the future. One conclusion we draw from the analysis is that the biological potential of the timber land itself will not likely be a constraining factor in future timber harvest levels. Rather, regulatory and land-use factors are more likely to impede a harvest level that coincides with the biological potential of the forested lands.

There are important policy implications from our findings. Lumber manufacturing in Washington has become the principal consumer of wood fiber in the state, and we projected, given their current high rates of capacity utilization by existing mills and the biological potential for increasing harvest levels, that lumber manufacturing can expand. While Washington's forest products sector has changed substantially due to the significant decline in timber harvest level over the past decades, the sawmilling sector has maintained its level of use of the harvest during this time. There has been a substantial decline in the number of sawmills, and the volume of log that crossed timbershed boundaries continues to be significant, but still, lumber manufacturing, a sector that consumed a small percentage of the log harvest level 20 years ago, is now the predominant end-user of logs harvested in Washington, and it is in a position to grow. The change in the composition of the forest sector was not driven by a substantial growth in lumber manufacturing but rather the decline in timber harvest levels and its impacts of the other forest sectors in Washington, primarily log exports.

The lumber manufacturing sector has not been without its share of change however. There has been a consolidation of milling capacity, and with it, a reduction in the amount of labor employed by sawmills. Lumber mills in

Washington have transitioned from a large number of smaller-sized mills capable of utilizing a wide range of log sizes to a consolidated sector that utilizes smaller logs with more capital and less labor. There is also much less mill-type diversity within the sector.

We conclude that harvest levels in the future are such that they should allow for lumber manufacturing to expand. We support this conclusion with the facts that capacity utilization rates have been high during the past decade and that timber harvest levels in Washington have adjusted to a lower level than in previous decades. The harvest level simulations suggested that current harvest levels are sustainable into the future over a couple of rotations. The simulations assumed conditions today will continue into the future. For this reason, further work is needed to assess changes in land-use patterns and regulatory constraints that may impact future timber harvest levels from Washington's forested lands.

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INTRODUCTION

A preliminary analysis of the sawmilling sector using the Washington Department of Natural Resources mill surveys found several interesting trends (Perez-Garcia 2005b). Lumber output increased while scaled log consumption declined. The number of small sawmills sharply decreased over the past three decades, while the number of larger mills slightly increased. The volume of logs that flowed across geographical areas continued to be significant. These trends occurred during a period when log harvest levels varied considerably and then declined dramatically after federal timber harvest restrictions went into effect. This paper examined selected mill surveys from 1968, 1978, 1988 and 1998.

Here, we expanded this earlier analysis. We discussed other trends and examined the future supply of saw logs to the lumber manufacturing sector. We used the biennial surveys from 1968 to 2002 published by Washington's Department of Natural Resources (WADNR), their Timber Harvest reports, the Department of Revenue's timber sales data, and yield tables for western Washington, among other data sources.

Lumber manufacturing in western Washington has become the principal consumer of wood fiber in the state. The reduction of timber harvest levels over the past two decades, among other factors, has had a greater impact on sectors other than the sawmilling sector. Logs going into exports and plywood production have declined. The lumber manufacturing sector has also been affected, but in other ways. As stated above, there has been a consolidation of capacity from numerous smaller-sized firms to larger mills, and with it, a reduction in the amount of labor that is associated with lumber manufacturing. This observation leads us to conclude that lumber manufacturing will serve to form the basis for the demand for Washington timber in the foreseeable future, rather than the export sector, for example.

We described the lumber manufacturing sector over the past three decades in the following sections. We discussed a projection of demand for lumber locally, nationally and internationally and related how the region's sawmilling sector might respond to the forecast. How productivity and average utilization rates have changed by timbersheds are described in the study. The analysis delineated Washington into eight timbersheds to facilitate the representation of data. The western region was broken out according to an earlier analysis of timber supply in western Washington (Adams et al. 1992 and Anderson et al. 1994); the eastern region was delineated according to Bare et al. 1995. To complement the utilization analysis, the study analyzed harvest volume shares by the sawmilling sector and projected timber supply into the future using timber yield information from Anderson et al. (1994) and timber harvest data from the Washington Department of Revenue.

A HISTORICAL DESCRIPTION OF THE LUMBER MANUFACTURING SECTOR

Washington produces lumber that is similar to products produced in Oregon and Northern California. These products compete in a North American market with other producers, such as southern lumber manufacturers and Canadian producers. The PNW products are also shipped internationally and compete globally for market share in many other countries. The extent of the North American market and the international trade in lumber begs the question: What is the outlook for PNW lumber in the face of national and international competitors?

A recently completed global analysis of softwood lumber manufacturing using the CINTRAFOR Global Trade Model (CGTM) (Perez-Garcia 2003) produced a projection of demand growth and, more importantly, how the PNW region might expand to supply the projected increase in softwood lumber demand. The results of the analysis are summarized below in Figure 1.

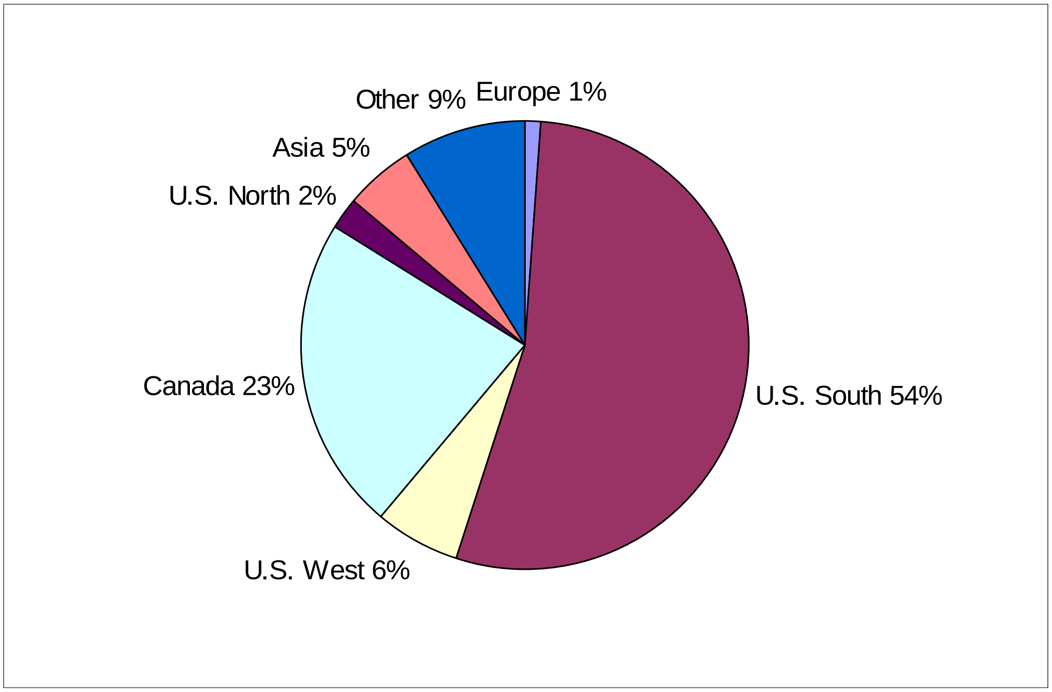

Figure 1. The distribution of market share of a projected increase in demand for softwood lumber from 2000 to 2040

Source: Perez-Garcia (2003, 2005b)

Figure 1 related the market share of saw log harvests required to meet an increase in softwood lumber demand around the world to 2040. This market share for the U.S. West region was estimated at six percent and it implies that 1.8 billion board feet (bbf) of additional saw log harvests would be required to meet the growth in demand by 2040. In other words, the report suggested about 7 to 8 modern sawmills with an annual capacity from 350 to 400 million board feet (mmbf) lumber tally. The projection suggested that the demand potential exists to expand the western US sawmilling sector. In this study we examined the implication of the projection more closely by examining several historical datasets and projecting timber supply into the future.

Historical Changes in Washington's Sawmilling Sector

We analyzed the biennial mill surveys produced by Department of Natural Resources personnel from 1968 to 2002 to understand the changes that have occurred in the lumber manufacturing sector in Washington.[1] These surveys contained information on the production levels and log consumption quantities, as well as other valuable information such as the capacity utilized and the sources of their log inputs. Two earlier results from an analysis of the published surveys suggested a lumber manufacturing sector that is concentrating its capacity into fewer mills while maintaining and even expanding its production level, and a sawmilling sector that is now the major source of demand for timber from federal, state, tribal and private lands (Perez-Garcia 2005b).

The surveys are comparable to other independent sources on log use and lumber production, and we first compared log consumption data using Washington timber harvest reports published by the WADNR (various years). Figure 2 charts the two data sets and indicates fairly consistent levels. We also compared lumber production estimates with Western Washington Products Association (WWPA) lumber production data and found consistent data up to the 1980s (Figure 3). Afterwards these two data series departed somewhat, with the WWPA data being consistently

[1] We would like to thank the Washington Department of Natural Resources and Bruce Glass for making the surveys available for use in this study.

lower than the Mill Survey data, with exception of 2002. This departure may be explained by the fact that mills included in the two surveys were not necessarily the same.

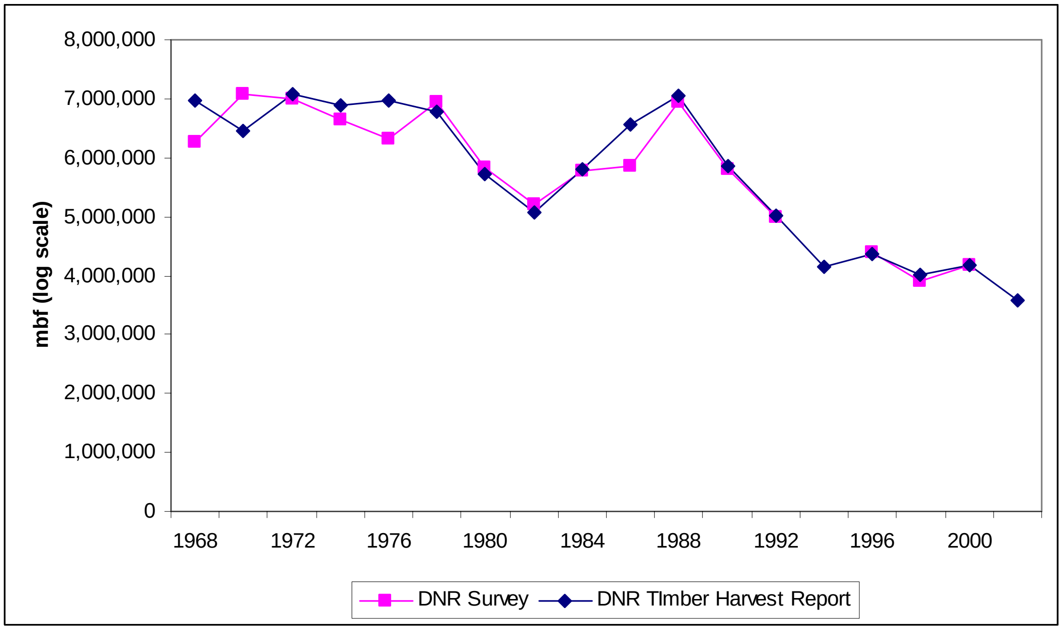

Figure 2. Biennial volume of primary wood consumption reported in the mill surveys and the timber harvest reports for the period 1968 to 2002 (includes all sectors). 1994 mill survey volume was not available at the time of the comparison.

Source: Bruce Glass, WADNR, personal communication (2004).

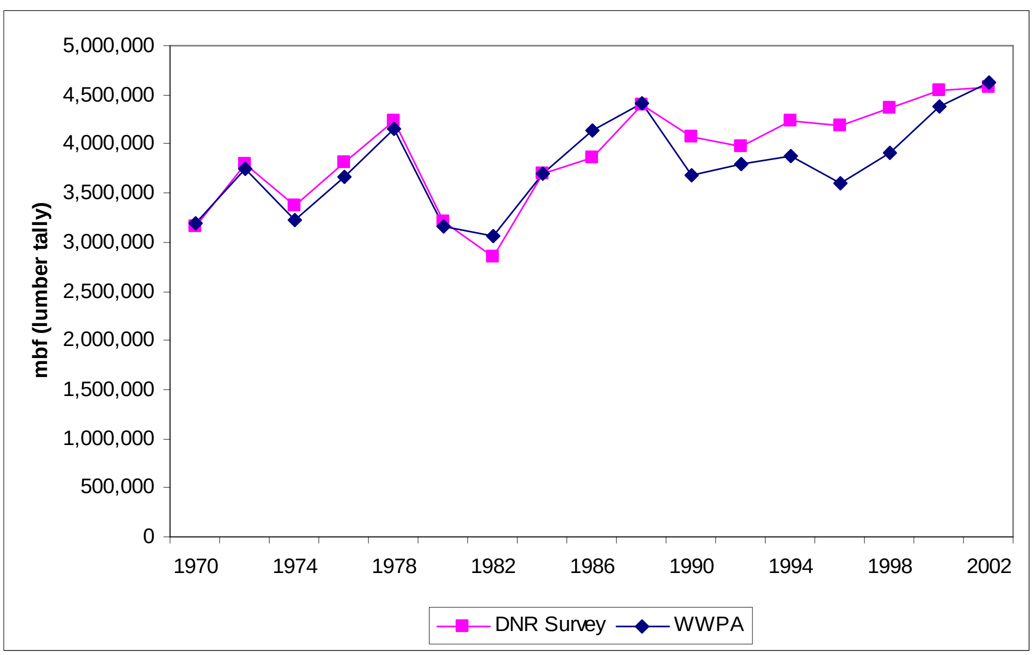

Figure 3. Biennial volume of lumber tally reported in the mill surveys and by the Western Wood Products Association for the period 1970 to 2002.

Source: Bruce Glass, WADNR, personal communication (2004) with mill survey updates for 1994 and 2002.

Figure 4 charts the total production of lumber for Washington, the total consumption of logs, and the number of operating hours reported in the sawmill surveys. Log consumption in 2002 has remained just below 2.5 billion board feet (log scale), while lumber production has reached around 4.5 billion board feet (lumber tally).

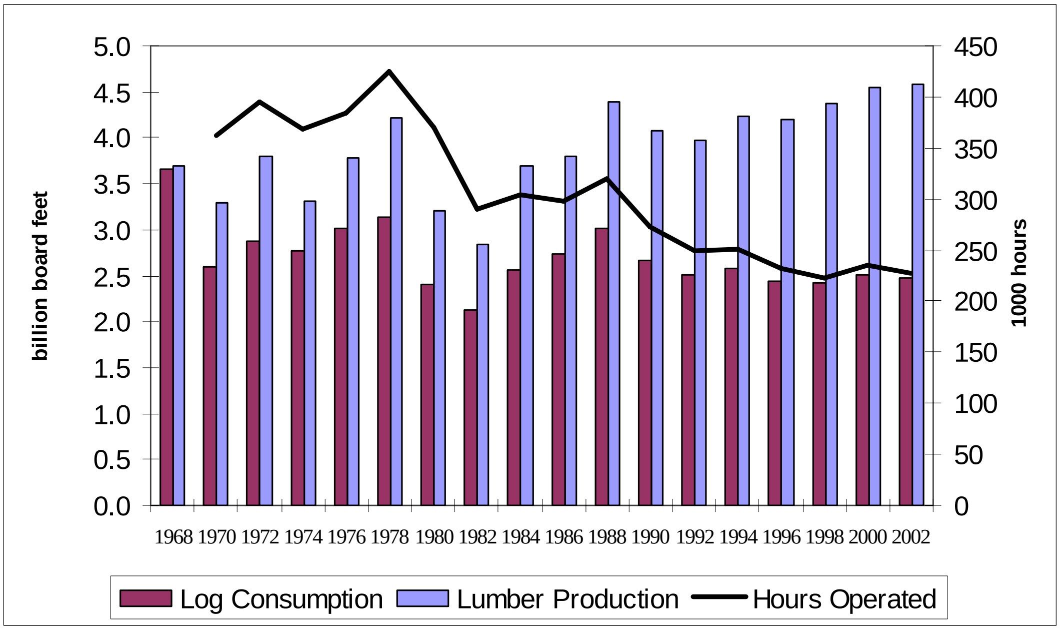

Figure 4. Log consumption, lumber production and reported hours of mill operation from biennial mill surveys.
Source: WADNR Mill Surveys (various years)

There may be several factors that can explain why lumber production has apparently increased while log scale volume has declined. This may be best explained by changes in the log sizes coming off of Washington's forested lands. Figure 5 shows such a decline. It is an example where log sorts associated with the larger diameter trees declined over time. The volume of #2 saw logs per acre has fallen below that of the # 3 saw log.[2] The effect of smaller diameter logs and greater use of lower log sorts by mills in and by themselves can have the effect of increasing the recovery ratio. It is difficult, however, to attribute an exact amount between greater log recovery by improved sawmilling methods, log scaling and over run effects due to smaller diameter logs being utilized.

Figure 4 also charts the number of hours mills were in operation for each of the survey years. Total hours reported in 1,000 units had dropped considerably from the peaks in 1978 and 1988 to 2002. Operating hours had fallen from a record high of over 400,000 hours in 1978 to a near record low of 225,000 hours in 2002. The 2002 data suggested that productivity had doubled since 1978 when over 400,000 hours were reportedly used to produce over 4 bbf of lumber. In 2002 about 225,000 hours were utilized to produce slightly more than 4.5 bbf of lumber. Hours operating per lumber output were more than double in 1982, a low point in lumber production, than in 2002. Improvements came after 1982 when mill closures occurred due to low product prices. Afterwards, the average operating rate of the remaining mills began to increase.

[2] Special Mill log grade is a log with 6 rings per inch minimum in the outer portion, a minimum scaling diameter of 16 inches and minimum log length of 17 feet. The No. 2 Sawmill log grade has no minimum rings per inch, a 12 inch minimum scaling diameter and 12 feet minimum length. The No. 3 Sawmill grade differs from the No. 2 in the minimum scaling diameter: 6 inches. The No. 4 Sawmill differs with a 5 inch minimum scaling diameter.

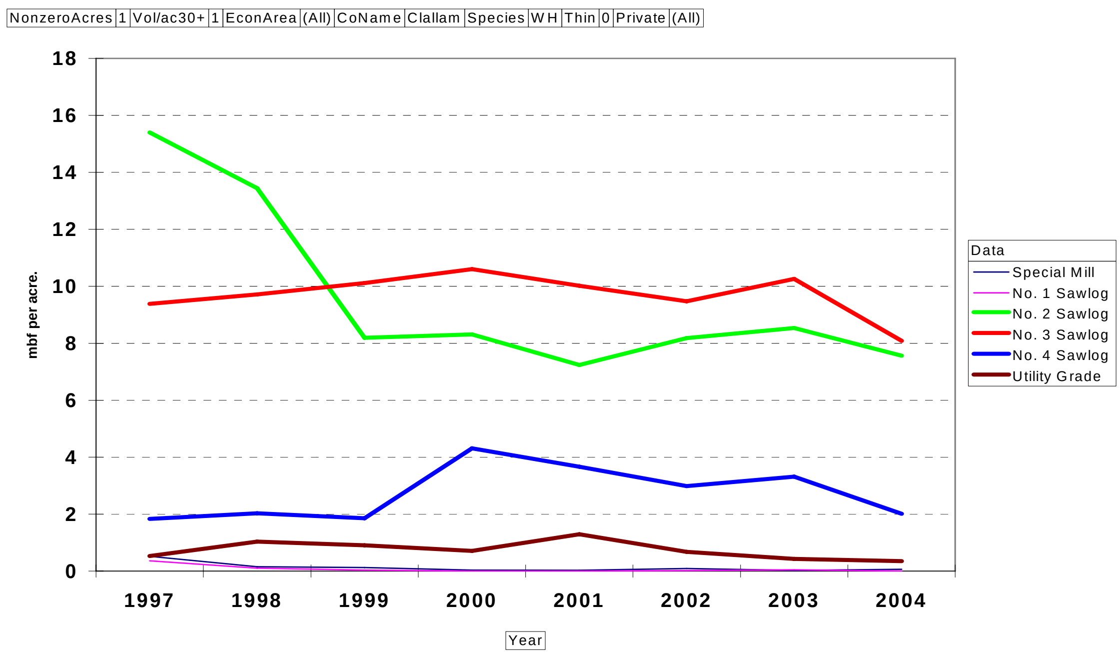

Figure 5. Average volume of timber harvest per acre by log sort and year of sale for western hemlock in Clallam county.
Source: Washington Department of Revenue

An Assessment of Capacity Utilization

Information on sawmilling capacity and its utilization were derived from the mill surveys. For almost all survey years, information on the number of shifts, the length of shifts and days operating were reported. An eight-hour shift capacity field recorded the maximum capacity of the plant. We summarized these surveys by constructing a measure of capacity utilization and analyzed its behavior over time.

Capacity utilization was defined as the ratio of the actual operating rate to a maximum operating rate. The annual actual operating rate is the number of eight hour shifts multiplied by the days operating and the eight hour capacity. The maximum operating rate per year is two eight hour shifts multiplied by 250 days multiplied by its eight hour shift capacity. We used a linear regression model to establish the relationship between actual utilization and maximum utilization. The coefficient associated with the maximum utilization variable was adjusted using indicator variables for year and timbershed. The estimated coefficients are the capacity utilization rates illustrated below. The timbershed boundaries differ from the economic area definitions utilized by the mill surveys to allow us to use data on timber inventory later in the study to analyze the potential supply of logs. Table 1 presents the county definition of these timbersheds according to Adams et al. (1992) and Bare et al. (1995)

Table 1. County and Timbershed Association

County	Timbershed	County	Timbershed
CHELAN	Central	CLALLAM	North Coast
DOUGLAS	Central	JEFFERSON	North Coast
KITTITAS	Central	ISLAND	North Puget Sound
KLICKITAT	Central	KING	North Puget Sound
OKANOGAN	Central	SAN JUAN	North Puget Sound
YAKIMA	Central	SKAGIT	North Puget Sound
ASOTIN	Inland	SNOHOMISH	North Puget Sound
BENTON	Inland	WHATCOM	North Puget Sound
COLUMBIA	Inland	GRAYS HARBOR	South Coast
FERRY	Inland	PACIFIC	South Coast
GARFIELD	Inland	KITSAP	South Puget Sound
LINCOLN	Inland	MASON	South Puget Sound
PEND ORIELLE	Inland	PIERCE	South Puget Sound
SPOKANE	Inland	THURSTON	South Puget Sound
STEVENS	Inland	CLARK	Southwest
WALLA WALLA	Inland	COWLITZ	Southwest
WHITMAN	Inland	LEWIS	Southwest
		SKAMANIA	Southwest
		WAHKIAKUM	Southwest

Source: Adams et al. 1992.

Figure 6 contains the state-wide, average utilization rate for the period 1968 to 2002 for sawmills. The peaks in 1972 and 1978 are notable from the figure, interrupted by the recessions in the early 1980s. These recessions and the collapse of prices in 1979 contributed to a low utilization rate in the early part of the decade, while a recovery in the mid 80s raised them, and a strong demand throughout the 1990s and into the early 2000s maintained them at fairly high levels.

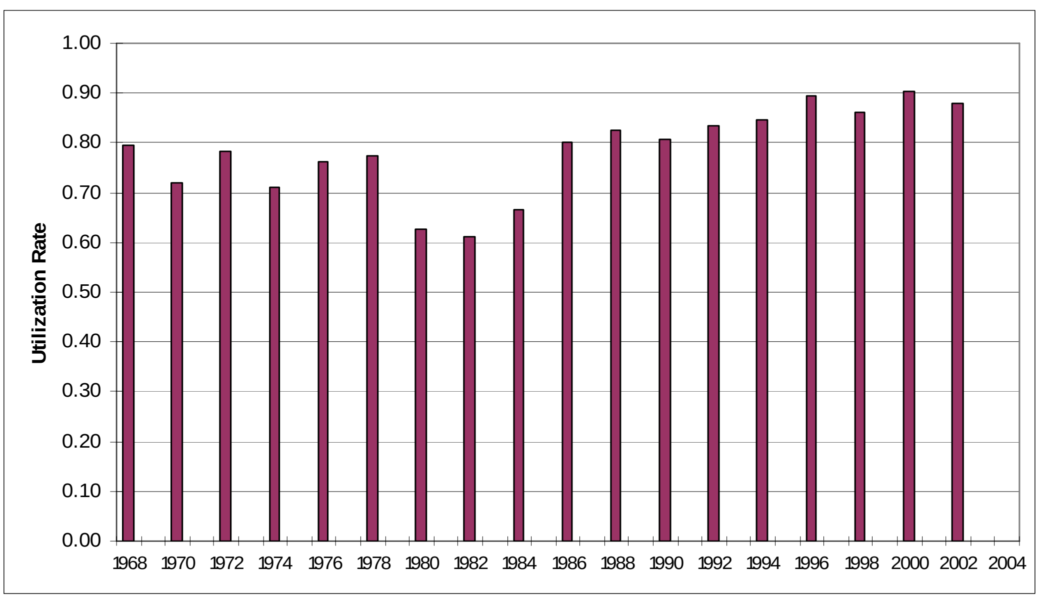

Figure 6. Average capacity utilization from biennial mill survey data from 1968 to 2002.

There are many factors that contribute to operating rate variation over time. When viewed against a price series, several interesting periods appeared. Figure 7 charts the composite lumber price presented in real terms in 1980 dollar value[3] versus the state-wide average utilization rate. There is a strong relationship between the two series with exception of the period from 1986 to 1992. The period was characterized by steady domestic lumber prices with an increase in operating rates. The decade of the seventies was a period of strong demand that led to increasing prices stimulating high operating rates. The collapse of prices in 1979 was unexpected, and eventually led to a reduction in the state-wide utilization rate. Figure 6 shows this decline beginning in 1980. There was a substantial loss in sawmilling capacity, and net lumber production from 1980 to 1982 declined by over 1 billion board feet. After the recessions in the early 1980s, housing market activities began to pick up. But this increase in demand was met by many lumber producers; including increased Canadian lumber imports and an expansion of sawmill output by the U.S. southern mills. As a consequence lumber prices remained depressed as supply outpaced demand growth. One possible reason for the apparent increase in the capacity utilization rate in 1986, which maintained itself throughout the remainder of the period, is that non-profitable capacity shut down, which reduced total capacity, and increased the average capacity utilization rate of the remaining mills.

This pattern, utilization rates that lie above the price index, appeared again in 2000 and 2002. However, an increase in prices in 2004 had likely avoided the need of mills to reduce operating rates. Otherwise, with a continued low price for lumber, operating rate adjustments would have likely been necessary, and one would had expected further squeezing out of low profitable capacity in the region. Survey data for 2004 was not yet available, but conversations with mill managers have indicated their relief that prices had recovered and, with it, returned the sawmilling sector to a healthier status.

If one were to extend the utilization trend into the future however, one might reveal some reasons for short-term concerns. An unexpected and sustained drop in lumber prices is likely to put downward pressure on sawmilling capacity in the state, particularly if the fall in prices is unexpected. This scenario may raise levels of concern with respect to an alleged housing bubble (Shiller 2005). Should housing demand falter in the U.S. it would represent a fall in lumber prices. Adding to this concern is the amount of potential increase in the supply from Canada due to mountain pine beetle salvage timber harvests (B.C. Ministry of Forestry 2005). Since a great deal of consolidation of the sawmilling sector has already occurred, a forced reduction in utilization rates would likely have a different impact today than it did during the early 1980s.

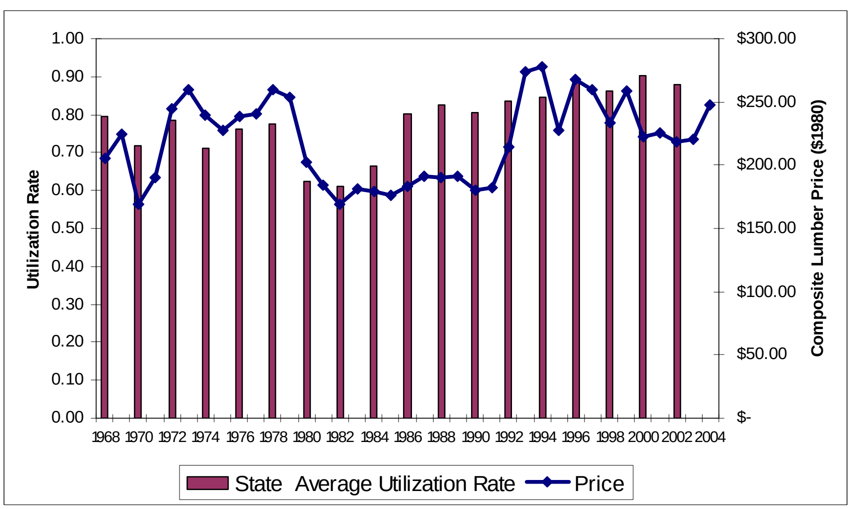

Figure 7. Average capacity utilization from biennial mill survey data from 1968 to 2002 and composite lumber price index deflated using the PPI.

[3] The historical composite price series was constructed using several sources including the CINTRAFOR Global Trade Model database and various Random Lengths publications.

If on the other hand, prices remain at their levels, or demand factors lead to upward price pressure, the utilization rates might suggest the need for additional capacity. Whether the state can support this additional capacity is addressed in a later section of the paper.

We next discuss utilization rates by timbersheds. There exist several differences in regional behavior for the North Coast timbershed (Figure 8) from the state-wide average. We speculate as to why in the following. The increase in operating rates in 1986 is the result of mill shutdowns that raised the average operating rates for exiting mills. Operating rates then continued to fall from 1986 to 1994. The trend continued forward even after lumber prices recovered, likely a result of the reduction in timber supply due to habitat conservation programs in the timbershed. Utilization rates for 2000 and 2002 were higher during a period of low composite lumber prices when new capacity entered the timbershed. We would expect that the 2004 survey will show a drop in the utilization rate as this new capacity did not sustain itself due to low revenues.

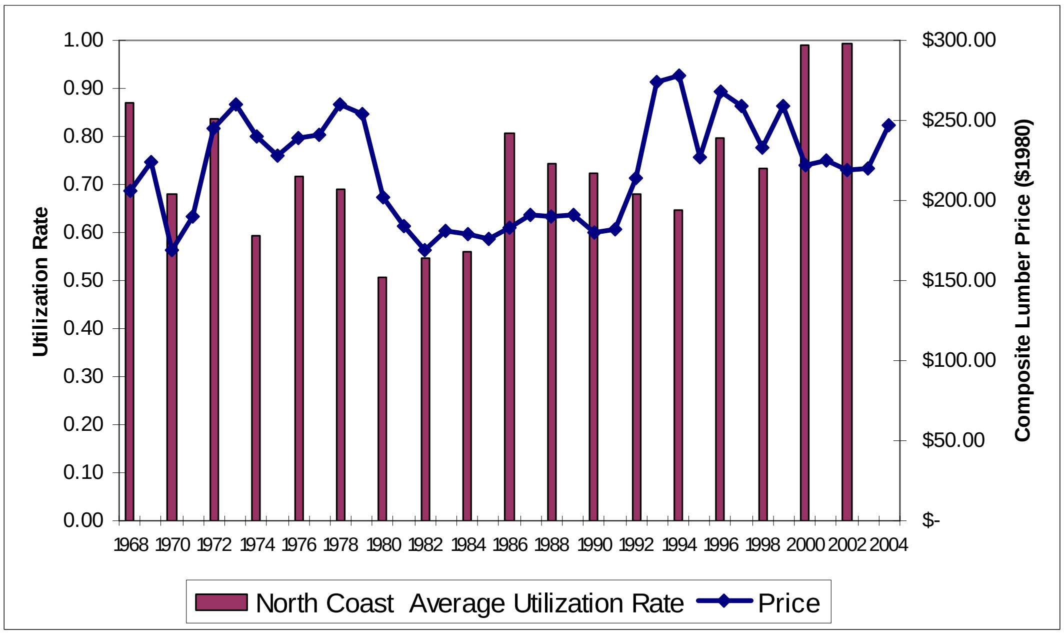

Figure 8. Average capacity utilization from biennial mill survey data from 1968 to 2002 and composite lumber price index deflated using the PPI for the North Coast timbershed.

In contrast, the South Coast timbershed sawmills responded with lower operating rates in 2002, and again a delayed response to the increase in lumber prices in 1993 and 1994 (Figure 9). The operating rate correlation with domestic lumber prices in the earlier period showed little relationship. Operating rates were above the state average. The mills also reduced operating rates in 1990 more so than the state-wide average indicated.

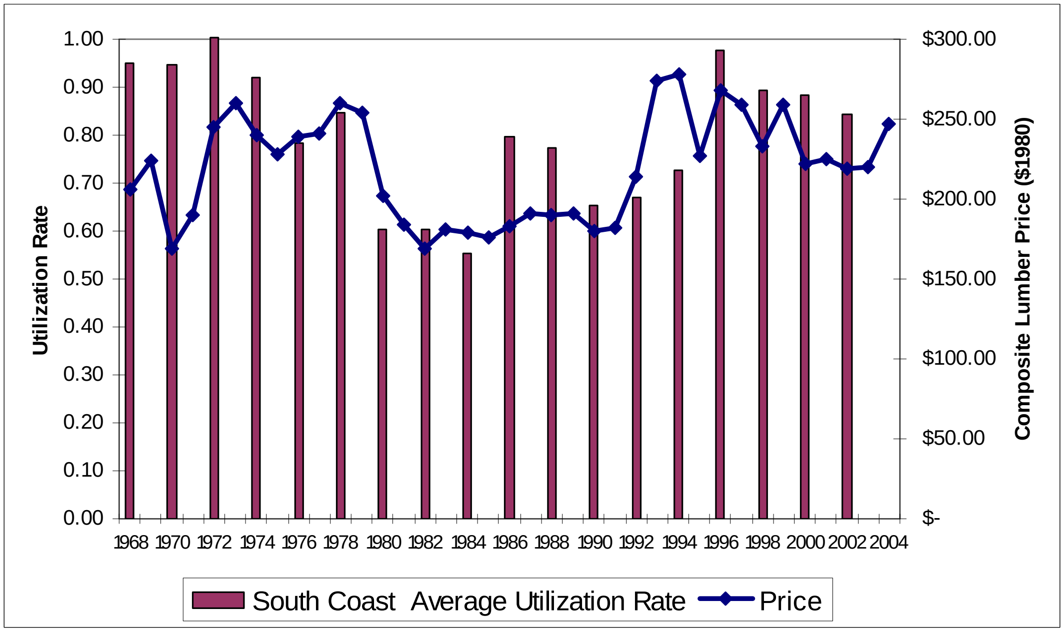

Figure 9. Average capacity utilization from biennial mill survey data from 1968 to 2002 and composite lumber price index deflated using the PPI for the South Coast timbershed.

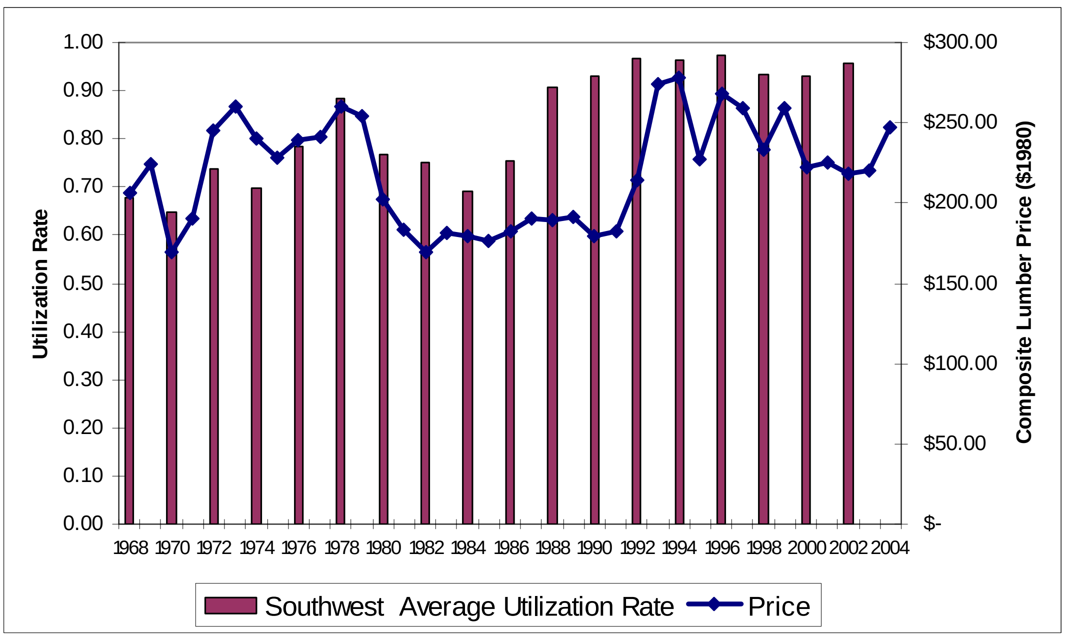

Figure 10. Average capacity utilization from biennial mill survey data from 1968 to 2002 and composite lumber price index deflated using the PPI for the Southwest timbershed.

Data for the Southwest mills indicated rather high capacity utilization rates relative to the state average (Figure 10). The operating rates had been sustained since the mid 80s. Further inquiry into the region's competitiveness may reveal the reason as to why they have been able to maintain above average rates throughout the period. As we shall discuss below, this timbershed has been the major lumber producing region in the state, but has had a steady downward trend in log use by the sawmilling sector since the late 80s. This lower level of consumption can be an indication of the shutdown of milling capacity over the period that produced a high utilization rate for those remaining mills, which maintained their plants in operations due to their competitiveness.

South Puget Sound timbershed data on utilization rates follow a similar pattern (Figure 11). While indicating some greater variability in 1990, and slightly lower rates in 2000 and 2002, the timbershed was characterized by high operating rates since 1986. If our hypothesis about why we might observe increased operating rates is correct, then an examination of the capacity that has shut down in the Sound Puget Sound timbershed may reveal whether the reason their operating rate is above the state-wide average in 1986 was due to increased competitiveness of remaining mill capacity. This analysis is beyond the scope of this review however.

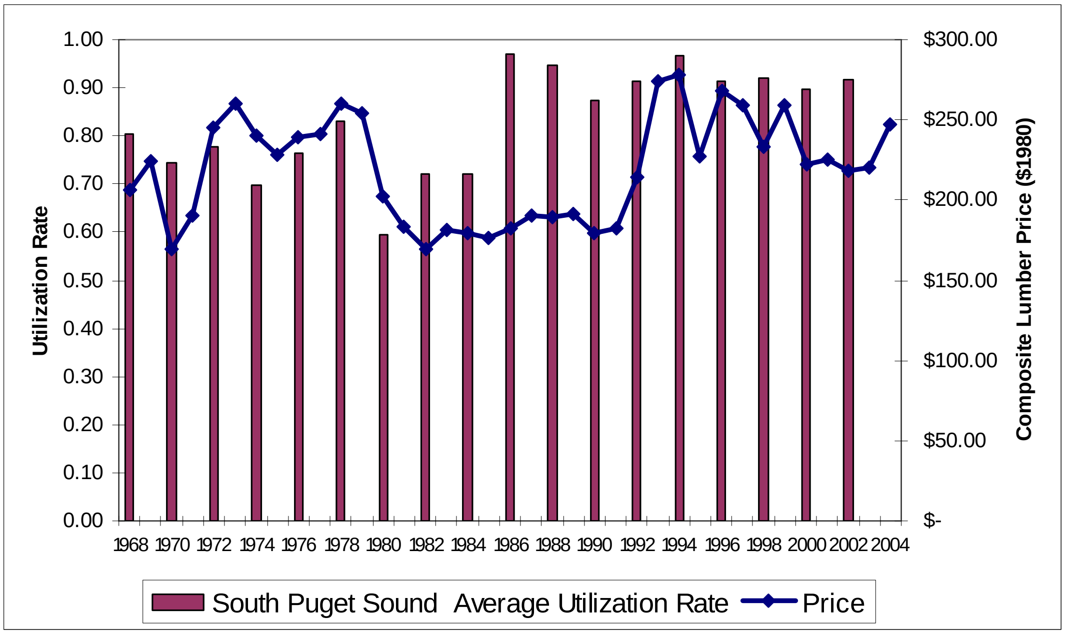

Figure 11. Average capacity utilization from biennial mill survey data from 1968 to 2002 and composite lumber price index deflated using the PPI for the South Puget Sound timbershed.

The North Puget Sound utilization rate mirrored the state-wide average rate. One notable difference was the decline in the rate observed in 1998. This may be due to the decline in Asian demand for lumber, but requires more investigation to confirm this.

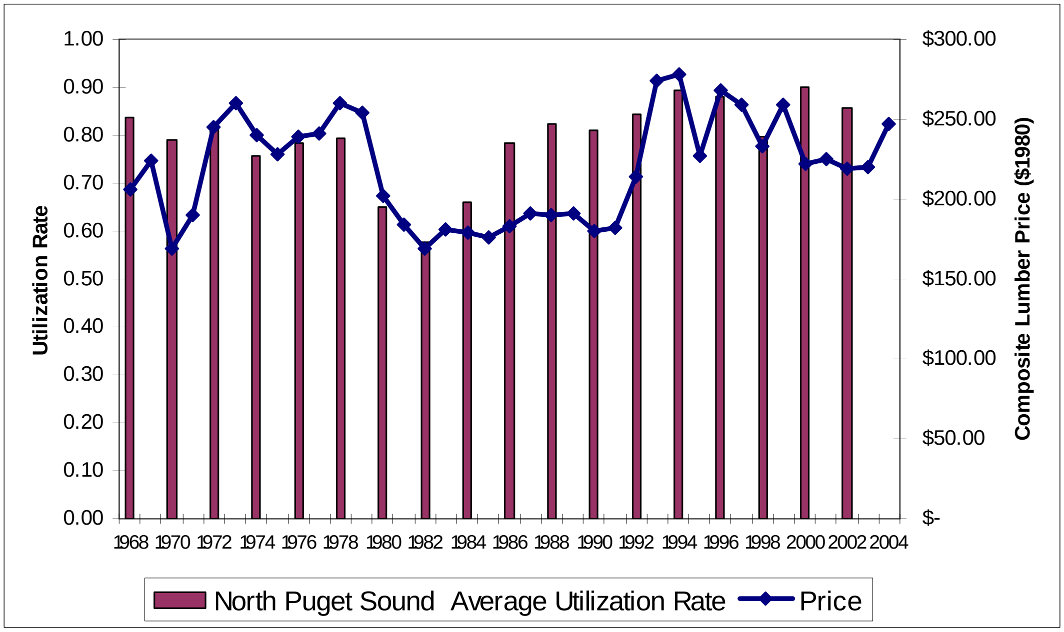

Figure 12. Average capacity utilization from biennial mill survey data from 1968 to 2002 and composite lumber price index deflated using the PPI for the North Puget Sound timbershed.

The average utilization rates for the two eastern Washington timbersheds, the Central and Inland regions are depicted in Figures 13 and 14, respectively. The Central region exhibited utilization rates that are above the composite price during the 1980s. Again, this may be an indication of where mills may have shut down due to lumber price collapse after 1979. Utilization rates observed for the Inland region were below the state-wide average up to 1984. Since then, they have remained below or near 80%, with exception to 1998 and 2000; two surveys that indicate expanded capacity utilization.

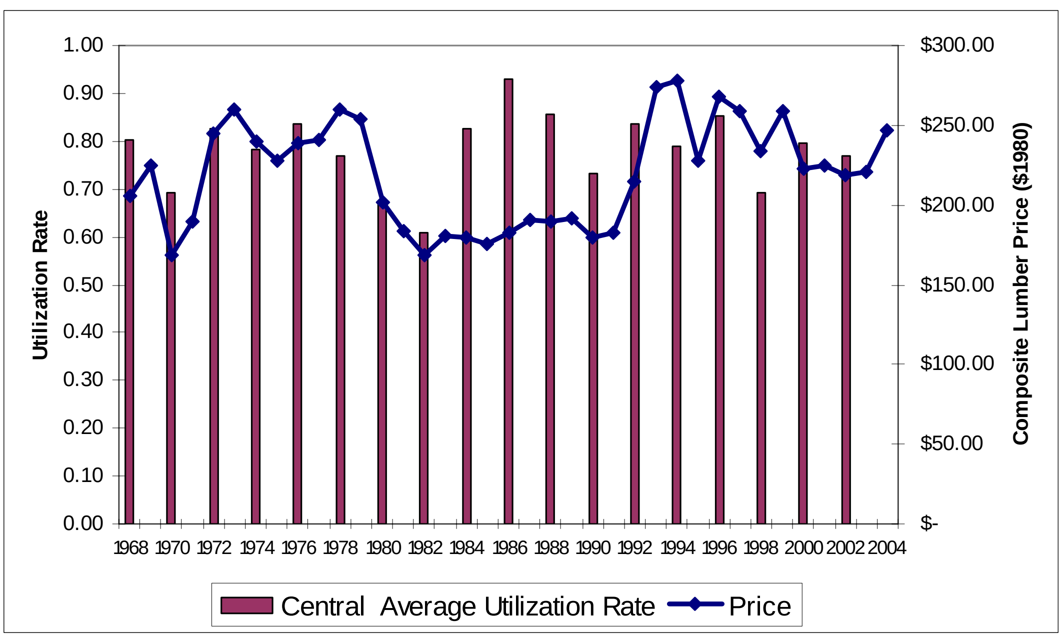

Figure 13. Average capacity utilization from biennial mill survey data from 1968 to 2002 and composite lumber price index deflated using the PPI for the Central timbershed.

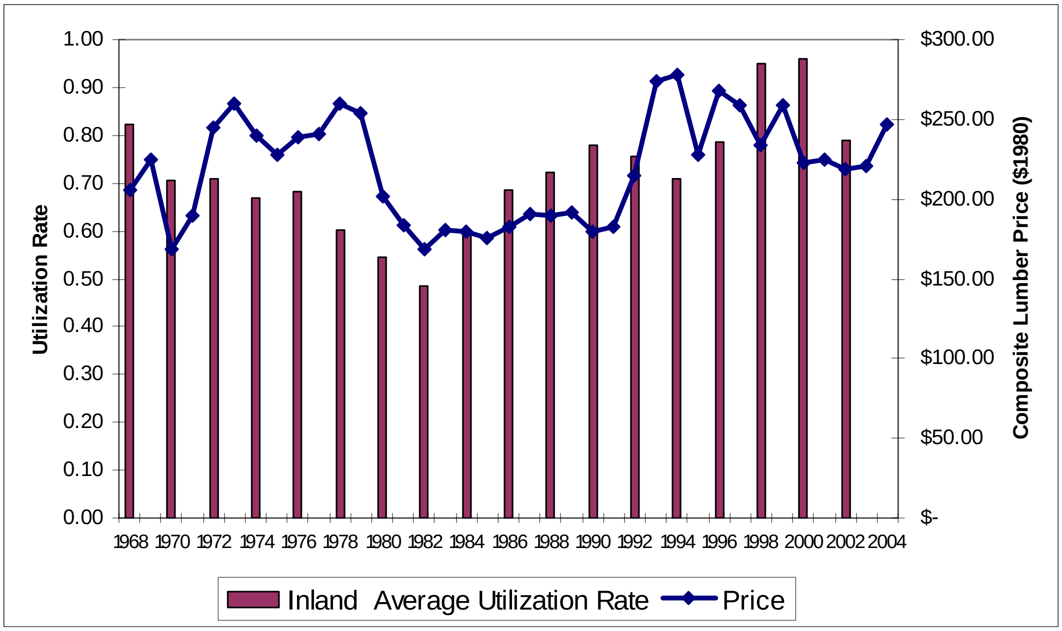

Figure 14. Average capacity utilization from biennial mill survey data from 1968 to 2002 and composite lumber price index deflated using the PPI for the Inland timbershed.

In summary, capacity utilization rates are related to the price of lumber and other factors. The low utilization rates observed in the early 80's are the result of lowered limber prices. Low lumber prices maintained while observing high utilizations rates may have been a result of increasing competitiveness with southern U.S. and Canadian mills after non-profitable mills shut down their operations. Regional differences observed are the result of region specific factors. In some timbersheds, harvest constraints impacted utilization rates within the area. For all mills however, strong demand led by the U.S. housing sector has maintained mill utilization rates at historically high levels. Further inquiry into the changes observed in the utilization rates is left for future study.

TIMBER USE BY SAWMILLS: A SUBREGIONAL ANALYSIS

In what follows we describe the timber harvest levels and their consumption by sawmills in Washington. We utilized the same timbershed definitions as above. For each region we utilized the data from WADNR mill surveys and the Department's Timber Harvest reports to portray the historical harvest levels and use of timber by sawmills. Log consumption was defined by the county that mills list as to the log's origin. In this fashion, we disaggregated log use within the timbershed from the total in-state use of that timbershed's timber harvest for the sawmilling sector. The difference between total harvest level and in-state use is the consumption of logs by the export, plywood, pulp and other forest products sectors.

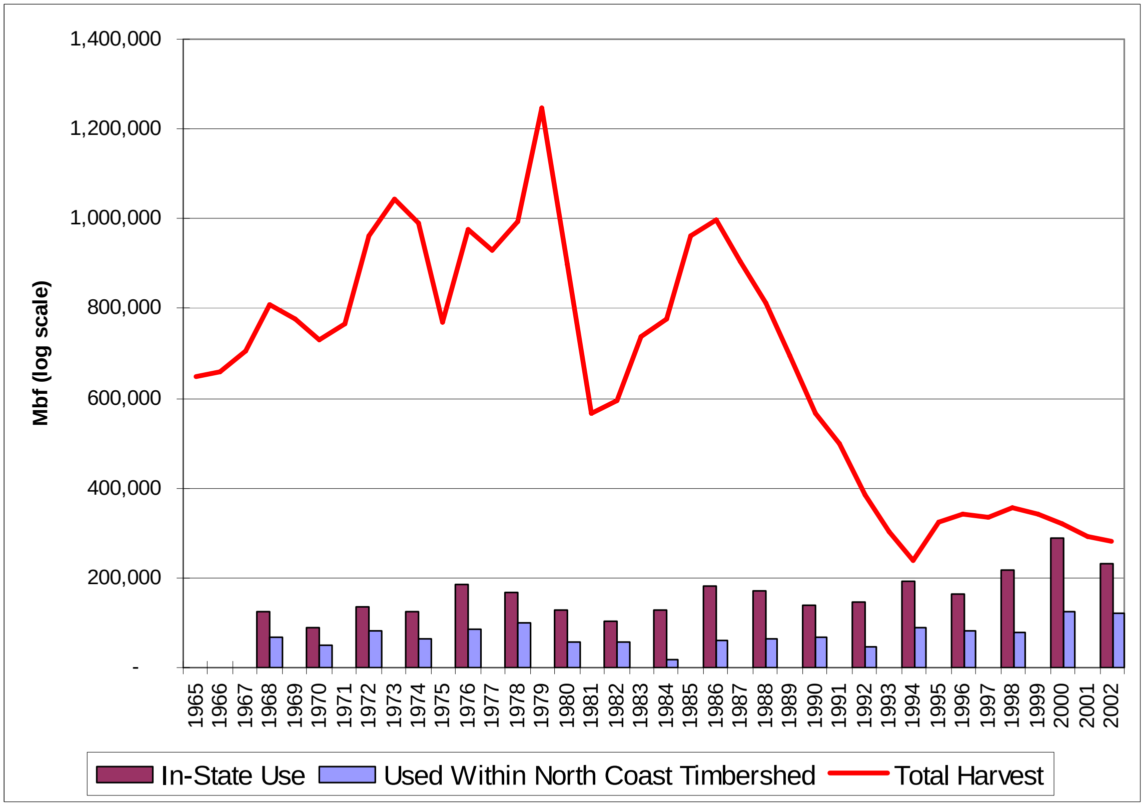

Figure 15. North Coast timbershed harvest levels (line), consumption by Washington sawmills (left bar) and consumption by North Coast sawmills (right bar).

Source: WA DNR Mill Surveys (various years) and Timber Harvest Reports (various years).

Two historical events have affected timber harvest levels in the North Coast region (Figure 15). The first decline in harvest level was the result of overpriced timber that burst in 1979. The second event was the decline in federal, state, and private timber harvest levels due to restrictions put in place to protect the habitats of the northern spotted owl and other species. Reported harvest levels for 2002 (the latest available timber harvest report) are at about 300,000 mbf.

Even with the sharp decline in harvests, the sawmilling sector in the North Coast timbershed (indicated by the bar labeled: Used within North Coast timbershed) had a positive trend in lumber manufacturing activity over the period 1968 to 2002. There were three low points since the peak consumption level reported in the 1978 survey. Low product prices due to a collapsed demand from recessions in the early 1980s and high-priced timber from over exuberant timber sale bidders following the golden years of the late 1970s led many mills to curtail operations. This was evident from the low consumption observed in the 1984 mill survey.

Federal, state, and private timber harvest restrictions put in place during the early 90s to protect the northern spotted owl and other species habitats reduced timber output. The 1992 mill survey reported the low point in log consumption. The collapse of the log export markets and closure of pulping capacity along with a growing demand for lumber by the domestic housing market led to a reported increase in log consumption in the 1994 survey; a response that may be attributed to the feedback effect between log and lumber markets.[4]

The collapse of the Asian currencies during the 1997-98 years led to a fall in demand for exports from the U.S. and Canadian lumber manufacturers. The Asian collapse of demand, even with a strong housing market in the U.S., led to a decline in log consumption by North Coast mills, as excess lumber existed for a short period of time. The increase in logs used by mills outside of the timbershed increased however. This is observed as the difference in heights between the two bars in Figure 16 and in subsequent figures. This may be due to the potential advantage of these mills to service the domestic markets. The timbershed's mills recovered in 2000 posting historically high log consumption levels.[5]

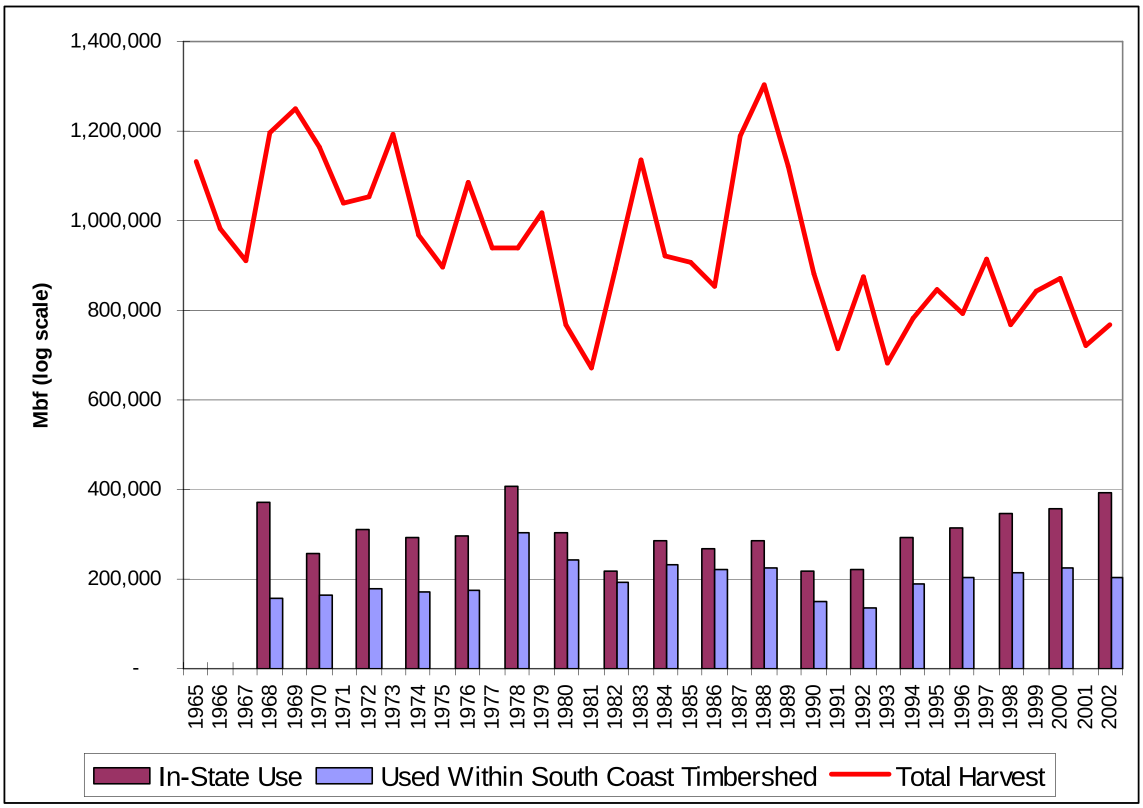

Figure 16. South Coast harvest levels (line), consumption by Washington sawmills (left bar) and consumption by South Coast sawmills (right bar).

Source: WA DNR Mill Surveys (various years) and Timber Harvest Reports (various years).

Perhaps due to the reliance on greater private timber lands for its source of raw materials, the South Coast timbershed harvest levels showed a great deal more variation than other timbersheds (Figure 16). Public timber harvest levels, which are the result of timber sold in an auction market under regulatory oversight, are less responsive to fluctuating market conditions. Evident were the harvest level declines in response to the energy shocks of 1974 and 1980. High lumber prices in 1978 shifted raw materials to the lumber manufacturing sector and then returned to levels that were slightly above levels in 1982 as demand collapsed throughout the U.S. The South Coast region is an area in Washington that has maintained its lumber manufacturing levels throughout the survey

[4] See Wiseman and Sedjo (1981) for the first treatment of feedback effects between log and lumber markets.

[5] A further analysis of the North Coast timbershed is contained in Perez-Garcia (2005a).

period and also showed the reduced consumption in 1990 and 1992 as a result of a market recession and other factors. One likely reason for this behavior was a higher level of log exports from the timbershed due to the shortage associated with federal and state timber that affected international markets. In 2002, a substantial volume of logs—about 200 million board feet log scale—used in lumber manufacturing left the area, a trend that has increased over time since the early 1980s.

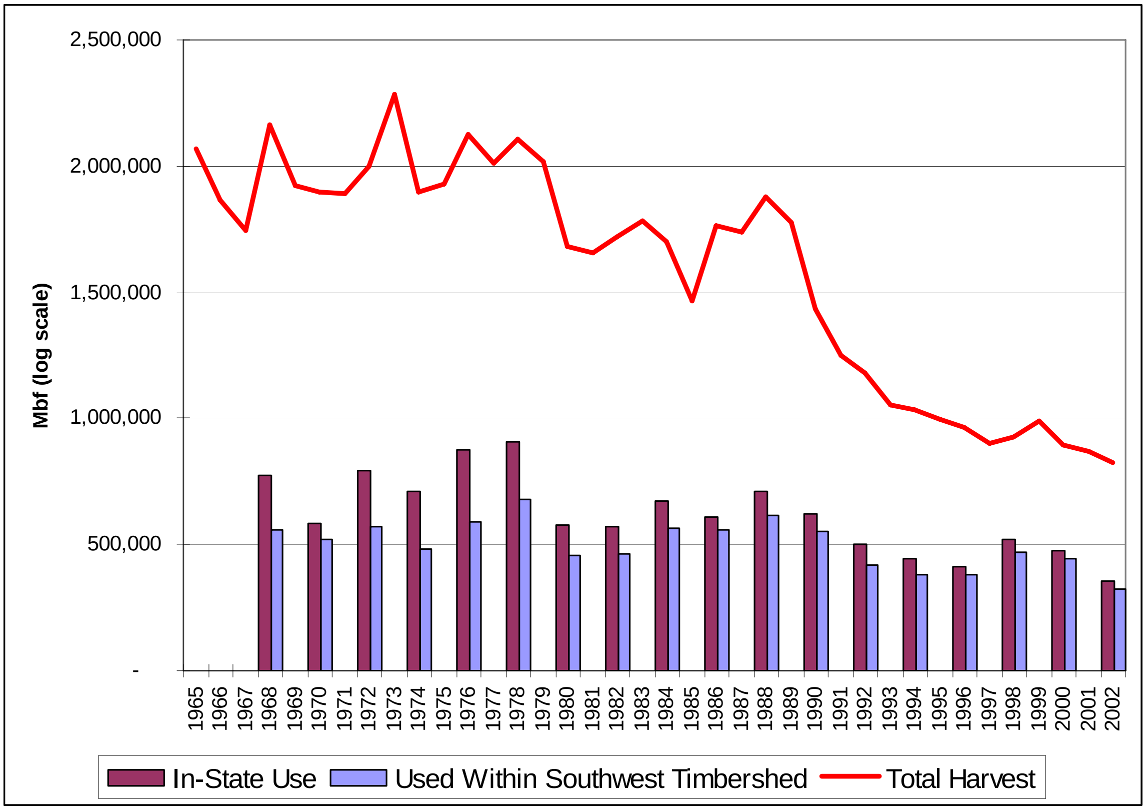

Figure 17. Southwest harvest levels (line), consumption by Washington sawmills (left bar) and consumption by Southwest sawmills (right bar).

Source: WA DNR Mill Surveys (various years) and Timber Harvest Reports (various years).

The Southwest timbershed, similar to the North Coast region, saw a large decline in timber harvest levels, which accelerated particularly since 1990 when habitat conservation restraints were put into place and affected both the public and private timber harvest levels (Figure 17). Unlike the North Coast region, however, the data suggested a declining trend in use of logs by the sawmilling sector since 1988. The timbershed is the region in Washington that has the highest concentration of sawmilling capacity, even with its reported historical low in 2002. Market factors evident in the other regions are also evident in this timbershed, including the demand shocks of the 1970s and early 80s. The data also indicates a reduction in the use of timber by mills outside of the timbershed over the study period.

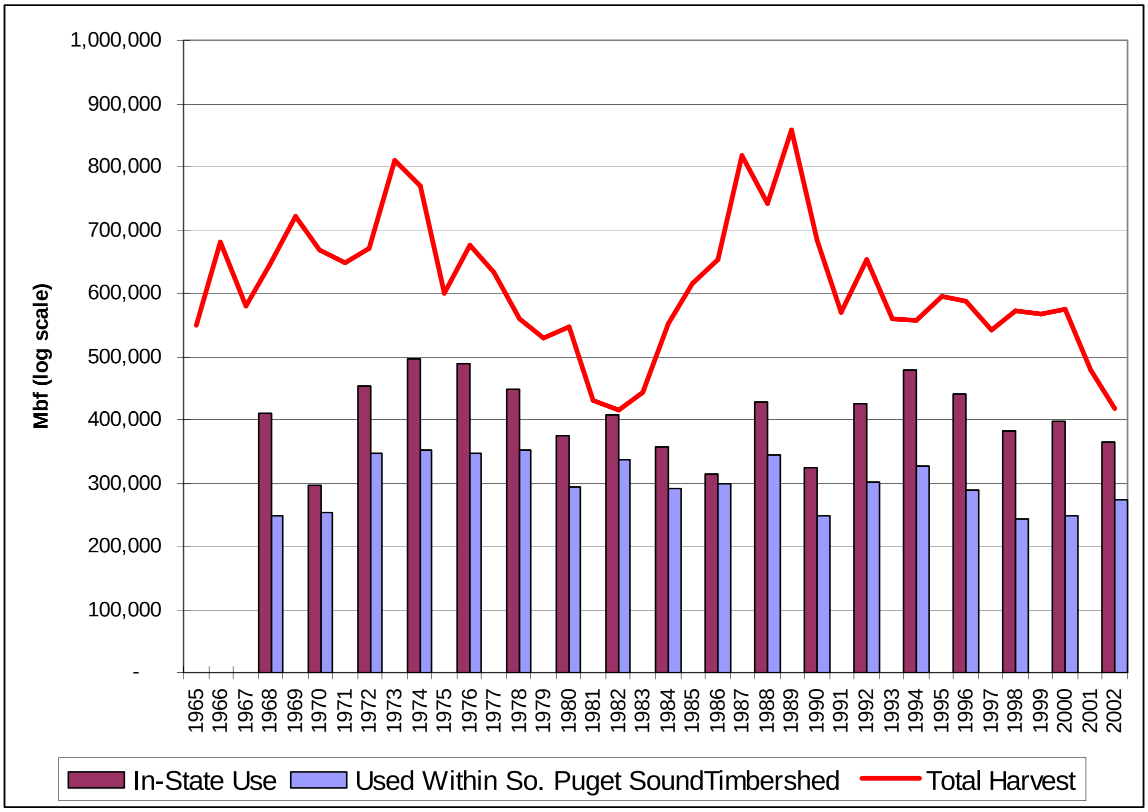

Figure 18. South Puget Sound harvest levels (line), consumption by Washington sawmills (left bar) and consumption by South Puget Sound sawmills (right bar).

Source: WA DNR Mill Surveys (various years) and Timber Harvest Reports (various years).

The South Puget Sound region has had much variation in the amount of logs consumed for lumber manufacture since the 1970s (Figure 18). The variation of about 400,000 thousand board feet (log scale) between 1982 and 1989 is substantial and similar to the variation in other timbersheds. Often the reason cited for this decline and then rebound in harvest level is the collapse of product prices and public timber sold but unmarketable due to economic conditions. Data for this timbershed indicated a downward trend in lumber manufacturing since its peak in 1988, and lumber manufacturing use of logs has leveled off since 1998.

Data for the North Puget Sound timbershed suggested a continued downward trend in timber harvest levels and the greater use of these logs, as a percentage of total harvest levels, in the sawmilling sector (Figure 19). There also appeared to be an increase in the volume of logs that were used by Washington mills outside of the timbershed as indicated in the 2002 survey.

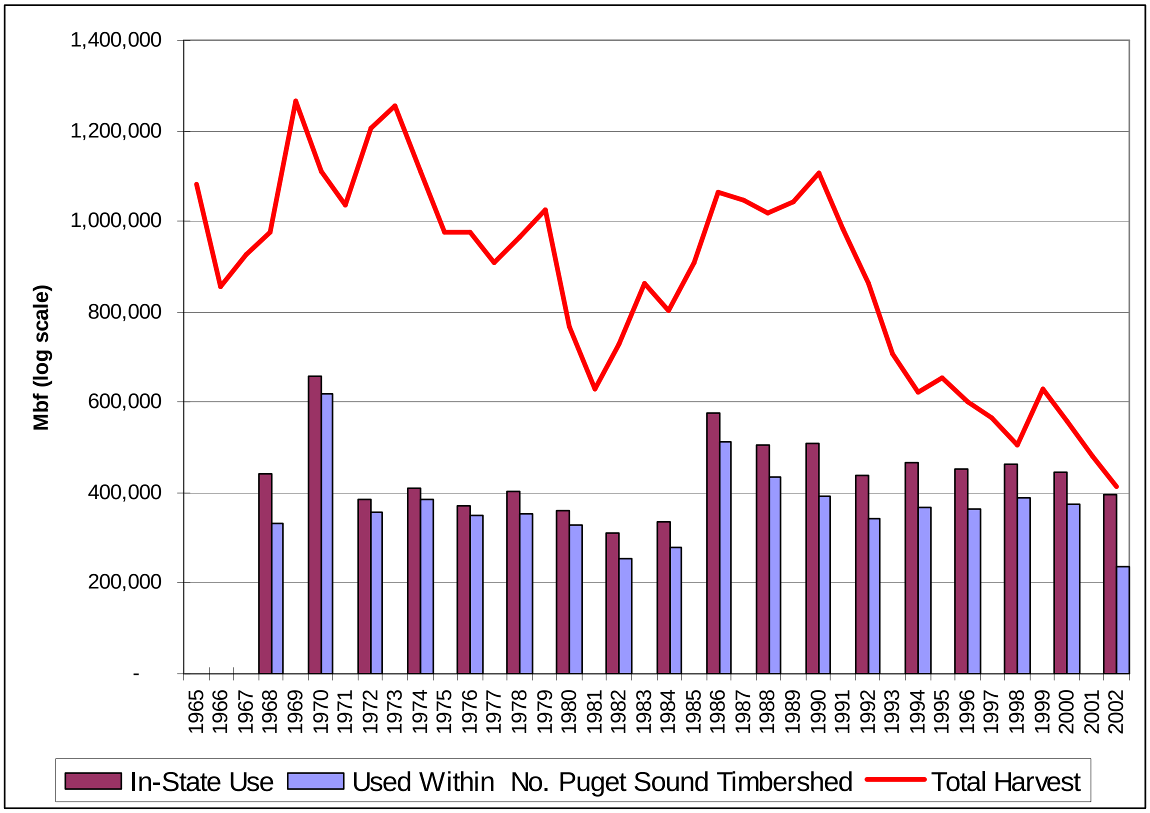

Figure 19. North Puget Sound harvest levels (line), consumption by Washington sawmills (left bar) and consumption by North Puget Sound sawmills (right bar).

Source: WA DNR Mill Surveys (various years) and Timber Harvest Reports (various years).

The eastern Washington timbersheds also displayed some interesting trends and relationships between the harvest levels and log use by sawmills. The data for the Inland timbershed presented in Figure 20 suggested a high correlation between timber harvests and logs used by the sawmilling sector prior to 1992. Afterwards, log volumes used by this sector dropped more dramatically than the timber harvest levels did. Demand for saw logs by sawmills increased slightly from 1996 until 2000, even though the harvest levels continued to trend downwards. Another departure from other western timbersheds was that saw logs were imported from other Washington timbersheds to feed the recovery of the sector during the 1980s. After 1990, the timbershed became a net exporter of timber harvests once again. Recent work on the sector can be found in Cohn and Blatner (2004) and Keegan et al. (2004).

Log use and timber harvest data for the Central timbershed in eastern Washington also showed a correlation between the two data series (Figure 21). Logs were imported by mills in the Central timbershed up until 1992. More recently the mills in the timbershed have been consuming approximately the same volume of timber harvests that go into the sawmilling sector.

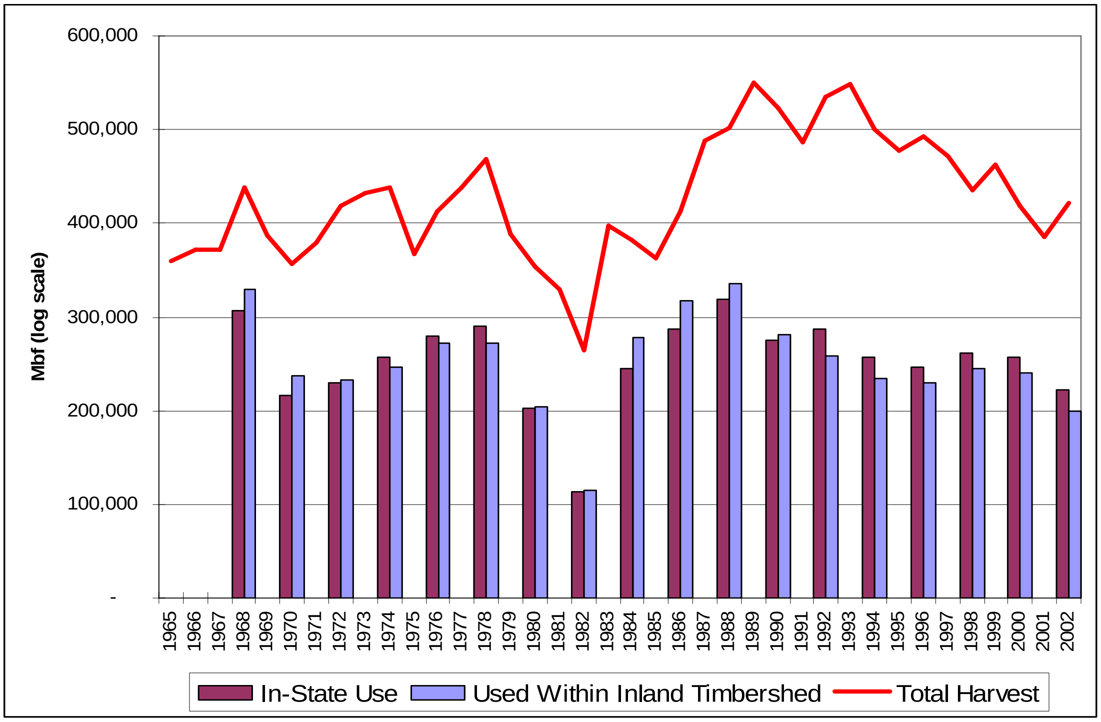

Figure 20. Inland harvest levels (line), consumption by Washington sawmills (left bar) and consumption by Inland sawmills (right bar).

Source: WA DNR Mill Surveys (various years) and Timber Harvest Reports (various years)

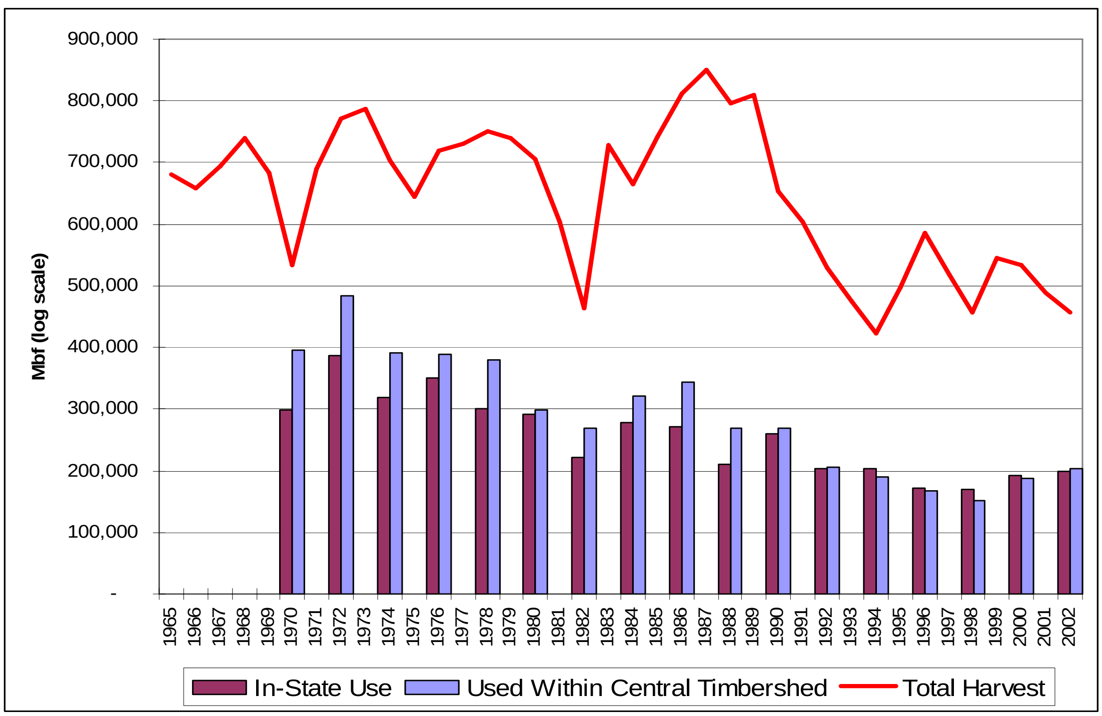

Figure 21. Central harvest levels (line), consumption by Washington sawmills (left bar) and consumption by Central sawmills (right bar).

Source: WA DNR Mill Surveys (various years) and Timber Harvest Reports (various years)

There continues to be substantial amounts of saw logs that move across timbershed boundaries, as measured by the difference in the heights of the bars in the previous figures. This harvest volume was used by sawmills in other timbersheds. There have also been substantial changes in direction of these flows over time. For example, flow of logs northward declined substantially since 1968. Figure 22 illustrates the current major directions of harvested timber with each timbershed that were consumed by sawmills outside of the timbershed, but within Washington state. There has been an increase in logs imported from B.C., and logs going to Oregon continue.

The major export flow from the North Coast rose from 35,000 mbf to 74,000 mbf and is consumed by mills in North Puget Sound. The South Coast timbershed transported nearly 100,000 mbf in 2002 to the Puget Sound regions. The Puget Sound regions had two major export flows of timber harvested with its sub-region. One flow moved northward to the northern mills (174,000 mbf to 58,000 mbf), and the second flow went eastward (47,000 mbf to 58,000 mbf). The flow of timber harvested northward has declined substantially over time. Overall, about 600,000 mbf of timber was transported across timbershed boundaries to be used by sawmills in other timbersheds. Logs coming from Canada and the continued flow of logs going to Oregon are also depicted in the figure, as well as a flow of logs that come in from the eastern timbersheds.

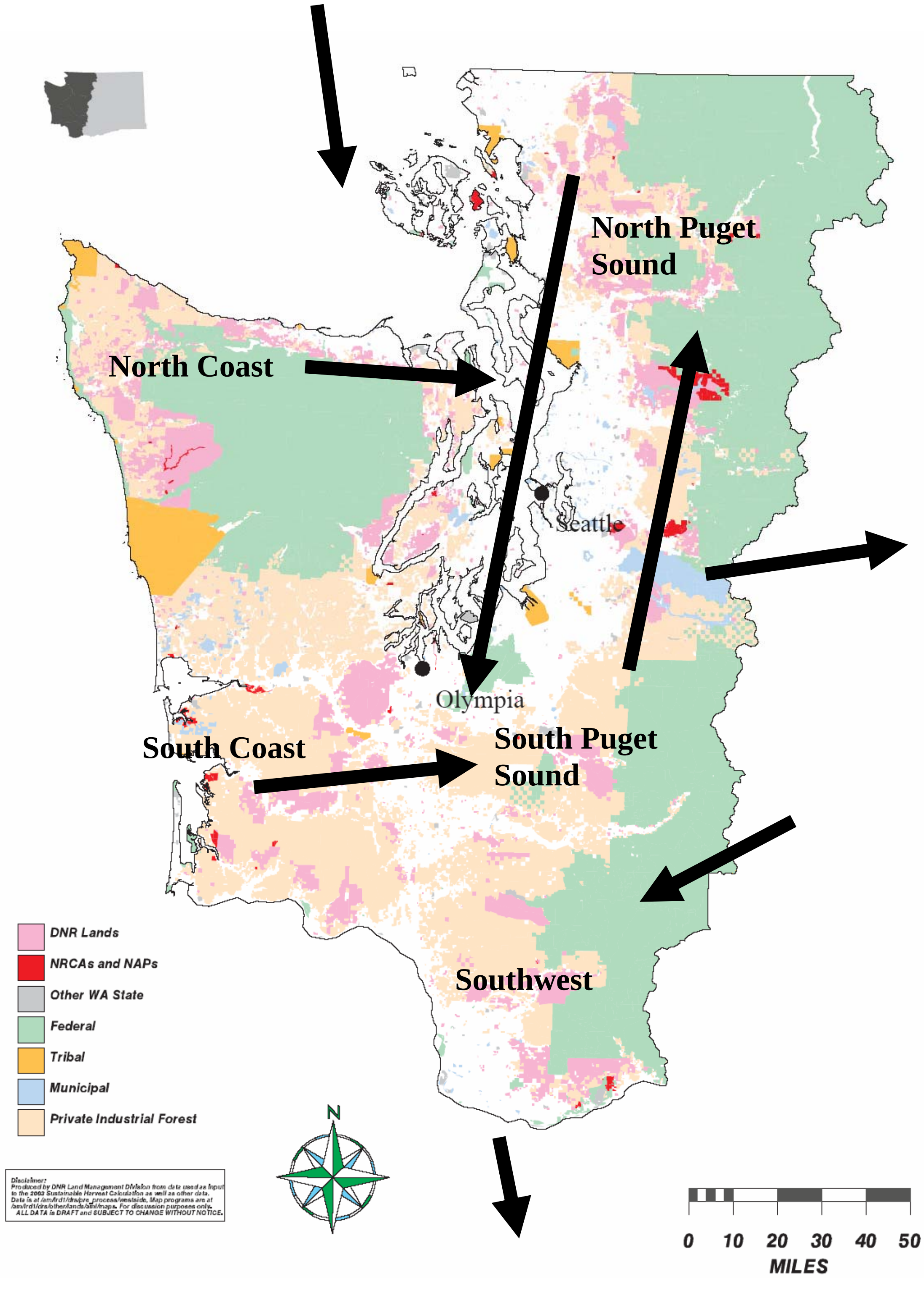

Figure 22. A map of western Washington with forest land ownerships timbershed locations and major flows of timber leaving the area and used by lumber manufacturers in other regions.

Map Source: WA DNR Sustainable Harvest EIS. (2004)

REGIONAL PROJECTIONS OF TIMBER SUPPLY

Our analysis next considered the regional projections of timber supply to assess the possibility to expand sawmilling capacity. To do so we developed a simplified projection model of timber inventory to help us identify periods in the future of excess timber supply. Regional Projections is a model developed to enable us to apply harvest projections along with growth and inventory data to make inferences about a timbershed's capability to meet the harvest requirements. The model is tailored to fit the parameters of the yield and inventory data provided in Anderson et al. (1994).[6] The model is a simple spreadsheet application built in Excel. A description of the model is provided in Appendix 1.

The process of making a harvest projection involved several steps. A first step was to assume a harvest level projection. This harvest level was then used to determine how timber inventory changes over time by imposing restrictions on how and where volume can be harvested to meet the harvest requirements. Validity of the harvest projection was accomplished using several metrics. Harvest volume per acre must be similar to historical harvest volume per acre. Rotation age must also be similar to historical data. Using these two metrics, we adjusted the harvest levels so that they produced harvest volume per acre and rotation age that were justifiable. The modeling process is an iterative process requiring hands-on application and knowledge of present and historical inventory and harvesting conditions.

The data used to provide the projection's validity were taken from the Department of Revenue.[7] We developed volume per acre averages for each timbershed over time using reported sales data and the associated timber cruise information. The volume per acre in mbf is reported in Table 2. A further analysis of these data will be forthcoming. The dataset was useful to study trends in volume per acre, but also useful to analyze the changes in species per acre and log sorts that are harvested.[8]

Table 2. Average volume (mbf) per acre for timbersheds based on reported timber cruise data

	North Coast	South Coast	North Puget Sound	South Puget Sound	Southwest
1997	45.73	44.89	37.72	47.16	55.34
1998	48.95	40.78	38.92	31.88	58.35
1999	37.06	53.86	44.95	39.92	39.71
2000	36.73	54.65	43.34	41.61	38.23
2001	34.96	44.67	36.89	32.30	67.45
2002	44.18	44.48	41.83	28.71	39.04
2003	37.37	40.74	36.55	28.01	44.18
2004	39.04	38.04	41.26	32.03	28.05

Source: Washington Department of Revenue, Timber Tax Division

We present next the results of the timber harvest projection analysis. For each timbershed we present two graphs. The first graph illustrates the harvest projection selected that met the requirements of valid age of rotation and volume per acre criterion. The harvest projection start year is 1990, in accordance to the data available in Anderson et al. (1994). These projections should be considered preliminary at best as further analysis with the spreadsheet model is needed, with perhaps a greater number of metrics to measure the validity of the results.

[6] During the course of working with the information provided in Anderson et al. (1994) we found an apparent editorial error in data presented in several tables that appear to make the data incorrect. Due to the lack of alternative data, we have assumed that the data are correct, but will investigate further the validity of these data with more recent statistics on inventory and yield for the timbershed in question. We found that the reported volumes and acres for western hemlock/Sitka spruce are the same as those reported for other softwoods and hardwoods for the South Puget Sound timbershed, i.e. these three species types had the same entries for volumes and acres in their respective tables.

[7] We would like to thank Lawrence Reeves for making this data available to us for use in this study.

[8] For an application of the type of multipliers that can be developed from this data set see Perez-Garcia (2005a).

For each region, harvested acres for 1990 and 1995 were determined by the model based on historical harvest levels that were available (up to 2002 at the county level). To meet the harvest requirements for these two periods, we constrained the model to harvest acres within a specified range of age classes (between 35 and 55 years). This was done to mimic the effect harvest restrictions have had on older-aged timber lands. Even flow projections of timber over the period 1990 to 2010 were developed, unless timber harvest levels could be increased substantially by harvesting the volume available on acres at harvest age.

The second graph provides the distribution of volume per acre by species. Acres by major species group are based on the breakout provided in Anderson et al. (1994). Harvest projections are extended to 2100 so as to encompass two fifty five-year rotation periods. Appendix 1 provides additional graphs useful in understanding the projection results from the model.

Using these two metrics and after several iterations of alternative harvest projections, we choose a level of 320,000 mbf for the North Coast timbershed (Figure 23). This harvest level led to an average of 8,750 acres harvested (Figure 24), with rotation ages of 45 and 50 years. The even nature of the harvest projection is the result of retiring older age class acres from timber production. Volumes from younger age plantings accounted for the 320,000 mbf harvest level projection. That is to say that harvest requirements during the later periods were met with acres having timber 45 to 50 years old indicating a potential to increase the harvest volume by including older acres or shortening the rotation age. Future analysis using the spreadsheet model can look at alternative harvest scenarios, but it appears that, under today's assumptions regarding forest land use in this timbershed, there was the potential to increase harvest levels after 2030.

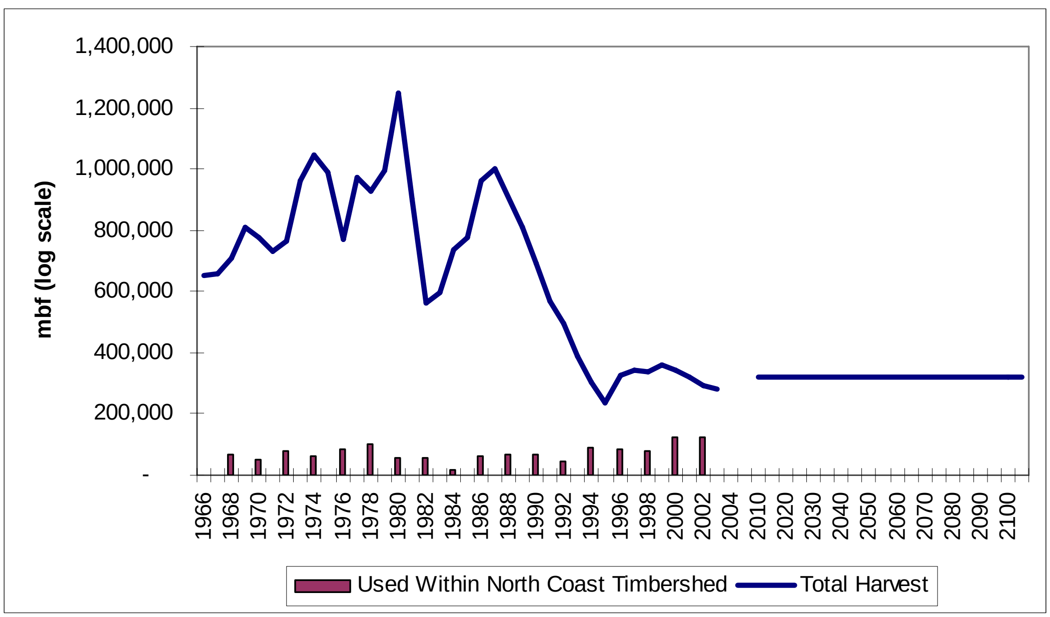

Figure 23. North Coast historical timber harvest level and projection with historical sawmill log consumption

The distribution of harvest by species is provided in Figure 24. The majority of the harvest is in the western hemlock type with an average of 53% for the projection period. Douglas fir is the second major species type with an average of 26%, followed by other hardwoods, primarily red alder. The amount of red alder acres varied over the projection period leading to a deviation in the volume per acre of this species. Low volumes per acre appeared in 2015 and 2020, and again in 2035. Other hardwoods, primarily red alder, on average comprised 18% of the per acre volume. The average volume per acre for the projection period is just under 40 mbf.

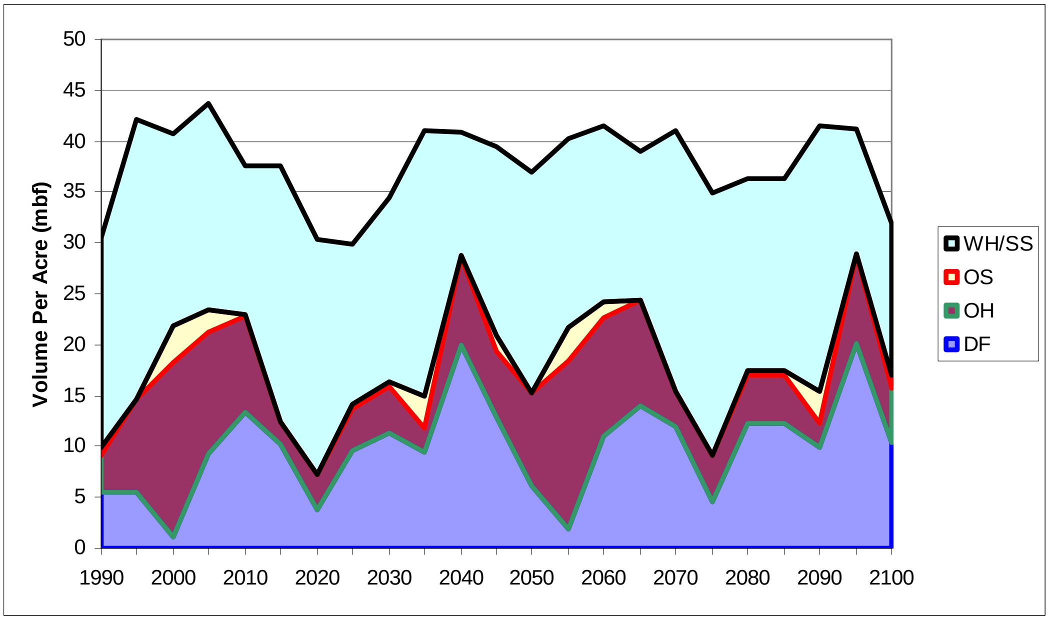

Figure 24. North Coast volume per acre distributed by species over the projection period 1990 – 2100. WH/SS is western hemlock and Sitka spruce; OS is other softwoods; OH is other hardwoods; DF is Douglas fir.

The harvest projection for the South Coast timbershed proved to be more optimistic (Figure 25). After several iterations of maintaining a rotation age and harvest volume within historical parameters, the projection indicated an increasing trend until 2040. Harvest levels start at 700,000 mbf and grow to 900,000 mbf. They are maintained at 900,000 mbf until they drop to 850,000 mbf in 2070. Further work with the spreadsheet model is likely to improve on this projection. The projected harvest level increase is an indication of the age class distribution prevalent in the inventory data. It suggested many young acres that will reach rotation age in the coming decades.

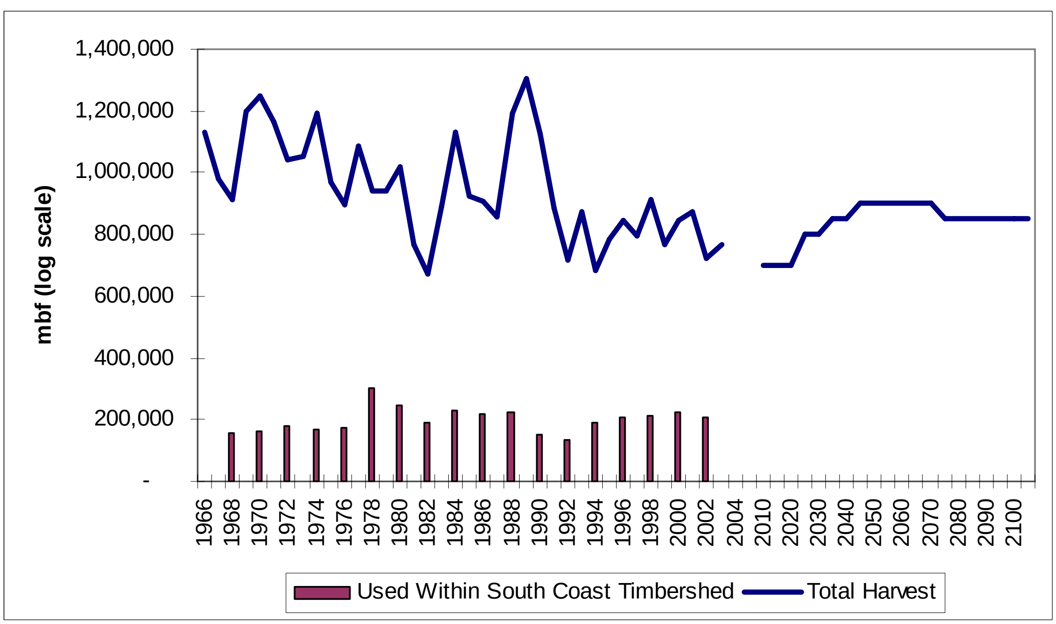

Figure 25. South Coast historical timber harvest level and projection with historical sawmill log

consumption

The average number of acres harvested annually over the projection period was 21,300 with rotation ages varying between 45 and 50 years. The proportion of 50 year old acres harvested varied over the projection period and reached a low point of 50% in 2070.

Figure 26 presents the volume per acre species distribution. On average, 47% of the volume per acre is Douglas fir, followed by western hemlock (32%) and other hardwoods (17%). There are periods where the other hardwood volumes represent a small percent of the volume per acre; the period from 2020 to 2035 and again in 2075 to 2085. The volume per acre during the historical periods—1990 and 1995—led to low average volumes. This is due to the constraints of the age of harvested acres imposed on the model by us. By 2005, volumes per acre recovered to historical levels and averaged around 40 mbf. Further work with the spreadsheet model will likely improve the projected harvest levels.

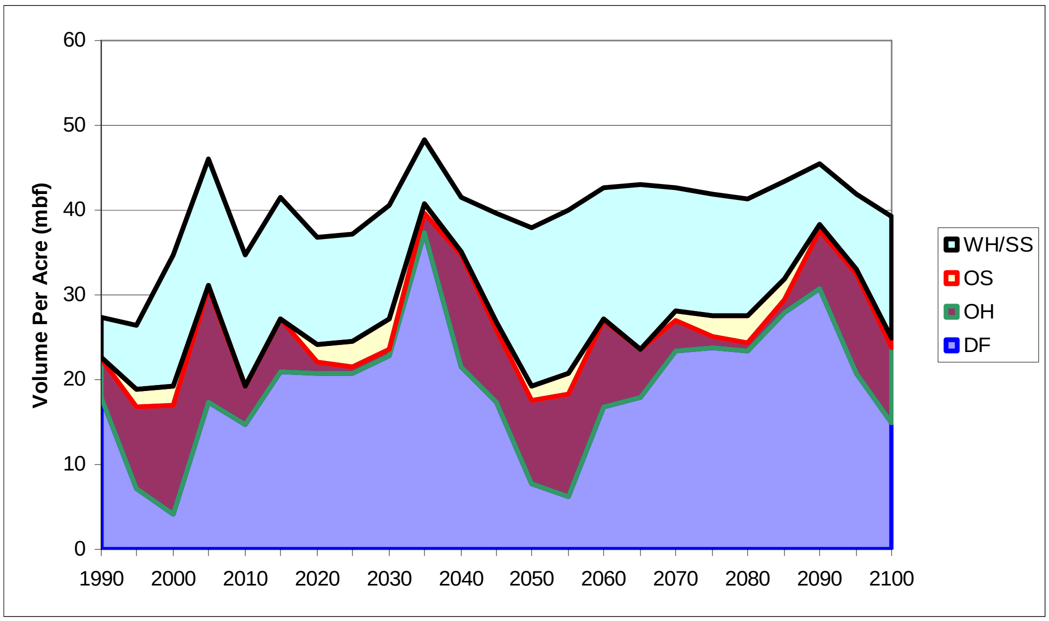

Figure 26. South Coast volume per acre distributed by species over the projection period 1990 – 2100. WH/SS is western hemlock and Sitka spruce; OS is other softwoods; OH is other hardwoods; DF is Douglas fir.

The harvest projection level for the Southwest Region was 850,000 mbf and was maintained at that level for the projection period (Figure 27). As in the case of the North Coast timbershed, this region's harvest was met by young age class acres. Opportunities to increase the harvest level existed by cutting timber in older age classes or by shortening the rotation age. On average 21,600 acres are harvested annually during the projection period, with a rotation age of 50 years. The average volume per acre was around 40 mbf (Figure 28). On average 65% of the timber was Douglas fir. The volume per acre varied substantially over the projection period, however along with other hardwoods, principally red alder. The other hardwood type comprised 23% of the per acre volume on average, followed by western hemlock (10%).

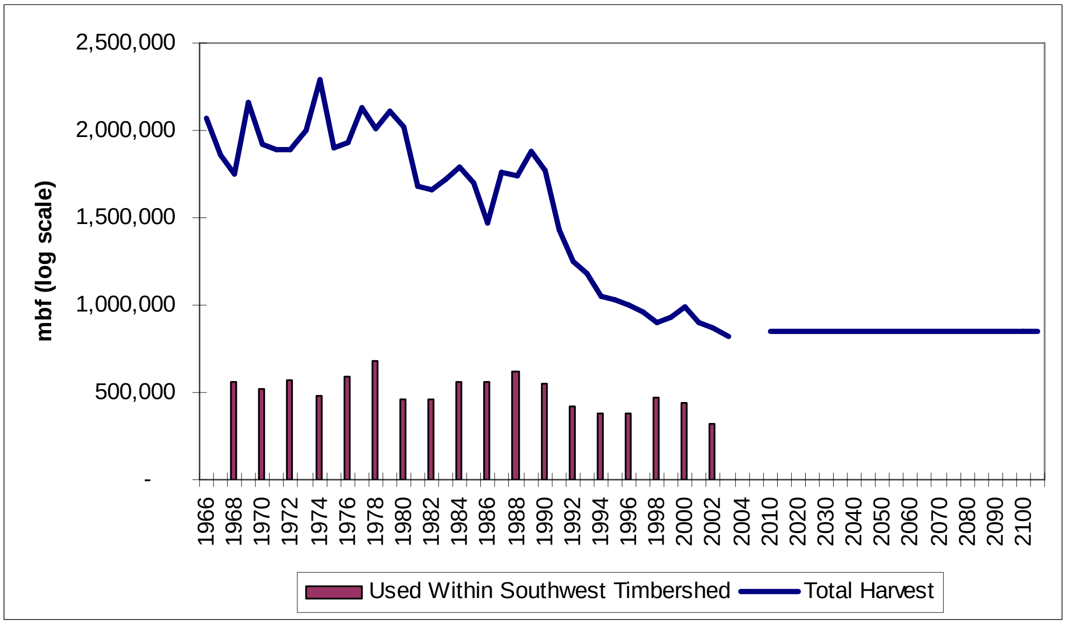

Figure 27. Southwest historical timber harvest level and projection with historical sawmill log consumption

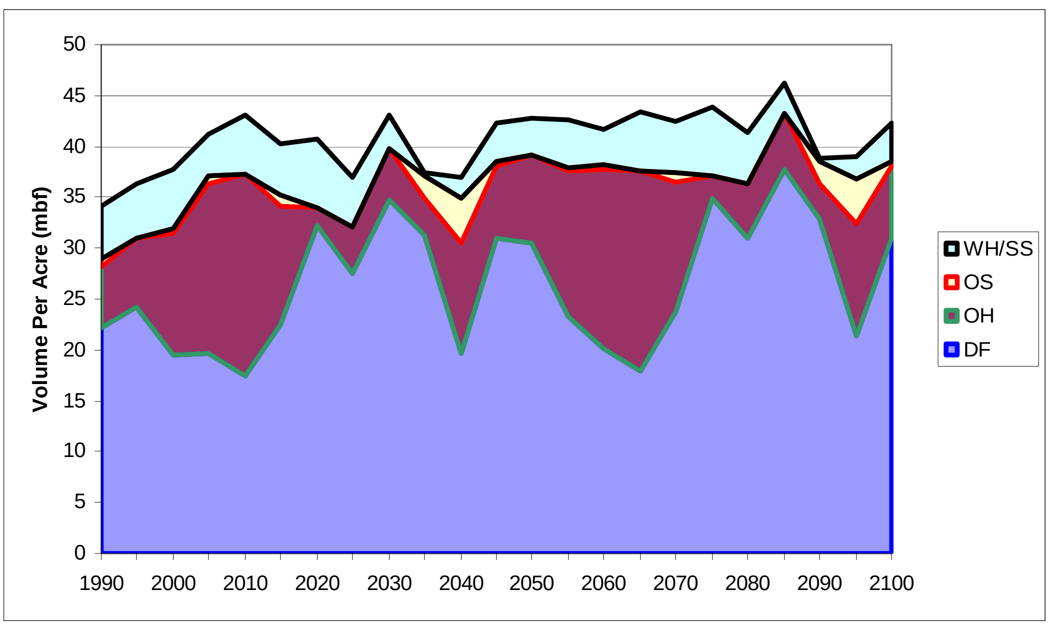

Figure 28. Southwest volume per acre distributed by species over the projection period 1990 – 2100. WH/SS is western hemlock and Sitka spruce; OS is other softwoods; OH is other hardwoods; DF is Douglas fir.

The harvest levels for the South Puget Sound timbershed was 425,000 mbf (Figure 29). An annual average of 12,400 acres is harvested with volume per acre fluctuating between 30 and 43 mbf (Figure 30). The rotation age shifted throughout the projection period. In the later years, a rotation age of 45 years was common. This was an indication of some tightness in the inventory in years 2060 onward as the model searched for inventory in younger age classes to meet the harvest requirement. The major species is Douglas fir comprising 71% of the volume on average. It fluctuated anywhere from 42% to 90% per acre. Other species averaged about 10%, but these distributions must be taken with caution as the reported acres and volume on these acres for other softwoods, other hardwoods and western hemlock/Sitka spruce were identical in the Anderson et al. publication and believed to be an editorial error.

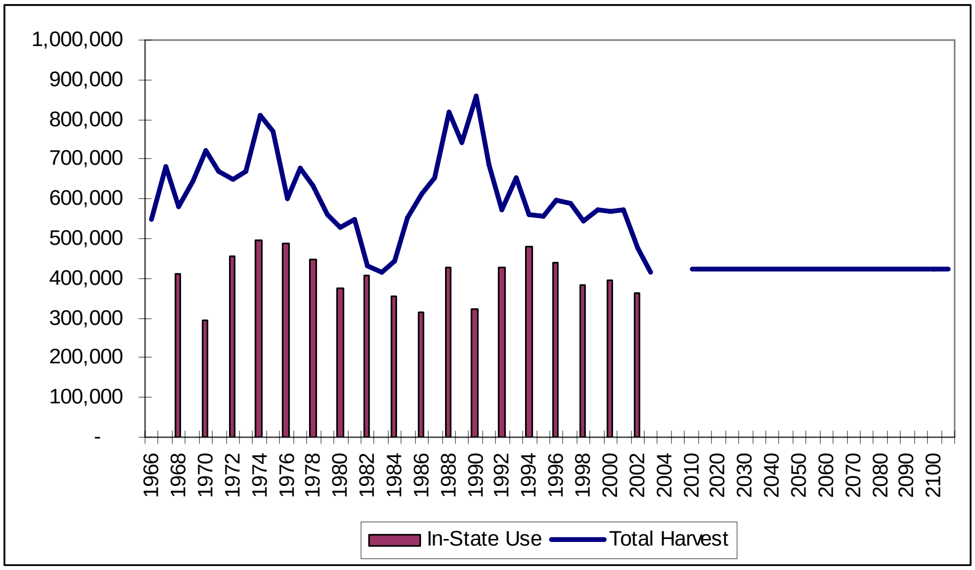

Figure 29. South Puget Sound historical timber harvest level and projection with historical sawmill log consumption

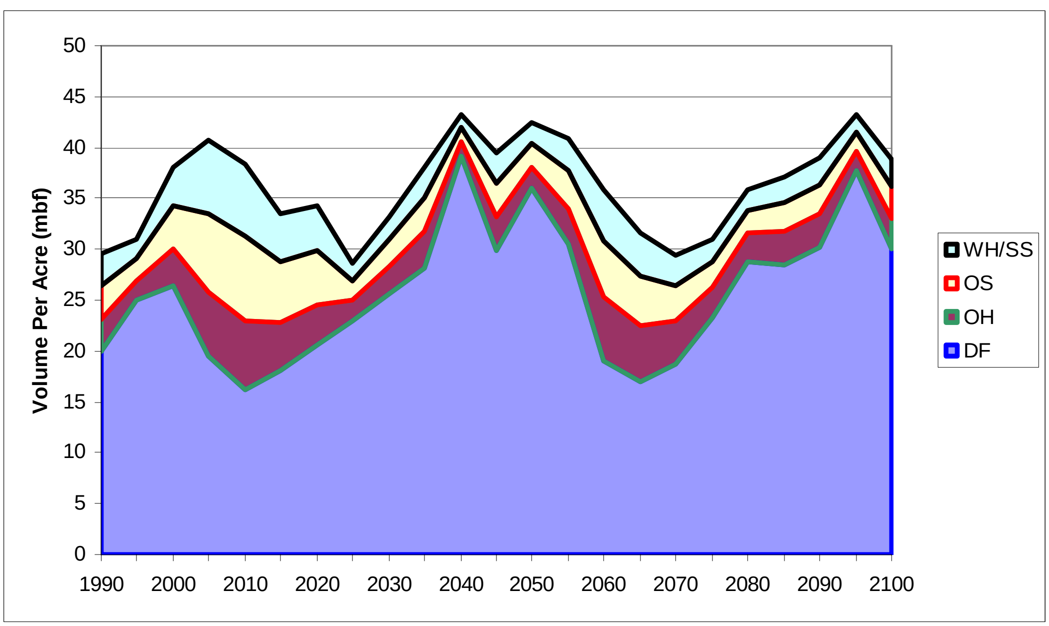

Figure 30. South Puget Sound volume per acre distributed by species over the projection period 1990 – 2100. WH/SS is western hemlock and Sitka spruce; OS is other softwoods; OH is other hardwoods; DF is Douglas fir.

The harvest level projection for the North Puget Sound timbershed was calculated to be 450,000 mbf. It was maintained at this level throughout the study period (Figure 31). An average of 13,400 acres was harvested with a reported 35 mbf per acre (Figure 32). The harvest age was mostly 50 years, but acres of 45 years were also included in the harvest projections. The North Puget Sound timbershed has a substantial volume in hardwoods. About 34% of the harvest is projected to be hardwoods, the same percentage that is projected for Douglas fir. Western hemlock and other softwoods comprise the remaining third of the per acre volume averages.

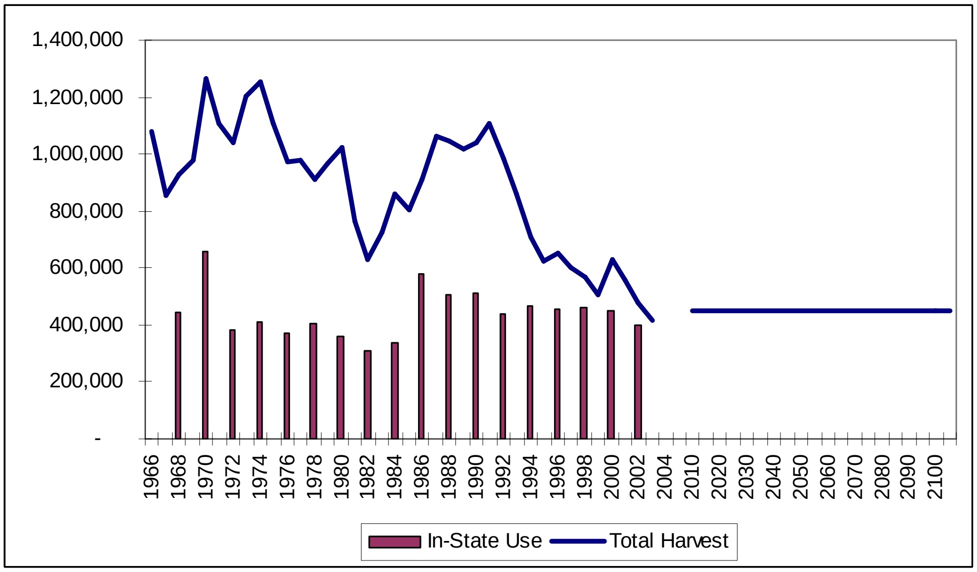

Figure 31. North Puget Sound historical timber harvest level and projection with historical sawmill log consumption

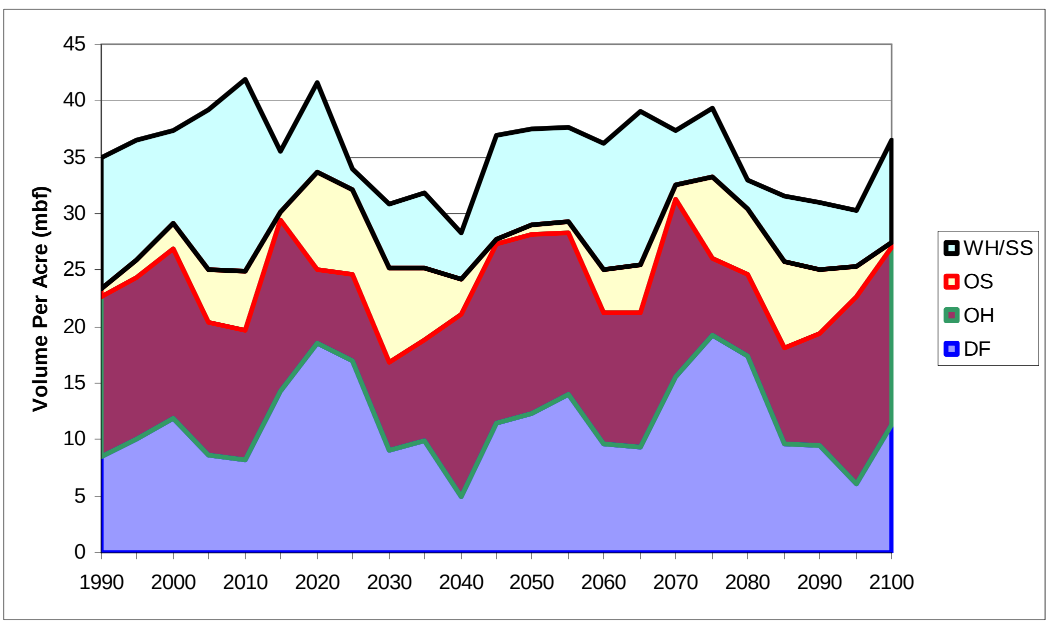

Figure 32. North Puget Sound volume per acre distributed by species over the projection period 1990 – 2100. WH/SS is western hemlock and Sitka spruce; OS is other softwoods; OH is other hardwoods; DF is Douglas fir.

DISCUSSION

We provided an assessment of the lumber manufacturing sector as part of a broader research agenda initiated by the USDA Forest Service Pacific Northwest Research Station to analyze the timber supply situation in Washington, the technological changes in milling and its effect on timber demand, and policy alternatives regarding the management for social, economic and environmental objectives. An earlier preliminary assessment identified the need to examine changes that have occurred in the lumber milling sector. Capacity changes, including mill consolidation and technological change were identified as an important point of study. The infrastructural needs in Washington's sawmilling sector included examining the existing mill capacity and its utilization.

The study examined operating rates by timbersheds over the period 1968 to 2002. We compared log use by sawmills by timbersheds with the log harvest level for each timbershed. We also projected timber supply, and examined the potential for timber supply to accommodate an expansion of sawmilling capacity using a fairly simplistic approach. To do so, we developed a model that projected harvest levels in western Washington timbersheds.

Log use by sawmills has increased in importance as timber harvest levels have been substantially reduced and the available log size and quality has narrowed. The sawmilling sector is currently the major consumer of timber in all timbersheds with exception of two timbersheds. In two timbersheds, the export sector was still prominent. The timber harvest projection suggested that lumber manufacturing will form the basis of demand for Washington timber in the foreseeable future.

Operating rates that were averaged across sawmills by timbershed demonstrated rational behavior throughout the period of study when viewed against a broad measure of the value of its product, the lumber composite price. Two exceptions were noted in the study. During the decade of the 80s, following the recovery from early recessions, the average operating rate appeared above the composite lumber price, relative to other periods in the sampled timeframe. This was explained by an adjustment in operating capacity. Removing capacity from productive use has the effect of reducing the denominator in our rate calculation and increasing the average rate. We supported this notion that capacity withdrawal led to the observed increase in the average rate by measuring net changes in lumber production. We found that in 1982, lumber production fell by more than 1 billion board feet (lumber tally). The same pattern of operating rates above the composite lumber price appeared again in 2000. A recovery in prices in 2004 has lessened the pressure on low profitability mills to maintain operations. In some timbersheds, the average operating rates have been at historical highs since the early 90s to the present. Further analysis of mills in these counties is warranted since continued high operating rates may signal the need to expand capacity.

Historically, the collapse of high product prices led to a significant readjustment in sawmilling capacity, more so than possibly the reduction in timber harvests during the early 1990s themselves. While high operating rates may be a sign that capacity expansion should be considered, it also becomes necessary to understand the potential impact of a sudden and unexpected drop in demand as well as increased supplies of products from other regions that compete with Washington sawmills. These two factors led to the observed price behavior in the 1980s. An unexpected drop in product prices with an increase in supply from B.C. mountain pine beetle salvaged lumber may lead to a period of continued low prices. However, many of the smaller-sized mills have already shut down in Washington leading to an interesting point as to whether Washington has excess capacity that can easily shutdown. Or, on the other hand, will continued strong demand from the U.S. housing sector maintain or increase price levels and signal the potential expansion of capacity?

The study also found that timber harvest levels can be maintained at their current levels using existing second generation forests. This finding needs to be investigated further. It assumed that land use patterns and regulatory and environmental conditions that exist today will be maintained into the future. Another way of interpreting this result is that land-use changes and regulations that restrict harvest levels will constrain timber harvest levels rather than biological supply potential. The rotation age that was associated with the harvest level projection reported in the study was usually around 50 years. If we lower this age we would likely see higher volumes coming off the inventory. Also, volumes in older age classes continued to expand reflecting the set asides of older growth timber from harvesting. In all timbersheds, except for the Southwest region, the harvest projection was maintained constant throughout the projection period to 2100. In the Southwest region, we were able to increase the harvest levels projection substantially.

We also presented a breakout of harvests by species. This work is perhaps the most tentative part of the study since it assumes that specie per acre distributions would be maintained from one rotation to the other. It nevertheless projected an interesting, even if tentative, outlook of harvest levels by species. Averages of the harvest distribution across the projection period are consistent with per acre distributions reported in timber cruise data over the past 8 years. Of considerable interest is the potential for hardwood production to decline throughout several periods within the timeframe of the projections. The projections of harvest levels by species require further study to fully understand the potential importance of these projections with respect to the hardwood milling sector.

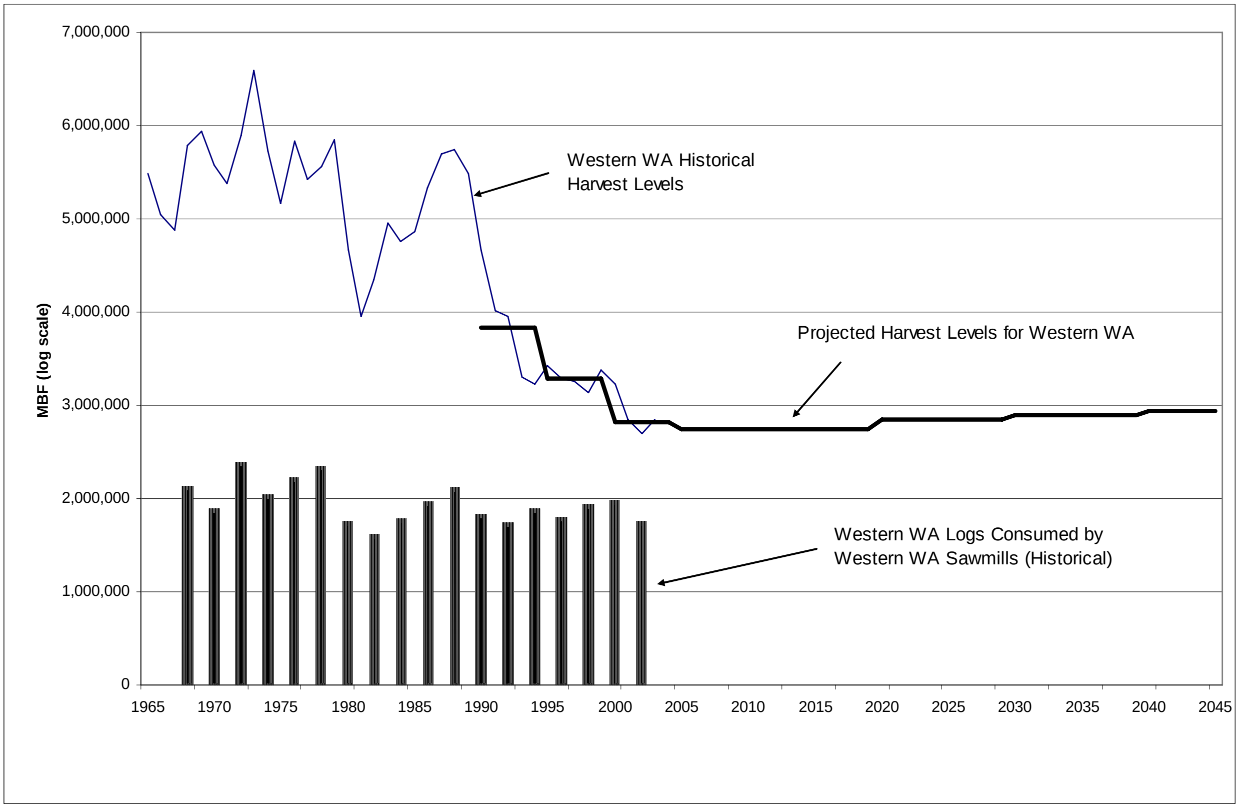

Figure 33. Historical and projected harvest levels for western Washington and historical log consumption levels by western Washington sawmills.

Figure 33 summarizes the western Washington harvest projection and includes log consumption levels by western Washington sawmills. The difference in volumes between harvest level and the volume consumed by sawmills is primarily log exports to international markets, Oregon and elsewhere.

CONCLUSIONS AND FUTURE WORK

The sawmilling sector in Washington has experienced significant changes over the past three decades. Despite significant reductions in harvest levels, the sector has increased production. The increase in output is the result of consolidation of operating capacity into newer, larger mills and a changing resource.

Utilization rates across the state have been high relative to the historic lows observed during the collapse of prices in 1979. A continuation of these high rates of operation may signal new capacity needs.

Harvest projections indicated that we can maintain current harvest levels, if not increase them, into the future, from a biological perspective. These projections lead us to expect the sawmilling sector to continue its presence at current levels with opportunities to expand.

These two factors--high capacity utilization rates and growing biological supply of timber--lead us to conclude that sawmilling capacity can expand in Washington. Changes in land-use and restricting access to this biological supply may become important factors limiting the growth of the sawmilling sector.

There are many opportunities for future work. The timber supply projections are considered preliminary and depend on assumptions that land use will continue its present use, and species and volume distributions today will continue into the future. Sensitivity analyses using alternative land-use patterns for the future and species composition are warranted. Further work is needed to assess changes in land use patterns and regulatory and environmental constraints that can impact future timber harvests from Washington forested land. Future work is also needed to assess capacity utilization changes and the historical competitiveness of the sector.

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APPENDIX 1

Regional Projections is a model developed to enable the user to apply harvest projections along with growth and inventory data to make inferences about a timbershed's capability to meet the harvest requirements. The model has been tailored to fit the parameters of the yield and inventory data provided in Anderson et al. (1994), which is a technical supplement to the CINTRAFOR publication *Future Prospects For Western Washington's Timber Supply* (Adams et al. 1994). The model is a simple spreadsheet application built in Excel.

The Workbook:

In Excel, spreadsheets open to what is called a workbook which is made up of a number of worksheets. The Regional Projections workbook contains eight worksheets. The main worksheet in the model is titled 'Harvest Projections'. It inputs data from other worksheets and performs calculations that estimate growth and harvest over a set period of time. There are two worksheets that are used for data input, 'Input Yield Table' and 'Input Acre-Volume-Harvest'. 'Input Yield Table' is a worksheet that includes all the yield tables provided in Special Paper 12A. These are used in the growth calculation performed in 'Harvest Projections'. 'Input Acre-Volume' contains both acre and volume data from Special Paper 12A and also historic harvest records for all landowners provided by the WA Department of Natural Resources (DNR).

The other worksheets are output sheets used for the analysis of the models results. 'Analysis' is a worksheet which provides diagnostic tools that visually depict the models projections. 'VolumeSpecieSite', 'AcreSpecieSite', 'HarvestAcreSPSite', and 'HarvestVolumeSPSite' are all worksheets where output data is pasted for easy use in analysis.

The Macros:

The model is run with a series of nine macros. Six of the nine macros are functions which copy and paste output data, of which five are for the creation of output tables and worksheets mentioned above. The remaining copy paste function performs a key role in the 'Harvest Projections' worksheet by moving the model from one period to the next. The timeline for the model is determined by its own macro. The Solver function in Excel is used to determine where harvest takes place. In each period of the model Solver is run by its own macro. Finally, there is an organizational macro which determines the order of operations.

The Harvest Level Predictions and the use of Solver:

The calculations of the Regional Projections model occur in the 'Harvest Projections' worksheet. This worksheet assembles a data table for a period from the data input worksheets and uses the Excel add-in Solver to determine how much volume in an age class should be harvested in that period subject to constraints. This data is then used in growth calculations that determine the data table in the next period that will be used by Solver. In this manner the model calculates the growth and harvest of the forest region iteratively by using a simple linear program.

Typically a linear program would not solve a problem like this iteratively, but rather all periods at once. The iterative approach was necessary because the growth formulas demand the use of division, which prevents Solver from working linearly. Consequently the model does not produce a global optima or global solution where all periods are simultaneously projected, but it is believed that the results are close approximations.

Solver works by establishing values for decision variables that either maximize or minimize an objective function subject to desired constraints. Decision variables in Excel can also be referred to as "changing cells" because they are cells whose values are determined by solver. These cells can be observed in the model as the bright yellow column labeled "Harvest". This column is constrained in two ways. First, harvested volume in an age class is not to exceed the actual volume present in that age class seen in the column labeled "SW Vol". Second the total harvest volume in all age classes must be equal to the level stipulated for that period. Each period has a harvest level that is found in the 'Input-Acre-Volume-Harvest' worksheet. The years 1990, 1995 and 2000 are levels based on historical data and the levels after that are determined by the user.
The objective function is the orange colored cell in the 'Harvest Projections' worksheet. The objective function in this model is to be maximized. Its value is calculated by the Excel function Sumproduct. The changing cells and

weight columns titled yield, and weight 1 are used in the Sumproduct. These weights are designed to further constrain the model to harvest in the age classes between 40 and 75 years of age. The model is most heavily weighted to harvest in the 45 and 50 year age class, but these weights can be easily manipulated by the user.

Running the Model:

There are three data tables found in the upper portion of the 'Harvest Projections' worksheet. The first is named 'data1990' and is assembled by referencing the data input worksheets previously mentioned. It establishes the initial volume and acre values within each species and site class and is static once established. The table next to 'data1990' is called 'datainput'. This area of the workbook changes in each iteration of the model through the use of a copy paste macro. Solver calculates the harvest for whatever period is present in the 'datainput' table. The third table is titled 'nextperiod'. This table utilizes information from 'datainput' and the harvest volumes dictated by Solver and calculates both growth in volume and change in age class acres in the next period.

In the initial iteration of the model the table 'data1990' is copied and pasted into 'datainput' by a macro. Solver then determines harvest levels and 'nextperiod' calculates the conditions in 1995. At this time the macros concerning output data copy and paste to the respective worksheets. A macro then copies 'nextperiod' and pastes the table as values into 'datainput'. Solver then determines the harvest in 1995. The model continues working in this iterative fashion until the final period determined by the user is reached.

The Growth Calculations:

The data table 'nextperiod' contains the calculations that determine growth in volume and redistribution of age class acres by harvest. There are four calculations, total acres, acres specific to species and site class, growth in volume specific to species and site class, and total volume. The composition of these formulas is detailed below.

Total Acres

This formula determines the total acres found in each age class after harvest. The value it returns is referenced by most of the other formulas. It consists of the two parts found below.

1. If no harvest has occurred in the previous age class in the previous period, then the acreage of the previous age class in the previous period will be used as the total acres in the current period.

   Else, if the total volume in the previous age class/previous period is equal to zero, then the acreage of the previous age class/previous period is used as the total acres in the current period.

   Else, (harvest has occurred in the previous age class/period) the previous age class/period's total volume minus the previous age class/periods harvested volume multiplied by the previous age class/period's total acreage then divided by the previous age class/periods volume. (This determines the acreage in a period adjusted for harvest.)

2. The calculation in 1 above is used for all age classes except the 0-4 age class. It is assumed that the 0-4 age class represents the acres that were harvested. Consequently the summation of all other age classes is subtracted from the total acres of the region to define the total acres in the 0-4 age class.

Acres Specific to Species and Site Class

This calculation assumes that when an age class is harvested the harvest is evenly distributed among the various species/site classes. When calculating an individual species/age class. In the example below the Douglas Fir High Site (DFHS) will be used.

> If there is no harvest in the previous period, then the acreage in the previous age class/period (DFHS) is used.
>
> If the acreage in the previous age class/period is equal to zero, then zero is used as the acreage in the current age class.

> Else (harvest has occurred in the previous age class/period) the acreage in the previous age class/period multiplied by the total acres in the current age class/period and then divided by the total acres of the previous age class/period.
>
> This calculation, like the calculation for total acres, is used for all age classes except 0-4. In calculating the 0-4 age class the formula is the same as in 2 above except the summation and total used are now species/site specific.

Growth in Volume Specific to Species and Site Class

This calculation references the yield tables found in the 'Input Yield Table' worksheet. These tables are used to estimate growth over time. All references to yield and growth below refer to this worksheet. In the example below the Douglas Fir High Site (DFHS) will be used.

> IF no harvest occurred in the previous age class/ period then the previous age class/period DFHS volume is added to the subtraction of the current yield from the previous yield (growth). This is then multiplied by the current age class/period acres of DFHS.
>
> Else the previous age class/period volume of DFHS is divided by the total volume of the same age class/period then multiplied by the harvest volume of the same age class/period. This is then subtracted from the growth that has been multiplied by the current age class/period acres of DFHS.

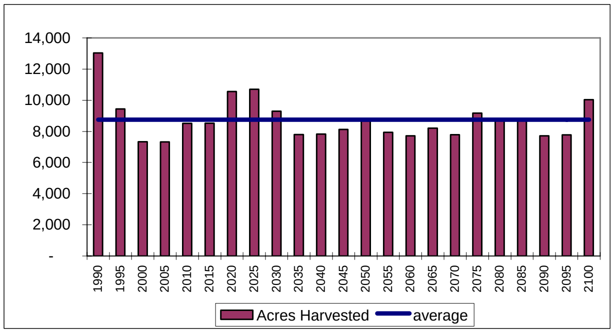
Total Volume

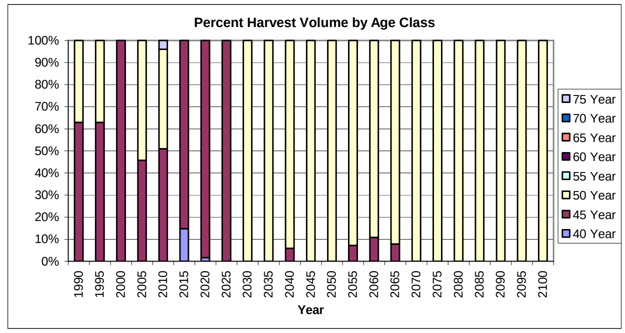
Total volume is calculated for an age class by simply summing all the volumes in the age class.

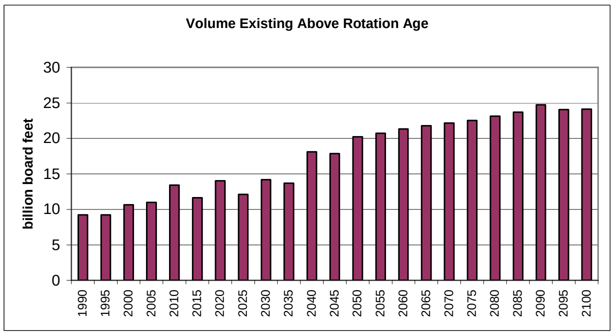
Regional Projections is a tool for making basic harvest and growth projections based on existing volume conditions in a forest region. The model is currently tailored for use with a specific data set, but could be adapted for other data sources. Its use is pertinent when iterative results are acceptable and the user prefers to work in Excel as opposed to a larger and potentially more cumbersome linear programming platform.

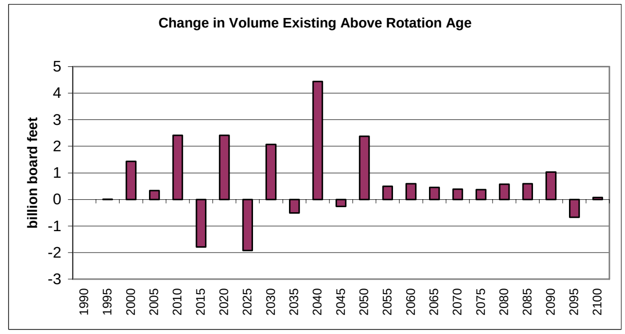
Analysis Charts

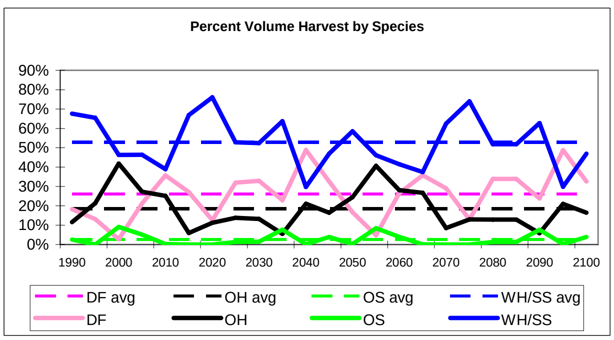
To assist in the analysis of the harvest projections, the worksheet model is set up to chart data series developed while the model solves period by period the harvest allocation problem. These charts are reproduced for each timbershed and labeled to assist in their interpretation.

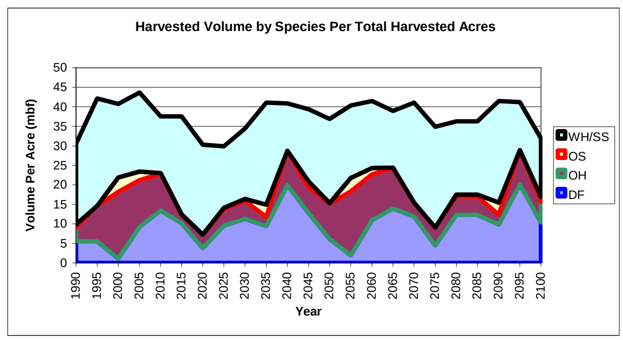


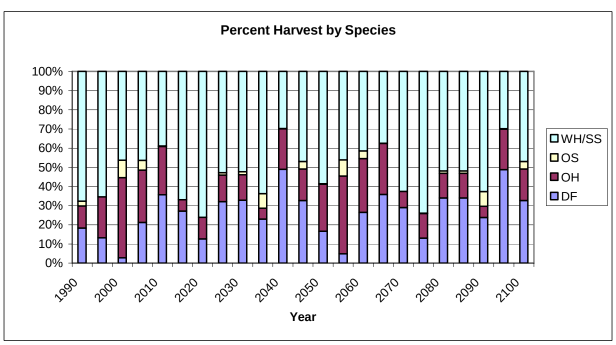


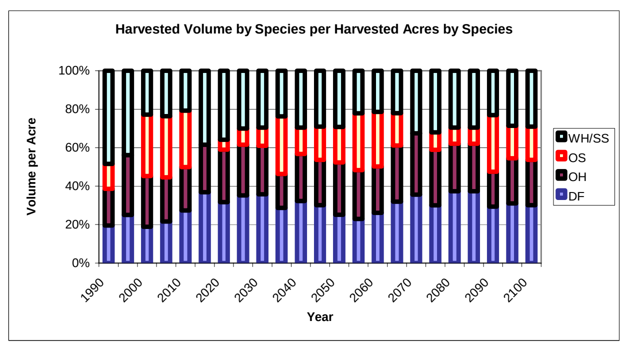








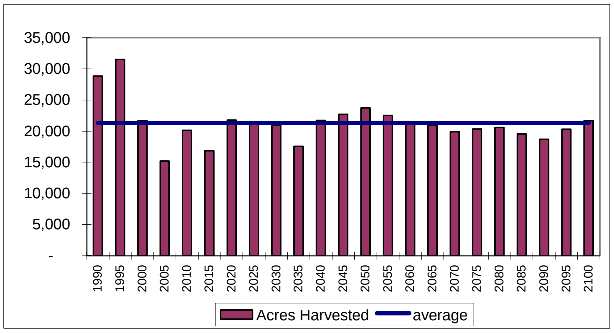


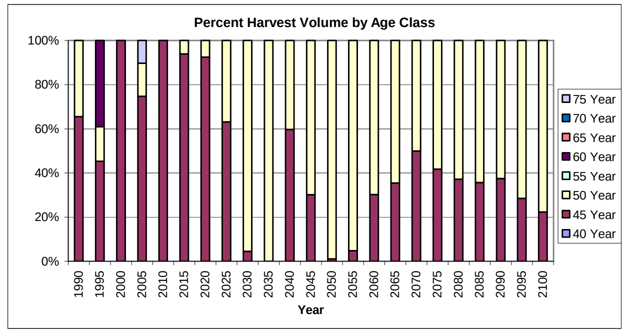


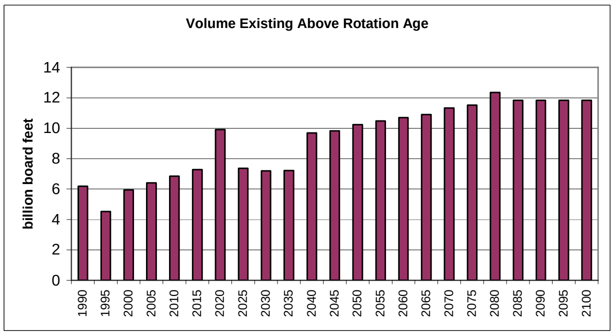
Region: **North Coast** **Run:** **7/16/2005 17:48**

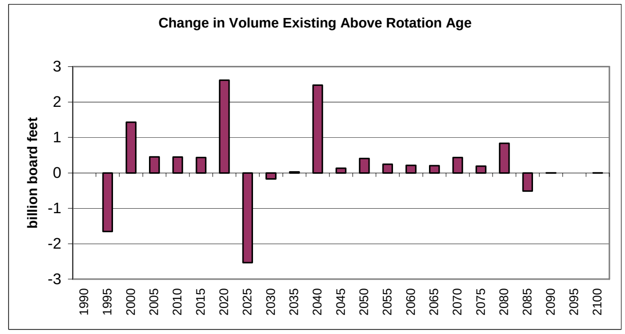
Harvest Level (mbf)

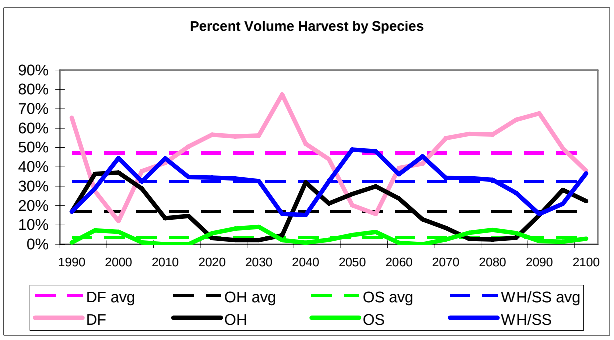
1995	**340,368**	**2050**	**320,000**
2000	**298,793**	**2055**	**320,000**
2005	**320,000**	**2060**	**320,000**
2010	**320,000**	**2065**	**320,000**
2015	**320,000**	**2070**	**320,000**
2020	**320,000**	**2075**	**320,000**
2025	**320,000**	**2080**	**320,000**
2030	**320,000**	**2085**	**320,000**
2035	**320,000**	**2090**	**320,000**
2040	**320,000**	**2095**	**320,000**
2045	**320,000**	**2100**	**320,000**

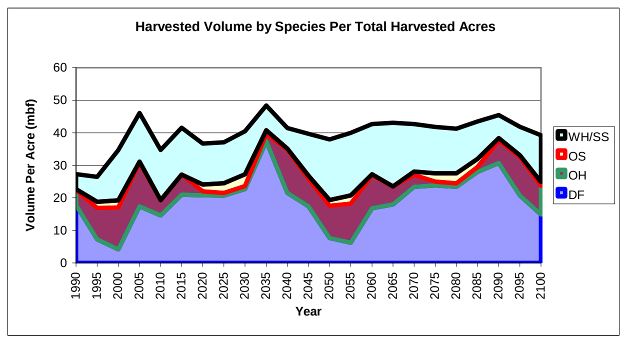


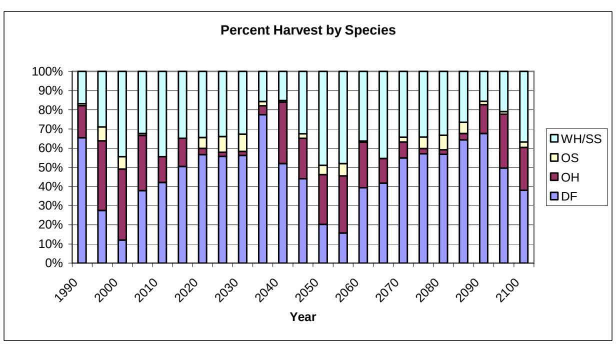


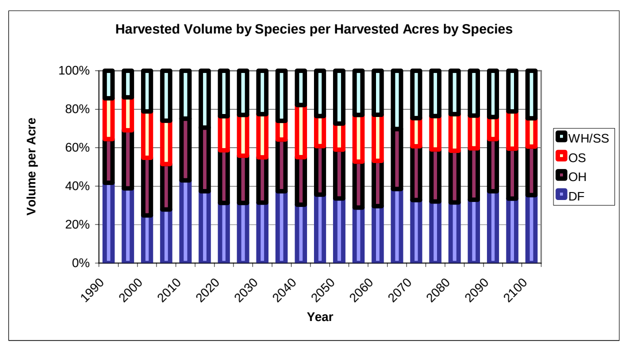










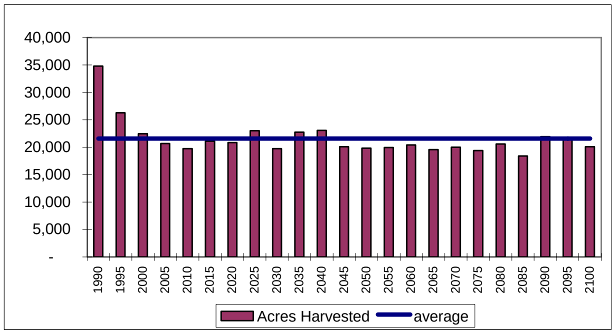


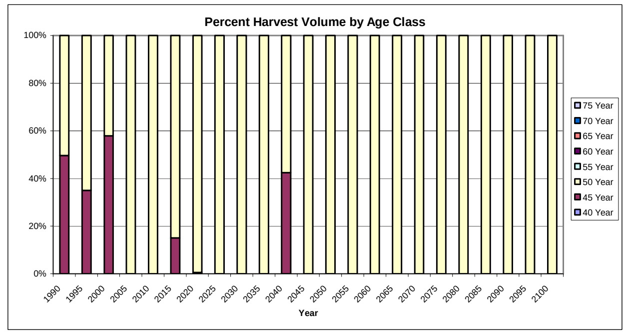
Region: **South Coast**

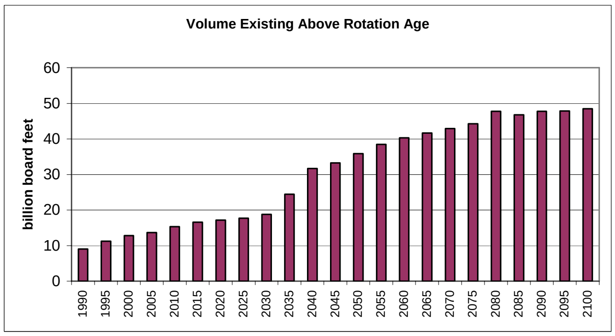
Run: **7/16/2005 17:49**

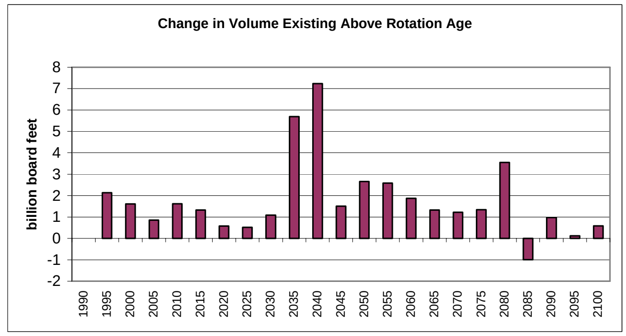
Harvest Level (mbf)

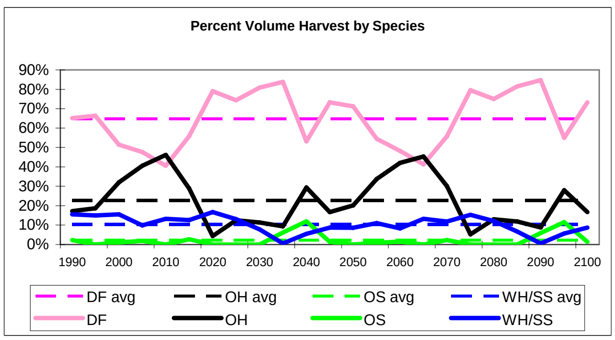
1995	**832,821**	**2050**	**900,000**
2000	**752,329**	**2055**	**900,000**
2005	**700,000**	**2060**	**900,000**
2010	**700,000**	**2065**	**900,000**
2015	**700,000**	**2070**	**850,000**
2020	**800,000**	**2075**	**850,000**
2025	**800,000**	**2080**	**850,000**
2030	**850,000**	**2085**	**850,000**
2035	**850,000**	**2090**	**850,000**
2040	**900,000**	**2095**	**850,000**
2045	**900,000**	**2100**	**850,000**

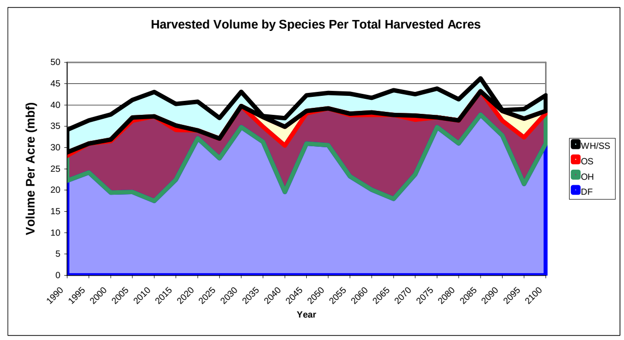


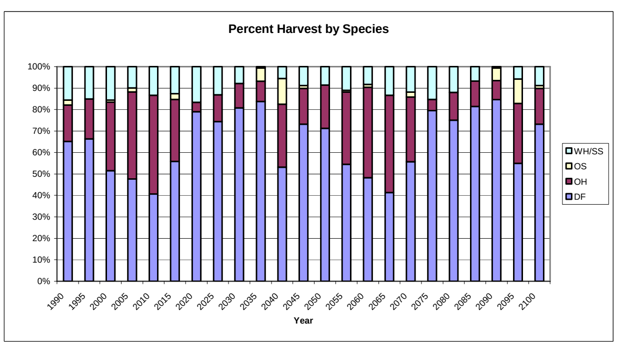


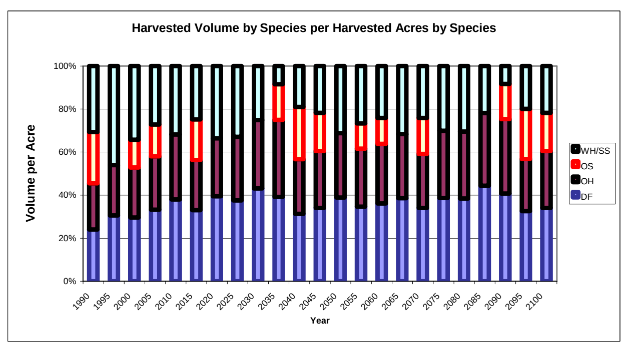












Region: Southwest

Run: 7/16/2005 17:42

Harvest Level (mbf)

1995	956,143	2050	850,000
2000	847,798	2055	850,000
2005	850,000	2060	850,000
2010	850,000	2065	850,000
2015	850,000	2070	850,000
2020	850,000	2075	850,000
2025	850,000	2080	850,000
2030	850,000	2085	850,000
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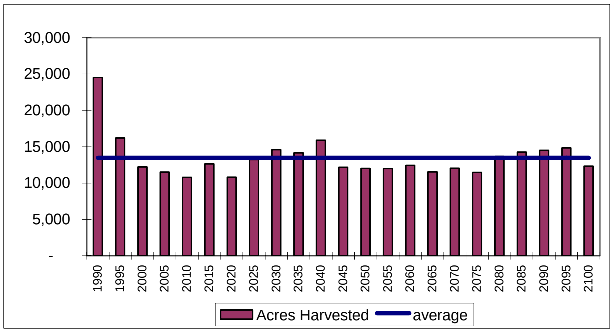
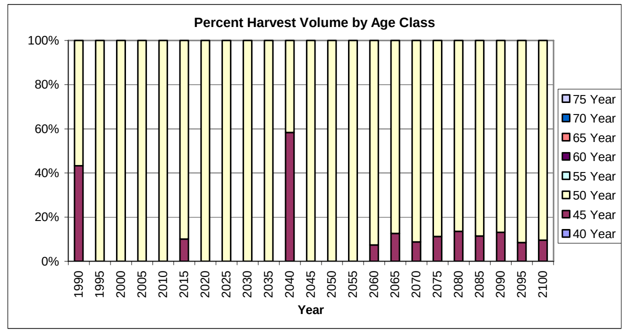
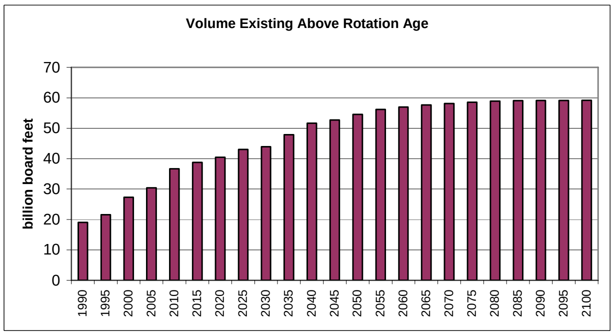
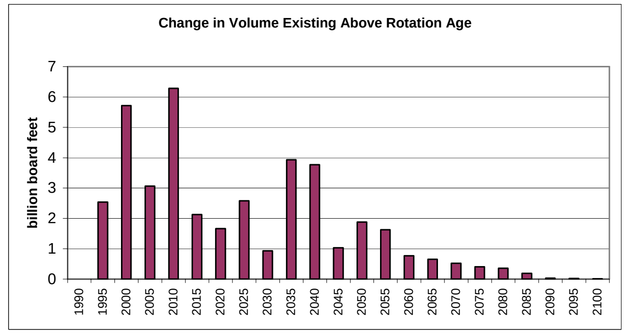
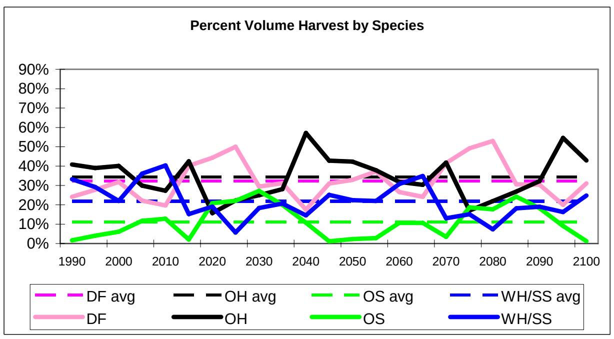
2040	850,000	2095	850,000
2045	850,000	2100	850,000

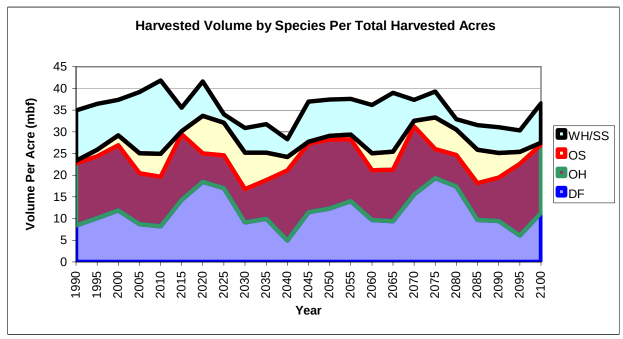


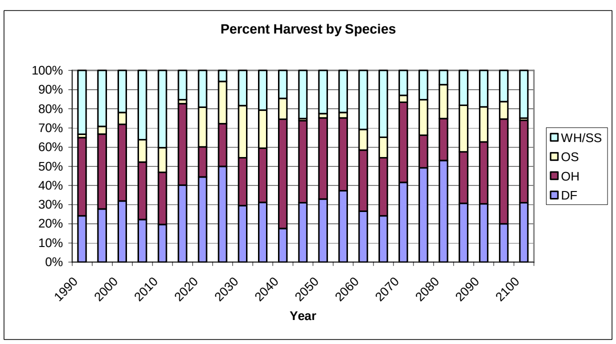


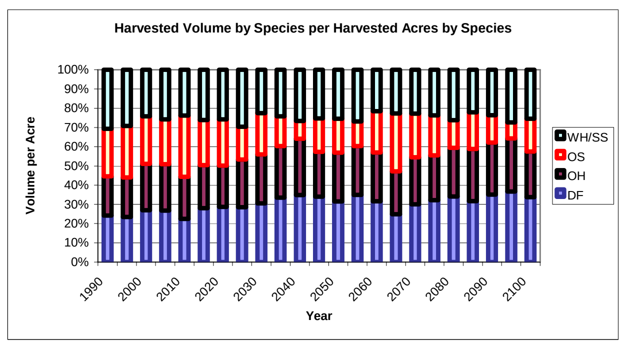










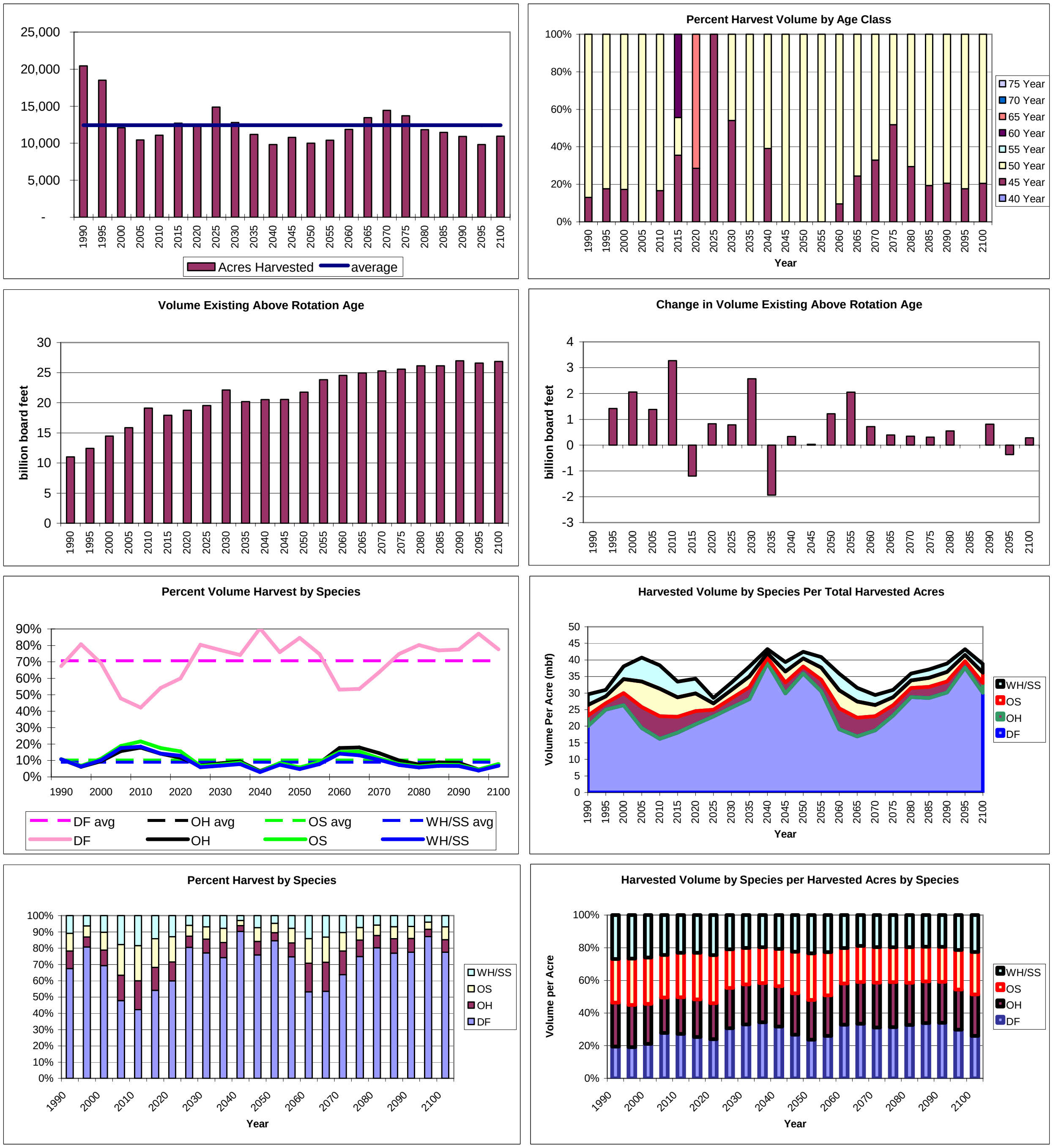


Region: **North Puget Sound**

Run: **7/16/2005 17:50**

Harvest Level (mbf)

1995	**591,040**	**2050**	**450,000**
2000	**456,900**	**2055**	**450,000**
2005	**450,000**	**2060**	**450,000**
2010	**450,000**	**2065**	**450,000**
2015	**450,000**	**2070**	**450,000**
2020	**450,000**	**2075**	**450,000**
2025	**450,000**	**2080**	**450,000**
2030	**450,000**	**2085**	**450,000**
2035	**450,000**	**2090**	**450,000**
2040	**450,000**	**2095**	**450,000**
2045	**450,000**	**2100**	**450,000**



Region: **South Puget Sound**

Run: **7/16/2005 17:52**

Harvest Level (mbf)

1995	573,052	2050	425,000
2000	460,395	2055	425,000
2005	425,000	2060	425,000
2010	425,000	2065	425,000
2015	425,000	2070	425,000
2020	425,000	2075	425,000
2025	425,000	2080	425,000
2030	425,000	2085	425,000
2035	425,000	2090	425,000
2040	425,000	2095	425,000
2045	425,000	2100	425,000