History of Timber Harvest in T3 Watershed Experiment

Final Report

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Author: Karena Iliakis, undergraduate student in the Program of the Environment and Department of Geography, University of Washington

Advisors: Teodora Minkova and Warren Devine, Washington State Department of Natural Resources

Introduction

The project described in this report is part of the T3 Watershed Experiment – a large-scale forest management experiment that compares current forest practices on state lands with novel treatments in providing environmental, economic, and social benefits. The study takes place on 20,000 acres of forested state trust lands across 16 watersheds in the Olympic Experimental State Forest (OESF) on the western side of the Olympic Peninsula, mainly in the Clearwater River and Hoh River drainages in Jefferson County (Figure 1). Selected watersheds are between 500-2000 acres, drain in a fish-bearing (Type-3, aka T3, stream) and are managed primarily by the Washington Department of Natural Resources.

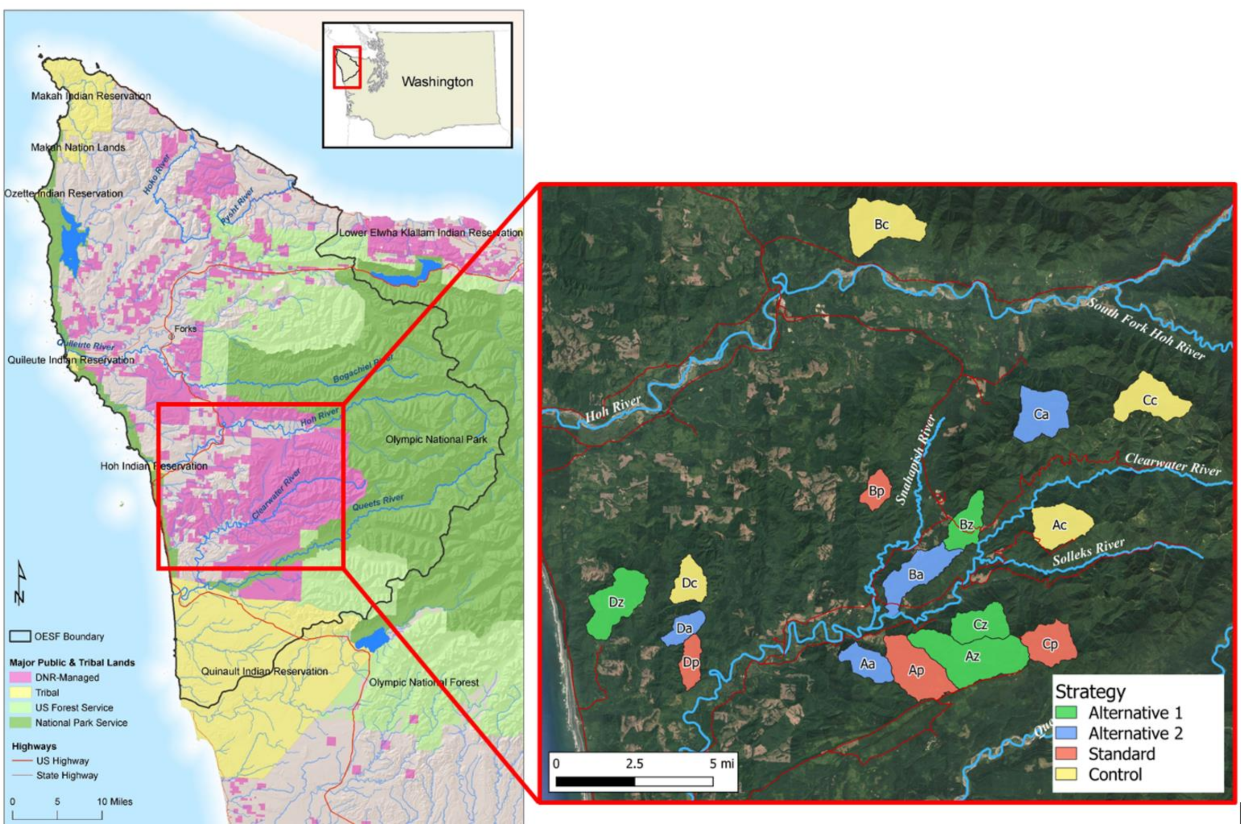

Figure 1: The study area. The 16 T3 watersheds are grouped into 4 blocks, and management strategies are assigned within the blocks. Specific treatments (not shown on map) will be applied in riparian and upland units based on assigned strategy.

Purpose

The purpose of this project is to create a comprehensive spatial account of management disturbances in the T3 study area. The specific objective is to map the timber harvest polygons in the 16 experimental watersheds between 1950 and 2022.

Need

The information on past land use will help to understand the current (baseline; pre-harvest) ecological conditions in the T3 study area and to interpret environmental responses to the experimental manipulations that will occur in these watersheds

Study Approach

1. Review of available information sources

   This included going through various GIS and written data to determine the possible uses for this project. Predominantly GIS data was used, however timber sale auction notices (prospectuses) was also heavily utilized. This information was then compiled into a single, accessible database.
2. Georeferencing and digitizing aerial photos (detailed description below)
3. Review and use of timber sale auction notices (prospectuses)
4. Use of existing GIS layers such as digitized LANDSAT and DNR completed timber harvests

Data Sources

All data sources examined were compiled into the "T3 Watershed Geographic Data Sources" spreadsheet. Table 1 includes the sources mentioned throughout this report. For a complete copy including data resolution, data location, information processing, and fidelity, contact Teodora Minkova at Teodora.Minkova@dnr.wa.gov.

Table 1. Information Sources

Data Source	Description	Information Provided
Aerial Photos 1950	Film and digital photos of the region containing watersheds Da, Dc, Dp, Dz, and Bp	Historical photographic account of early logging and pristine forest
Aerial Photos 1967	Film and digital photos of the region containing the 16 watersheds	Historical photographic account of early logging and pristine forest
Aerial Photos 1995	Film and digital photos of the region containing the 16 watersheds	Historical photographic account of regional logging
Aerial Photos 2005 – 2017	Aerial imagery from the USDA National Agricultural Imagery Program (NAIP); Combined photo mosaic containing the 16 watersheds	Recent photographic account of historical logging
1961 Forest Cover Maps (Mylars)	Map of forest stands from	Stand origin year, primary and

	1961; covers 12 of the 16 experimental watersheds	secondary species', stand density, log size, plot acreage, plot area and length in unknown units, metadata includes legend
DNR Timber Harvest Records – GIS Data	GIS layers of DNR timber harvest and silviculture activities; Relevant layers are "Completed Harvest" and "FMA (Grouped)"; Covers harvests from 1992 to 2022	Harvest technique, harvest date, sale ID, timber volume
DNR Road Management Records – GIS Data	GIS layers of DNR current roads by activity status; Relevant layer is "roads.shp" with more to be digitized	Road location, active status, maintenance, ownership, usage, some grades
Remote Sensing Forest Resource Inventory – RSFRIS	2022 wall-to-wall remote sensing forest inventory used by DNR	Estimated tree ages/origin years, primary/secondary species, snags, avg. diameter
Satellite Imagery	Digitized LandTrendr data - Application that detects land and forest cover changes from 1984 to 2012 and contains imagery dating back to 1955	Detected land changes, land imagery, logging sale areas, dates of first harvest
T3 LiDAR Data – Slope	LiDAR data containing the slope and land features within the T3 watersheds	Slope data, river location, road location
Timber Sale Auction Notices (prospectuses)	One-page descriptions and maps of Board-approved timber sales for auctions dating back to 1973	Application number, sale name, species, log volume in board feet, original auction price, final bid price, road development plan, many records also contain location maps

Project Processes

<u>Setup</u>

All processes utilized ArcGIS Pro, and the extension *Spatial Analyst* was downloaded. All maps and datasets were set to the coordinate system *NAD 1983 HARNS StatePlane Washington South FIPS 4602* for standardization. The Basemap utilized for all processes is the *ESRI World Imagery Basemap.*

<u>1950 Image Georeferencing Process</u>

Georeferencing and georectification of aerial imagery are processes that define the absolute location of a feature within imagery and remove geometric distortions. The Georeferencing tool in ArcGIS Pro was used in this process. First, identifying features such as roads, logging plots, and mountain/hill chains were compared to the World Imagery Basemap supplied by ESRI as well as with previously georeferenced 1967 imagery of the T3 watersheds. The images with the most prominent features (predominantly the segment of Highway 101 that runs along the coast) were lined up and georeferenced first. Each image contains between 15 and 55 control points, with images containing ocean and heavy land change outside of the watersheds having less, and images containing more watersheds and more identifiable features having more. Only one image, 4-6, had no features that could be identified, so it has been left out of this dataset. The images were all georeferenced to the Basemap first for consistency, and adjustments between images were done after all were placed (Figure 2). The primary object here was to ensure that distortions in the images (pitch, edge distortions, shadows) were accounted for, and that the transition between images was smooth. All images used either the 2nd or 3rd polynomial for adjustments. Once images were geolocated, they were then put through the Geoprocessing tool *Clip* and were clipped to the area in and around the watershed. Finally, the images were combined using the Geoprocessing tool *Merge to New Raster* and transformed into a single TIFF file. This was done with just the 1950 images and the 1950 and 1960 images together. The purpose of combining the 1950 images separately is to provide an isolated source that can be analyzed without overlap from the 1960 images. Having a separate file that contains both decades provides a more holistic view of the region at the time as the 1950 imagery only contained the D block watersheds, while the 1960 imagery contains all watersheds.

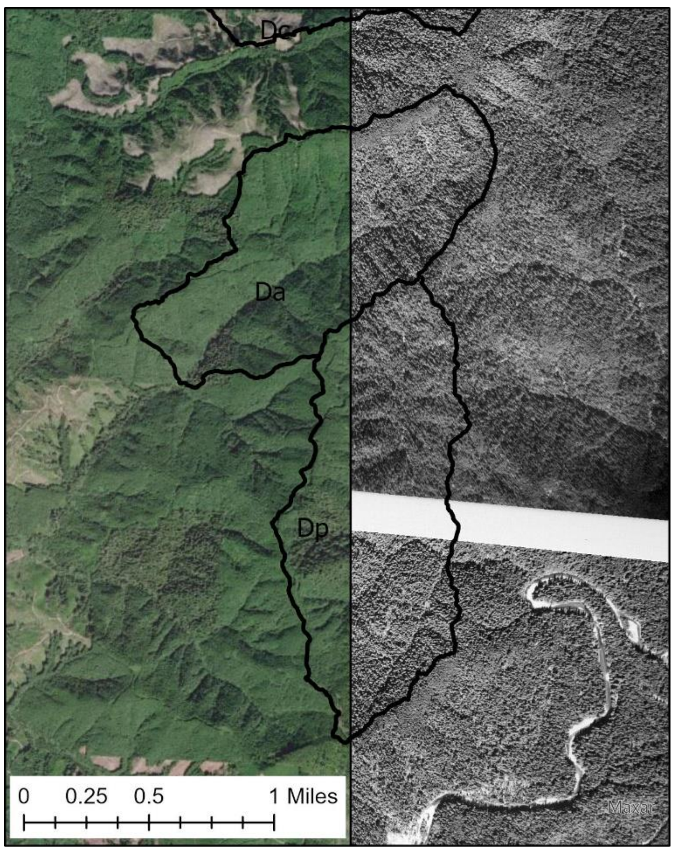

Figure 2: Split image of the referenced basemap (left) and the georeferenced 1950 images (right) in watershed blocks Da and Dp

The limitations of this process include human error while georeferencing, significant land changes affecting control points, such as river channel migration between the 1950 images and the Basemap, lack of starting location leading to one image being unidentifiable, and the tilting of the plane taking the photos.

1950's/1960's Digitizing Process

For digitizing and visualizing man-made land disturbances from the 1950's and 1967 aerial imagery, a new group was created, "Digitized Features". This was to ensure data was contained in the same area. Three shapefiles were then made for points (timber harvest landings), lines (roads), and polygons (large-area disturbances/logging). All objects were made using the *Create Features* tool. First, roads were traced with the simple line feature, using sharp edges for ease instead of rounding. Then, disturbances – areas with no tree cover - were digitized using the Polygon and simple line feature. The edges of harvests are considered where the base of trees in the adjacent forest begin. Finally, points were placed for landings along roads where larger cutouts indicate the placement of large machinery. The attribute table was then partially populated using information from the imagery as well as the *Remote Sensing - Forest Resource Inventory System (RS-FRIS)* resource and the digitized *1961 Forest Cover Maps (Mylars).* This was done because *RS-FRIS* contains an estimated age of each current stand of trees, so the harvests in the 1967 images could be no older than RS-FRIS-estimated current age. This was not used on all polygons, as *RS-FRIS* shows ages for trees regenerated after a second harvest, making this data irrelevant to this set of polygons. The Mylars contain the ages of forest stands at the time the maps were drawn, which is presumed to be 1961 based on dates on the original map drawings. If logged territory was mapped here, the harvest occurred before 1961, and if it did not appear, it occurred after 1961.

The limitations of this process include any inaccuracies in the 1950 georeferenced photos or the Mylars due to human error, as well as time constraints that limit the extent of the landing zone and road shapefiles. The RS-FRIS estimation of stand ages is also known to have errors.

1970's/late 1980's Digitizing Process

Digitizing and visualizing man-made land disturbances from the 70's and 80's relied heavily on *Timber Sale Auction Notice (Prospectuses)* from 1973 to 1991*,* a LANDSAT layer digitized by a UW student in 2019 and covering years 1971 (generally) to 1991, a 2022 LiDAR Slope layer managed by the DNR, and mosaics of 1990 and 2005 aerial photos from NAIP and obtained by the DNR[1]. The *Prospectuses* were scanned in over the course of three non-consecutive days and sorted into files by month. Data used in this process includes timber sale auction date, final date for possible harvest, application number, timber sale name, and township and section. Prospectuses from April 1976 and onward also contained sketches of the harvest units, which included general river and road locations, proposed road locations, application numbers of adjacent active harvests, general location of adjacent harvests, and year of adjacent harvests. These prospectuses were then compared to a *T3 Watershed* layer and two layers that contained Township and Section information in ArcGIS Pro, and prospectuses for timber sales that were not within the T3 watershed boundaries were removed. Then, beginning in April 1976, the maps contained in the sales as well as the descriptive location were compared to first the 90's imagery and an old growth layer[2] (perpetually on). If the sketch aligned with variations in the imagery (evidence of logging), then the boundaries were drawn using the *Create Features* tool. If an accurate boundary could not be found but the general location was known from the prospectus, the prospectus map was then compared to LiDAR data that visualized rivers and a DNR provided roads layer.

[1] In the T3 study area, the aerial photos in the 1990's mosaic are believed to have been taken in 1995.

[2] This is a separate polygon layer created from RS-FRIS by isolating all stands of trees 80 years and older.

If a timber sale boundary could still not be confidently created, it was then compared to the digitized LANDSAT layer. Finally, if the boundary could not be found using all the resources above but there is evidence of that harvest having taken place, the best approximation was made using all known information. This was done predominantly by comparing boundaries of adjacent timber sales, looking for minute changes in 1990's aerial imagery, and using prospectus maps of nearby timber sales (not necessarily adjacent). After individual prospectuses were mapped, the following data from the prospectuses was added to the attribute table: timber sale date, final date for possible harvest, application number, timber sale name.

If a prospectus did not contain a map, the township and section information was compared to imagery to determine if there was visible timber harvest in the described area. Since many plots had already been filled in by trees by the time the aerial photo was taken, the previous methodology was repeated focusing on prospectus maps in the township/section that also contained information relating to the harvests of interest. This did not provide data that was as precise, however utilizing the resources above, a best approximation was made.

A simplified processes relying heavily on the digitized LANDSAT layer was not used as the spatial and temporal reliability was questionable. This layer contained generally correct locations of the harvests; however, the original LANDSAT imagery was about 60 meters/pixel, which makes it difficult to accurately identify the harvest boundary. As a result, occasionally polygon edges would not line up with timber harvests on imagery, or multiple harvests would be grouped into one polygon. The years of first harvest in the layer were also close to the years in the prospectuses, however there were areas with years that did not align with the years the harvest/sale were active, predominantly where multiple harvests were presented as one, or the harvest year was outside of the scope of the LANDSAT data (such as <1972).

Other limitations included certain prospectuses not containing maps, predominantly from the early 70's, and some timber sale records being unaccounted for and leaving noticeable gaps in the management record.

<u>1990's to 2020's Digitization Process</u>

All polygons for 1992 onward were already created and listed as *DNR Timber Harvest Records – GIS Data*. These are managed by data stewards at the DNR and updated regularly, as shown by 2022 harvests being included. The process for adding these to the previous data was straightforward. The harvests that intersected with the T3 Watershed Boundary Layer were selected and turned into a new layer. The attribute table was then reconfigured such that it matched the attribute tables of the other 2 layers, and the layer was eventually merged with the other two, as this was the final set of years to be compiled.

There were no complications or limitations in this process.

<u>Composite GIS Layer Creation</u>

Once all polygons were created in the individual layers, the data management tool *Merge* was used to combine them into a final composite layer. The Merge Rule setting was not changed from "first" in any of the output fields. In *Environments*, the coordinate system was set to *NAD 1983 HARNS StatePlane Washington South FIPS 4602.* The layer was named to "All Known Harvests", then the tool

Featureclass to Shapefile was used to export the layers. This was done so the layers would be accessible to those who do not use ArcGIS Pro or ArcGIS Maps.

For a copy of the shapefile, contact Teodora Minkova at Teodora.Minkova@dnr.wa.gov.

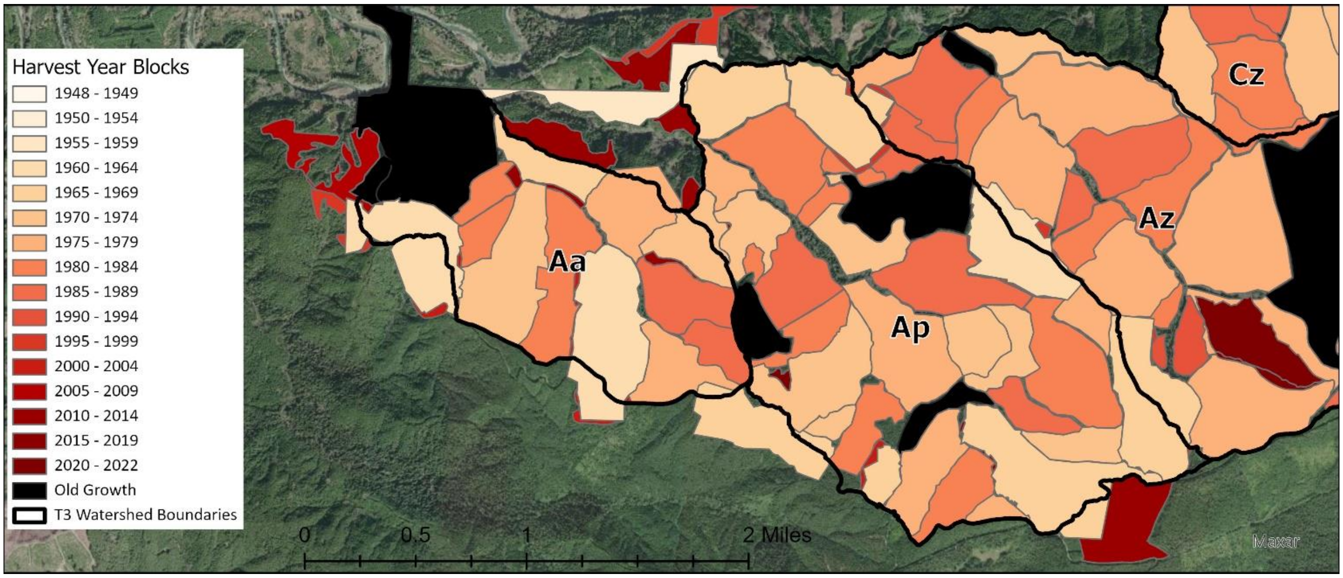

Figure 3: Watersheds Aa, Ap, Az, and Cz from the All Known Harvests Shapefile

<u>Attribute Table</u>

The columns created for the attribute table of the composite GIS layer are listed and described in Table 2.

Table 2: Description of GIS layer attributes

Column name:	Description:
Shape	The type of feature (point, line, polygon)
DataSource	The primary sources for location and boundaries of the harvest
MngmtDist	The type of disturbance in the area, limited to harvest activities as of March 2023
EarlyYr	The earliest possible year that the harvest could have occurred based on available data; if information was collected from the prospectuses, this is populated with the timber sale date even if the exact year of harvest is known (i.e. KnownYear is populated)
EarlyYrSc	The source that provided EarlyYr
LatestYr	The latest possible year that the harvest could have occurred based on available data; if information was collected from the prospectuses, this is populated with the year timber was required to be removed, even if the year of harvest was known (i.e. KnownYear is populated)

LatestYrSc	The source that provided LatestYr
KnownYear	When available, the known year of the harvests
KnownYrS	The source that provided KnownYear
TSAppNum	When available, the timber sale application number, traditionally found on prospectuses and later in the DNR Management Layer
TSName	The name of the timber sale, traditionally found on prospectuses and later in the DNR Management Layer
Notes	Any additional notes or warnings pertaining to the sale, including noted windstorms, specific prospectuses used outside of the primary, and validation warnings
Area Acres	The calculated area in US Survey Acres of each harvest polygon, utilizing the coordinate system *NAD 1983 HARNS StatePlane Washington South FIPS 4602*
EstYr	The estimated year used for calculation. When available, this is the value in the KnownYear column, and when unavailable, it is the average between EarlyYr and LatestYr. If only one of those two years is known, it is that year (this is rare).

Source Hierarchy

Not all sources were considered equally reliable, and they were prioritized based on their spatial and temporal reliability (Table 3). Sources that shared similar reliabilities were used often in conjunction and with no specific order. The following is the source with a general ranking of usage (1 – 5 with 1 being low priority and 5 being highest priority), what the source was predominantly used for, and reasoning for ranking:

Table 3. Reliability ranking of information sources

Source:	Use:	Ranking:	Reasoning:
Imagery (Compiles 1950s Imagery, 1967 Imagery, 1990s Imagery)	Spatially locating harvest plots, providing sharp boundaries for plots, providing EarlyYr/LatestYr depending on each harvest	5	This data is highly spatially reliable as even the 1950 and 1967 imagery has a very high resolution. The year the images were taken can be used as the EarlyYr/LatestYr depending on if the year was available for the images. Caution was used with the 1950 imagery due to possible georeferencing errors.

DNR provided Timber Sale Auction Notices (Prospectus)	Spatially locating harvest plots, providing general shape of plots, EarlyYr/LatestYr, known year depending on each harvest, application number, harvest name, other details	4	Township and Section data is very helpful in generally locating harvests even if the sketches are rough and not much more than the general shape can be derived. The prospectuses contain nearby rivers and roads that can also be used to locate the plots, and if the harvest is not a resale, the years are accurate.
T3 LiDAR Data – Slope (LiDAR)	Provides slope data for the T3 watersheds, including river valleys and higher hills	5	This data is highly spatially reliable currently and can be used alongside most prospectuses assuming rivers or roads are noted, however due to land changes, using in comparison to older prospectuses was less reliable.
Digitized Satellite Imagery / LANDSAT Harvests (Satellite)	Spatially locating harvest plots and estimating years of first harvest	3	This data has a medium to low spatial resolution, and some of the years provided are either too generalized to use outside of LatestYr (ie <1972) or did not align with the years allocated for the harvests. This was useful for locating harvests with prospectuses that did not have maps, and it was used for filling in areas of known harvests that had no available data in other sources.
DNR Timber Harvest Records – GIS Data (DNRHarvest)	Spatially locating harvest plots and boundaries, providing year of harvest, application number, sale name, harvest type	5	This data is highly spatially and temporally accurate, and it was taken at face value. Little to none was changed in the usage of this layer.
1961 Forest Cover Maps (Mylars)	Spatially locating harvest plots and providing age of stands	2	This data has a medium to low spatial reliability and a medium temporal reliability, so this data was used mostly for estimating possible EarlyYr/LatestYr.
Remote Sensing Forest Resource Inventory (RSFRIS)	Spatially locating harvest plots and providing age of stands	1	This data has a medium to high spatial reliability and a medium to low temporal reliability, because adjacent harvests that occurred 10-20 years apart are

			often grouped together, so it is not as useful in estimating harvest year. It was used when no other option could be found for some harvests, however it was not regularly used.

Data Analyses

Using the finalized composite GIS layer, a quantitative analysis of the changes in harvested area over the mapped period (1950-2022) was done. The purpose was to summarize the amount, type, and distribution of management disturbance over time. The summarization was broken down into 5-year intervals (1945-1949, 1950-1954, 1955-1959 . . . 2020-2023), as well as by harvest type. These include regeneratioin harvest (documented as ClearCut and later as Variable Retention Harvest), salvage (including ClearCut/Salvage), and thinning (documented as Commercial Thinning and later as Variable Density Thinning). The total acreage of all watersheds as calculated by ArcGIS Pro was 20385.78 acres, and this was the amount used in the calculations.

The following metrics were calculated using *Microsoft Excel* pivot tables and simple formulas:

1. Sum of acres within watersheds harvested per 5-year interval by type of harvest
    a. Utilizing =SUM()
2. Percentage of acres harvested per 5-year interval by type of harvest
    a. Utilizing =SUM()/20385.78
3. Cumulative frequency as a sum of acres harvested per 5-year interval (excludes overlapping harvests)
    a. Utilizing =SUM() + previous interval harvest
4. Cumulative frequency as a percentage of acres harvested per 5-year interval (excludes overlapping harvests)
    a. Utilizing =(SUM() + previous interval harvest)/20385.78
5. Change in average and maximum size of harvests that are at least partially within the watersheds
    a. Utilizing =AVERAGE() and =MAX()
6. Final harvest of old-growth (final harvest of primary forest)
    a. Utilized a visual analysis of the final composite GIS layer broken down by 5-year intervals
7. First harvest of second-growth (first harvest in previously harvested forest)
    a. Utilized a visual analysis of the final composite GIS layer broken down by 5-year intervals

Results:

Table 4. Sum of acres harvest per 5-year block by harvest method

Acres Harvested per 5 Years				
5 Year Block	Regenerative Harvest Acres	Thinning Acres	Salvage Acres	Total Acres
1945-1949	35.824	0.000	0.000	35.824
1950-1954	42.006	0.000	0.000	42.006
1955-1959	354.743	0.000	0.000	354.743
1960-1964	759.735	0.000	0.000	759.735
1965-1969	1629.007	0.000	0.000	1629.007
1970-1974	3391.478	0.000	0.000	3391.478
1975-1979	4241.971	0.000	272.944	4514.915
1980-1984	1000.189	0.000	1325.072	2325.262
1985-1989	2320.671	0.000	118.490	2439.160
1990-1994	455.075	0.000	0.000	455.075
1995-1999	4.897	462.338	0.000	467.235
2000-2004	0.000	165.614	0.000	165.614
2005-2009	15.676	0.000	0.000	15.676
2010-2014	71.245	433.724	0.000	504.969
2015-2019	137.411	501.089	0.000	638.500
2020-2023	39.481	119.559	0.000	159.040
Total Harvest	14499.409	1682.324	1716.506	17898.239

Table 5. Percentage of acres harvested per 5-year block by harvest method

Percentage Harvested per 5 Years				
5 Year Block	Regeneration Harvest %	Thinning %	Salvage %	Total %
1945-1949	0.1757%	0.0000%	0.0000%	0.1757%
1950-1954	0.2061%	0.0000%	0.0000%	0.2061%
1955-1959	1.7402%	0.0000%	0.0000%	1.7402%
1960-1964	3.7268%	0.0000%	0.0000%	3.7268%
1965-1969	7.9909%	0.0000%	0.0000%	7.9909%
1970-1974	16.6365%	0.0000%	0.0000%	16.6365%
1975-1979	20.8085%	0.0000%	1.3389%	22.1474%
1980-1984	4.9063%	0.0000%	6.5000%	11.4063%
1985-1989	11.3838%	0.0000%	0.5812%	11.9650%
1990-1994	2.2323%	0.0000%	0.0000%	2.2323%
1995-1999	0.0240%	2.2679%	0.0000%	2.2920%
2000-2004	0.0000%	0.8124%	0.0000%	0.8124%
2005-2009	0.0769%	0.0000%	0.0000%	0.0769%
2010-2014	0.3495%	2.1276%	0.0000%	2.4771%
2015-2019	0.6741%	2.4580%	0.0000%	3.1321%
2020-2023	0.1937%	0.5865%	0.0000%	0.7802%
Total Harvest	71.1251%	8.2524%	8.4201%	87.7977%

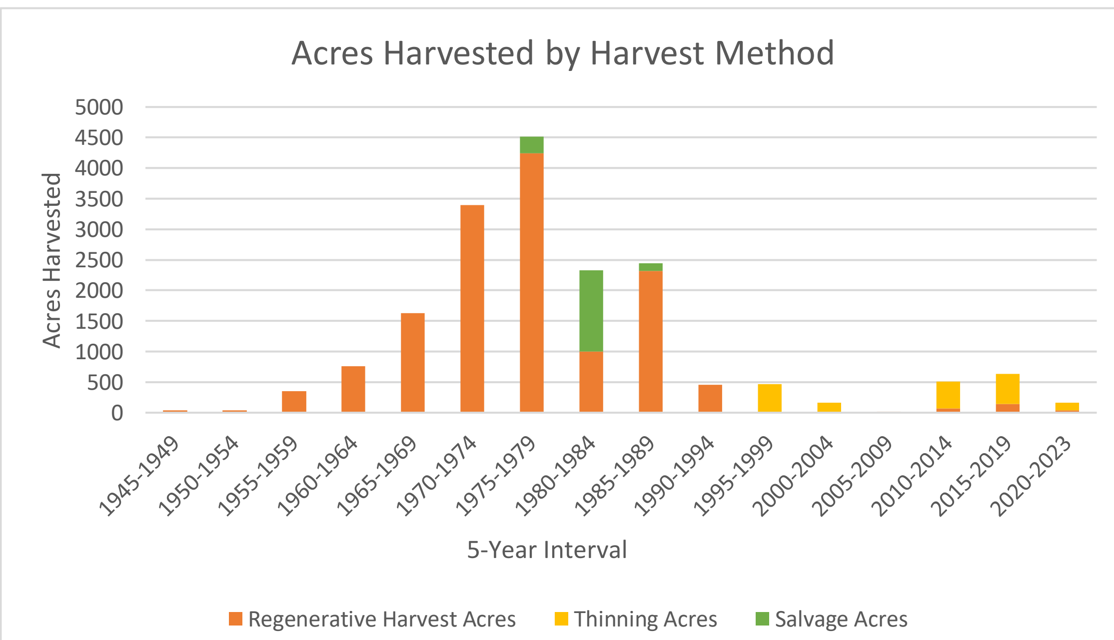

Figure 4: Area harvested per 5-year block by harvest method

Table 6. Cumulative percentage and sum of acres harvested per 5-year block. This excludes areas of second harvest with mapped first harvest

Cumulative Percent and Acres Harvested per 5 Years		
5 Year Block	**% Cumulative Harvest**	**Harvest Acres**
1945-1949	0.18%	35.824
1950-1954	0.35%	77.831
1955-1959	2.09%	432.574
1960-1964	5.82%	1192.309
1965-1969	13.81%	2821.315
1970-1974	30.45%	6212.793
1975-1979	52.59%	10727.708
1980-1984	64.00%	13052.970
1985-1989	75.96%	15492.130
1990-1994	78.19%	15946.738
1995-1999	78.22%	15951.635
200-2004	78.22%	15951.635
2005-2009	78.22%	15951.635
2010-2014	78.22%	15951.635
2015-2019	79.46%	16205.710
2020-2023	79.46%	16205.710

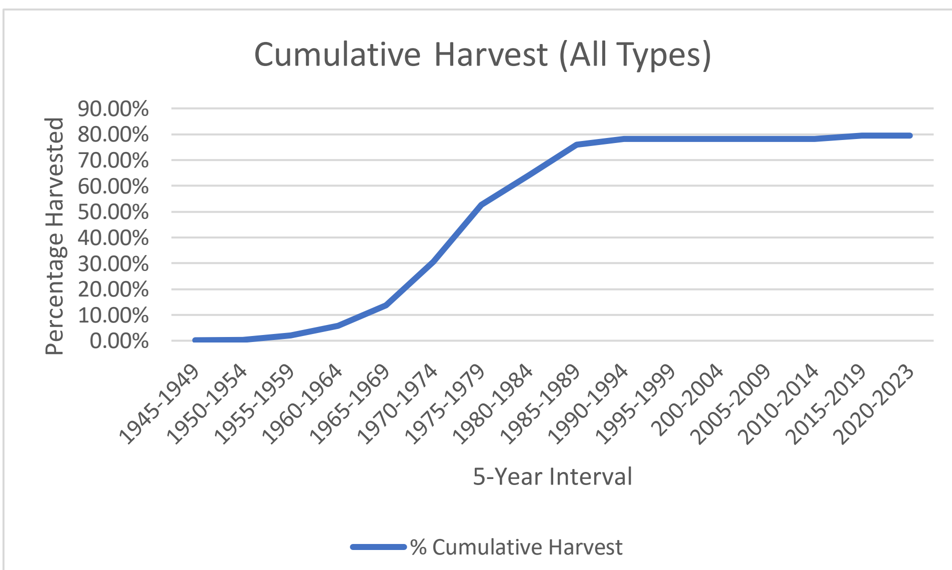

Figure 4: Cumulative Percentage Harvested per 5-Year Block

Table 7. Average and largest harvest units per 5-year block

Average and Largest Harvests per 5 Years		
5 Year Block	Avg Harvest Size	Largest Harvest
1945-1949	37.817	37.817
1950-1954	40.981	68.068
1955-1959	89.570	253.390
1960-1964	53.157	138.639
1965-1969	73.344	271.162
1970-1974	65.267	237.477
1975-1979	62.173	279.681
1980-1984	38.918	117.298
1985-1989	69.763	182.029
1990-1994	60.426	89.110
1995-1999	105.764	265.250
2000-2004	79.386	168.495
2005-2009	62.720	62.720
2010-2014	98.055	390.254
2015-2019	147.886	405.884
2020-2023	61.428	119.559
Total Acres Harvested	1146.656	405.884

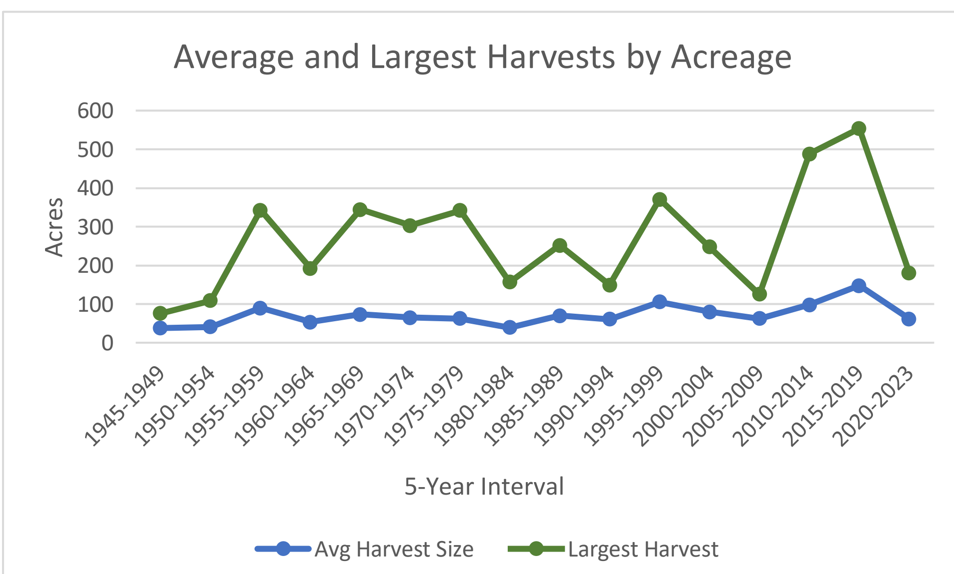

Figure 5: Change in the average and largest size of harvest units over time

Other Findings

The final harvest of old growth (primary forest) was in 1998 with the sale “Rusty’s Remains”, ID #44794. The first harvest of second growth (previously harvested forest) was in 1995 with the sale “New Tree Thinning”, ID #54125.