ASPEN DECLINE IN SOUTHEAST IDAHO

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ABSTRACT

This study investigated trends in aspen (*Populus tremuloides*) extent and distribution in southeast Idaho at a landscape scale specifically to inform future targeted management decisions for Bureau of Land Management (BLM) project partners seeking to promote aspen stand health within their jurisdictional boundaries. Remotely sensed satellite imagery from Landsat 5 Thematic Mapper (TM), Landsat 8 Operational Land Imager (OLI), and Landsat 9 Operational Land Imager Plus (OLI+) in addition to aerial imagery, distance to streams, topographic layers, and *in situ* observations were used to train a probabilistic decision forest model to model aspen at three different scales: 1) a focused study area (FSA) scale, 2) a watershed basin scale focusing on two basins of particular interest to project partners, and 3) targeted regions of interest where BLM partners have conducted active management in the since the early 2000s. Climatic datasets were used to interpret model results including mean annual, growing season, and winter Tmax and Tmin, precipitation, snow water equivalent, growing degree days, and frost-free days. In addition, historic wildfire locations were used to better understand the disturbance regime in the study area. The decision forest model suggests aspen has declined in extent across the FSA by approximately 50,000 acres (32%) between 2004 (163,356 acres) and 2025 (112,320 acres). Results of watershed basin analysis show spatial variability with some basins exhibiting stable aspen extents while others show declines. Personal communications with land managers having extensive working knowledge of the study area indicate the model overestimated aspen extent especially in early model years when Landsat 5 was used. A combination of interacting factors may be driving the decline of aspen including (1) a lack of disturbance and infrequent fires affecting aspen in the northern section of the FSA, (2) rising Tmin, Tmax, growing degree days, and frost-free days causing prolonged periods of stress –especially during drought years-- leaving them susceptible to secondary disturbance factors like pests, pathogens, and increasing competition pressure with conifers. Even when considering uncertainties in these models, aspen are most likely experiencing a decline across eastern Idaho. Further research, monitoring, and management activities to promote aspen habitat is merited.

Keywords: *Aspen, Idaho, climate, wildfire*

INTRODUCTION

Aspen (*Populus tremuloides*) are the most widespread broadleaf tree in North America and are frequently the only broadleaf species in otherwise conifer-dominated boreal landscapes (Kitchen et al. 2019). Often referred to as a keystone species (Wilson 1992), aspen serve a disproportionately important role in the biodiversity and functioning of the ecosystems in which they appear (Kay 1997). They also provide a number of critical ecosystem services including nutrient cycling, carbon sequestration, and provide both food and shelter for many species of plants, insects, microbes, and animals (Kouki and Martikaenen, 2004). Aspen exist across diverse ecological settings and as a result, exhibit a variety of ecological roles, making generalizations challenging and context specific studies of aspen necessary for well-informed management (Romme et al. 2001).

While aspen declines have been reported across the western United States (Singer et al. 2019), few studies have focused specifically on aspen populations in southeast Idaho. This study sought to fill this gap by using remotely-sensed imagery to classify and map changes in aspen extent and distribution across southeast Idaho (**Figure 1**). The study uses remotely sensed data from Landsat 5 Thematic Mapper (TM), Landsat 8 Operational Land Imager (OLI), and Landsat 9 Operational Land Imager Plus (OLI+) in addition to aerial imagery, climate data, and *in situ* observations. These data were used to train a probabilistic decision forest (DF) model to map aspen distribution between 2004 and 2025 and investigate trends in aspen extent and relationships with conifers at a landscape scale. Project partners at the Bureau of Land Management plan to use findings from this study to inform future targeted management decisions with the goal of promoting aspen health and overall ecosystem function in aspen-dominated landscapes within their jurisdictional boundaries.

Abiotic factors

As the most widely distributed tree species in North America, aspen thrive across a diverse range of habitats from boreal forests to montane areas (Mitton & Grant, 1996). The range of aspen-dominated landscapes are largely shaped by abiotic factors including temperature, precipitation, snowpack and timing of snowmelt, soil composition, elevation and other topographic factors.

Climatic conditions are highly variable over aspen's expansive range, especially annual precipitation and temperature extremes. Precipitation within aspen's native range across North America can be as low as 16 cm annually in the semiarid west and may exceed 750 cm annually in parts of Canada (DeByle and Winkour, 1985). In addition, aspen can tolerate a wide range of temperature extremes, and have been documented in areas that experience winter minimum temperatures as low as -57° C and summer high temperatures up to 41° C (Perala et al. 1990). Given these relatively broad conditions, the range of aspen is still limited by growing season temperatures, availability of sunlight, and its requirement for a surplus water supply when the overall water balance exceeds evapotranspiration (Perala et al. 1990).

Declining winter snowpack (Mote et. al. 2005 and 2018) and both faster and earlier spring snowmelt may impact aspen populations (Brodie et. al. 2012). The reason for this is two-fold: (1) aspen have a relatively shallow root system and are unable to tap into deep groundwater supplies as done by conifers. As a result, aspen rely largely on snowmelt and rainfall during the growing season to satisfy water needs. (2) A deep snowpack may help young aspen suckers avoid being browsed by elk and deer simply by being covered during the winter months. In contrast, a shallow snowpack (a) leaves aspen suckers vulnerable to browsing during these months, (b) melts more quickly in the spring and early summer, and (c) provides limited water during the growing season. Stress from drought conditions damages aspen's xylem and this damage accumulates over time, which allows the impact of drought to persist sometimes for years after a prolonged period of drought (Anderegg et al. 2013).

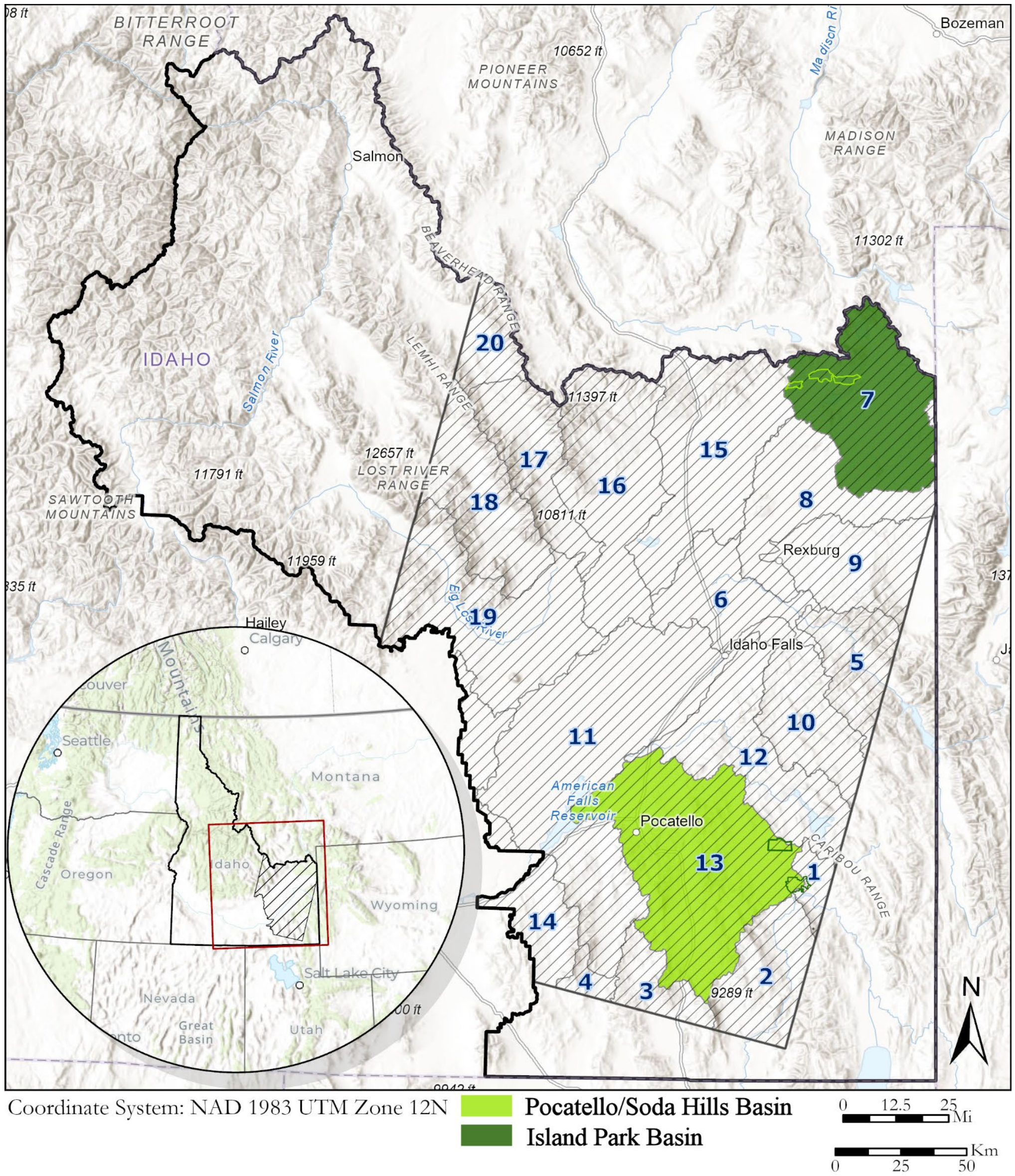

Figure 1. *Study area in Southeast Idaho with 20 watershed boundaries (HUC08) used for analysis. The bold black outline represents the initial study area comprised of four Bureau of Land Management field offices in eastern Idaho; Pocatello, Salmon, Challis, and Upper Snake. The hatched black area is the smaller focused study area that was used for analysis. The light green watershed basin (13) contains Pocatello and Soda Springs, areas of noted interest to BLM partners and therefore studied in more detail. The dark green watershed basin (7) contains Island Park, another area of noted interest to BLM partners and therefore studied in more detail. Watershed basin 13 contains two smaller areas of noted interest including the Ten-Mile area and Soda Hills area. Watershed basin 7 contains three smaller areas of noted interest including Icehouse, Yale Kilgore, and Sheridan Ridge.*

Aspen grow on a variety of soils ranging from shallow and rocky to deep loamy sands and heavy clays (USDA, 1975). Soils that are well drained, loamy, and high in organic matter, calcium, magnesium, potassium, and nitrogen tend to support aspen well (Boyle et al. 1973). While soils tend to be only a minor limiting factor for aspen, another study suggests soil structure may be linked to the age and successional type of aspen stands with stable aspen habitats frequently associated with a thick mollic horizon and Pachic Cryoborolls soil type (Cryer & Murray, 1992). Stands tend to expand into soils with thinner mollic horizons, but tend to thicken the rich mollic horizon as the trees mature and drop leaves and build organic matter in the soil (Buol et al. 1989). Seral stands that interface with conifers that encroach are often on less rich soils. Aspen functional types are influenced by the structure and composition of the soil that they grow in while also influencing the soil composition and structure (Cryer & Murray, 1992).

The elevational distribution of aspen in North America ranges from sea level on the Atlantic and Pacific coasts to approximately 3500 meters above sea level in northern Colorado (DeByle & Winokur, 1985). Near the northern limit of their range, aspen are not found above 910 meters and near the southern limit, aspen are rarely found below 2440 meters. Individual aspen trees tend to be poorly developed when found at either end of these elevation limits with most trees in Colorado and Utah found between 1280 and 3350 meters (Perala et al. 1990). In the Intermountain West, aspen can be found on all aspects and grow well wherever there is sufficient soil moisture. However, north-facing slopes tend to provide more favorable soil moisture conditions (Mueggler, 1988).

Biodiversity

Highly productive and structurally diverse, non-riparian aspen forests support greater biodiversity than any other upland forest type in the western United States (Chong et al. 2001; Mueggler 1985), providing critical ecosystem services including the indirect sunlight needed to support a biologically diverse understory (Mueggler 1985). When aspen dominated landscapes transition to other types, notable biodiversity is lost in vascular plants, nonvascular plants, vertebrates, and invertebrate organisms (Bartos and Amacher 1998; Bartos and Campbell 1998a, b; Kuhn 2011). Furthermore, many species of plants, animals, insects, and microbes rely on the services provided by aspen (Kouki and Martikainen 2004) including hare, black bear, deer, elk, grouse, and numerous songbirds (Scott and Crouch 1987; Patton and Jones 1977). Old and decaying aspen are important for wildlife (DeByle and Winkour, 1985), suggesting the ecological importance of aspen across all life stages. Aspen corridors also enhance the connectivity of a variety of species including pollinators, small mammals, and birds that would otherwise be subject to the negative impacts of habitat fragmentation (DeByle and Winkour, 1985). Connected networks of aspen maintain ecological processes and species interactions, but as aspen-dominated ecosystems decline, so do these same benefits and many species suffer as a result.

The recruitment of aspen suckers following disturbance can be negatively impacted by browsing and grazing ungulates like deer and elk (Walker et al. 2014). While cattle typically do not browse aspen, they can negatively impact sucker recruitment by trampling young stems (Bork et al 2013). Case studies in the GYE suggest long term large herbivore exclusion in areas where aspen are starting to regenerate could result in higher aspen recruitment rates (Beschta et al. 2016). The re-establishment of predator-prey dynamics through the reintroduction of wolves in the GYE has been shown to reduce ungulate populations and establish a landscape of fear (Laundre & Ripple, 2010) which influences the behavior and spatial range of prey animals. This population reduction may in turn help decrease winter browsing pressure from deer and elk and promote beneficial use of aspen groves by beavers who improve their local hydrology, which may subsequently allow aspen to better establish after a disturbance (Beschta et al. 2016).

With shallow root systems and abundant deciduous leaves, aspen are effective at sequestering large amounts of carbon and provide enough indirect sunlight for a biologically diverse understory (Boča and Van Miegroet, 2017). Their rapid growth and high nutrient demand also play a role in enriching soils (Ste-Marie and Pare, 1999) and cycling nutrients including water, carbon, nitrogen, and phosphorus (Kurth et al. 2014).

Competition

Across much of its range, aspen compete with conifers (Bartos, 2001). At lower elevations (below 2000 m) and under more xeric conditions --where soil moisture is limiting-- juniper (*Juniperus spp.*) can quickly encroach in areas previously dominated by aspen (Wall et al. 2001). Extended drought conditions and long periods between disturbance by fire can limit aspen's ability to regenerate clonally, leaving stands vulnerable to replacement by more drought tolerant species like juniper. Juniper encroachment often coincides with drier, warmer climate conditions that are well-suited for juniper seed production and establishment. Unlike aspen which cycles nutrients quickly and enriches soils to promote a biodiverse understory, juniper acidifies the soil and cycles nutrients much more slowly, making it difficult for aspen to re-establish (Bates et al. 2006).

At the upper end of aspen's elevational range, competition with conifers such as Douglas fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*) is more common. Aspen grow quickly after disturbance by fire, but after enough time post-disturbance taller conifers tend to shade out aspen causing individual aspen stands to decline. However, the cycle of competition restarts after another major disturbance. Under current climate conditions, lowland aspen stands and aspen in wet microsites near streams transition to conifer cover more slowly while upland mixed aspen/conifer stands experience more rapid conifer establishment. A 2009 study quantifying successional rates in western aspen woodlands determined an average fire return interval of 50-70 years is desirable for the maintenance of aspen in upland areas where conifers are present. Under longer fire return intervals, many aspen in mixed aspen/conifer forests could be lost within 80-200 years (Strand et al. 2009). However, with increasing fire frequency (Weber & Yadav, 2020) this trend may be reversed in favor of aspen. Conversely, increasing drought severity (Anderegg et al. 2013) causes stress to aspen and could negate potential gains from increasing fire disturbance.

In addition to browsing pressure and competition with other vegetation types for critical resources like water, nutrients, and sunlight, aspen are also susceptible to numerous damaging agents including diseases and pests. Some of the more common infections in the western US include various shoot blights, leaf spots, leaf rust fungi, powdery mildew, viruses, trunk rot fungi, bacteria, and an array of cankers (Perala, 1990). As a host to a wide variety of insects (DeByle & Winkour, 1985), only a few types have been known to potentially cause severe damage to aspen. These groups of concern are 1) defoliators like the western tent caterpillar (*Malacasoma califonicum*) and leaf miners like the aspen leaf miners (*Phyllocnistis populiella*), aspen blotch miners (*Phyllonorycter tremuloidiella* and *Lithocolletic salicifoliella),* 2) borers like the poplar borer (*Superda calcaruta*) which opens up channels that make aspen more susceptible to fungal infections, and 3) sucking insects including the vagabond aphid (Mordvilkoja vagabunda) which causes a twisted gall of leaves at twig tips and aphids of the genus *Pemphigus* as well as leafhoppers in the genera *Idiocerus* in the western US which cause leaf browning and can rupture twig bark (Perala, 1990).

All these factors including competition, disturbance, insects, and disease are critical components of a functioning aspen ecosystem and under ideal conditions, would not be cause for concern. However, changing climate patterns like increasingly frequent and prolonged drought conditions leave aspen stressed, resulting in increased vulnerability to infection by secondary agents like insects and disease (Sucoff, 1982).

Disturbance dynamics and conservation measures

Aspen woodlands can range from highly fire-dependent seral communities succeeded by conifers to relatively stable, self-replacing, non-seral communities that may not require fire to stimulate regeneration (Shinneman et al. 2013). While aspen do reproduce sexually, their ability to produce asexually to form an aggregation of genetically identical stems following a disturbance like fire or clearcutting gives them a competitive advantage to act as an early successional species in comparison to slower-growing, non-clonal conifers (Burton, 1966). Aspen's vegetative growth mechanisms are often enhanced by disturbance, allowing for quick succession into suitable areas post-disturbance (Long & Mock, 2012). Fire return intervals vary greatly, but in a well-functioning ecosystem, fire is frequent enough (50-70 years) to stimulate sufficient post-disturbance suckering to satiate browsing requirements (Endress et al. 2012).

Understanding disturbance dynamics can help natural resource managers make ecologically informed management decisions in aspen-dominated systems. Research in the field of environmental conservation shows that small prescribed fires may encourage some aspen regeneration, but may not facilitate long-term aspen gain due to continued pressure from over-browsing, rapid establishment of grasses and shrubs, and limited reduction of competing conifer populations (Wilde 2014). Wilde also suggested higher severity, controlled burns may be a useful management tool to improve aspen regeneration and recruitment by reducing conifer competition while increasing suckering and growth rate and encouraging higher concentrations of defensive compounds including phenolic glycosides and condensed tannins (Lindroth & Clair, 2013) which may increase aspen's resilience to herbivory (Wan et al. 2014).

In addition to being shaped by a variety of abiotic factors, aspen distribution is also influenced by humans, who simplify landscape patterns (Krummel et al. 1987) through activities such as fire suppression, expansion of the wildland urban interface (WUI), clearcutting, and emitting large quantities of greenhouse gases that may contribute to warming climate trends (Romme et al. 2001). Historic fire suppression over the 20th century dramatically altered fire return interval and forest structure in fire-adapted ecosystems leaving a wide range of long-lasting impacts on landscapes across the western US. This resulted in dense, overstocked forests, a large accumulation of flammable forest material, compromised forest health and resilience, and as a result increasingly large and destructive wildfires.

METHODS

Data Acquisition

Landsat 5 Thematic Mapper (TM), Landsat 8 Optical Land Imager (OLI), and Landsat 9 Optical Land Manager+ (OLI+) 30-meter spatial resolution multispectral satellite imagery was used for this study. Each scene contained less than ten-percent cloud cover and was acquired via the United States Geological Survey (USGS) Earth Explorer data portal. Images were selected from the Landsat Collection 2, Level-1 dataset. Images with the least amount of visible cloud cover, snow/ice, or smoke contamination were selected. Eleven overlapping scenes were necessary to cover the initial study area, whereas two overlapping scenes were used to cover the focused study area (FSA), containing 56% of the initial study area acreage (18,231,036 acres initially and 10,254,436 acres FSA).

Due to phenological variability across the FSA as well as cloud, smoke, and snow contamination within both spring (when aspen first green up) and fall imagery (when aspen exhibit striking gold leaves), a single set of imagery comprised of two Landsat scenes was selected for each study year during the growing season (mid-July through mid-August). While each year between 2000 and 2025 was investigated for clear imagery, some years did not provide any usable imagery and were not included in this study.

Topographic layers were acquired from the NASA RECOVER database. These layers include elevation, aspect, landform, maximum curvature, slope, and topographic shape. A distance to streams layer was also created using the Distance module in Idrisi TerrSet (subsequently referred to as TerrSet) and the USGS National Hydrography Dataset (NHD) Rivers, streams, and flowlines layer to calculate and assign a Euclidean distance to each pixel from the nearest perennial or intermittent stream. For use with Landsat imagery, these layers were resampled from 10-meter spatial resolution to 30-meter spatial resolution using the resample geoprocessing tool in ArcGIS Pro with bilinear interpolation, then clipped to the extent of the study area to feed into the decision forest model.

The United States Geologic Survey (USGS) Watershed Boundary Dataset (WBD) is a hydrologic unit dataset that covers the contiguous United States. The hydrologic unit 8 (HUC08) layer was clipped to the FSA and used to assess changes in aspen extent, conifer extent, and climate variables within a watershed scale.

A BLM regions of interest (ROI) layer was created in ArcGIS Pro using a combination of polygon layers for the Soda Springs watershed provided by BLM managers and polygons that were manually digitized to contain managed aspen stands within three BLM project areas in the Island Park watershed. The Ten-Mile and Soda Hills polygons were provided directly by BLM partners and the Sheridan Ridge, Icehouse, and Yale-Kilgore manually digitized.

The Historic Fires Database (HFD) was downloaded from the Idaho State University GIS Training & Research Center website. It contains all documented wildfire perimeters from across the Western United States from 1950 through 2024. The dataset was clipped to the size of the FSA and temporally filtered to contain only fires from 1980 to 2024 for use in subsequent analysis.

Climate trend datasets were developed by Keith Weber as part of the National Science Foundation (NSF) Idaho Community-engaged Resilience for Energy-Water Systems (I-CREWS) project for the years 1980-2022. These datasets were created using the Daymet daily surface weather dataset (Weber, 2025) and downloaded in multidimensional cloud-raster format. Climate datasets used in this study included mean annual maximum/minimum temperature, mean growing season maximum/minimum temperature, sum of annual precipitation, sum of annual growing season precipitation, sum of annual snow water equivalent, annual growing degree days, and annual frost-free days.

Data Preparation

All Landsat scenes were atmospherically corrected in TerrSet's Landsat archive import module where multispectral bands were converted to reflectance using the Cosine(t) model of reflectance correction (Chavez, P.S. 1996).

Using the QA Pixel band provided with each Landsat scene, Boolean cloud masks were created using the raster calculator in TerrSet. In this step, unobstructed or clear pixels were given a value of one and pixels containing cloud, cloud shadow, snow, ice, or smoke were given a value of zero. Each spectral band file was multiplied by its respective cloud mask such that obstructed pixels were given a no data value of zero and therefore omitted from further analysis.

Vegetation Indices

Prepared imagery was used to calculate spectral indices which were used as model inputs to differentiate aspen from other landcover classes. Based on insight from Nieminen (2014) and Hogland et al. (2019), the following indices were calculated: Normalized Difference Vegetation Index (NDVI; Equation 1; Kriegler et al.,1969), and Modified Soil Adjusted Vegetation Index (MSAVI2; Equation 2; Qi et al., 1994). In the equations below, NIR is the near infrared band's surface reflectance, Red is the red band's surface reflectance, SWIR is the shortwave infrared band's surface reflectance.

Equation 1. $NDVI = (NIR - Red)/(NIR + Red)$

Equation 2. $MSAVI2 = \frac{2*NIR+1-\sqrt{(2*NIR+1)^2-8*(NIR-Red)}}{2}$

A ttasseled cap transformation was also applied to imagery which produced layers representing the greenness, wetness (or moistness), and brightness. These data layers were also included as inputs to the model.

Principal Component Analysis

For each Landsat scene, the spectral bands were added to a raster group file in TerrSet. Using the principal component analysis (PCA) module, the first principal component image for each scene was extracted using the Forward T-Mode analysis type and an unstandardized covariance matrix and in all instances, this first PCA component band accounted for 90% or more of the total variability found in the Landsat bands. PCA was used to load the largest amount of variability within the original datasets while removing redundancy between band files (Richards, 2013).

Concatenated Layers and Raster Group Files

All image files used UTM 12N spatial reference system and were concatenated together in TerrSet's CONCAT module to create continuous layers for each band, NDVI, MSAVI2, and PCA layers. These concatenated layers were then clipped to the minimum bounding box around the FSA using the WINDOW module. The topography and distance to streams layers were already continuous over the state of Idaho, so these were simply clipped to the same dimensions as the satellite imagery-derived layers. All these layers (n = 19 for Landsat 5 years, n = 20 for Landsat 8/9 years) were stored within a single raster group file (RGF) for each study year.

Field Sites

To train and validate the models, a set of known field sites was created using a combination of field observations, interpretation of aerial imagery, and the LANDFIRE Existing Vegetation Type (EVT) model (USDOI, USGS, USDA, 2023). While this study focused on aspen in particular and conifers secondarily, the field sites for model training and validation were grouped into ten land cover classes (**Table 1**).

Table 1. Ten land cover classes were used for classification with Decision Forest in TerrSet.

Class ID	**Class Name**	**Samples (*n*)**
1	Aspen	432
2	Sagebrush steppe	389
3	Conifer	233
4	Agriculture	142
5	Water	305
6	Impervious surfaces	76
7	Basalt	144
8	Riparian	116
9	Cottonwood	76
10	Maple	138

The field points feature class was randomly subset in ArcGIS Pro using a 50-50 split for each landcover class. In other words, half of the points were used for training the decision forest models and the other half were reserved for independent validation of the models. The training and validation point feature classes for each study year were converted to raster layers with 30-m resolution matching all other raster input layers used in this study.

Decision Forest Modeling and Validation

Using the Decision Forest module in TerrSet, the RGF files described above were used as inputs for the Decision Forest models. The parameters for each model run were as follows: four variables were allowed at each split, 100 trees (model iterations), output hard classification image, and output probability images. The Decision Forest models were trained using the rasterized training field sites layers described above.

Model outputs for each study year were validated using the Error Matrix (ErrMat) module in TerrSet. ErrMat creates an error matrix that tabulates the different land cover classes assigned in the ground truth image. It determines how many instances of each class were classified in agreement between the output model and the validation sites. Similarly, it also calculates the number of instances where the classified model and validation data do not agree and are thus, are considered in error. Furthermore, ErrMat calculates the error of omission and the error of commission for each class, as well as overall error, and the kappa index of agreement (KIA) for each class and for the overall model. Specific to this study, ErrMat provided an initial sense of model reliability and helped identify useful or problematic input layers and direct future iterations of decision forest modeling. To calculate each matrix table, the output hard classification model was used as the categorical map image tested against the raster layer containing reserved validation field sites (input ground truth image).

Statistically-Derived Probability Thresholds

To calculate and compare predicted aspen acreage, predicted conifer acreage, and avoid gross over classification, a statistically-derived probability threshold (PT) was applied to both the aspen and conifer class layers for each model year. To derive the PT, the pixel value at each reserved validation point was extracted from the aspen class and conifer class probability layers. From these datasets, the mean probability value was determined. This value became the PT applied to each model resulting in mean probability values ranging from 0.56 to 0.63 (**Table 2**). Aspen class and conifer class pixels with values greater than or equal to the PT for each corresponding model year were assumed to contain pure, dense aspen and subsequently used for further analysis. This process was repeated for conifer land cover as well. Two Boolean raster layers were created for each model year using the appropriate PT for aspen (or conifers) using TerrSet's raster calculator.

The PT-derived Boolean raster outputs for aspen and conifer cover classes for each model year were converted from Terrset RST format to TIF format and imported into ArcGIS Pro. The raster layers were then converted into polygons using the Batch Raster to Polygon tool with the "simplify polygons" option selected. Using the Batch Calculate Field function, an Acres field was added to each of the new vector layers using the following equation:

Equation 3: $Acreage = Shape\ Area\ (meters^2) * \ 0.000247105$

To further reduce overprediction, a minimum mapping unit (MMU) of one acre was applied using the Batch Export Features function where vectorized model outputs were filtered to only contain polygons greater than or equal to 1 acre in size.

Table 2. Statistically derived thresholds (PT) for aspen and conifer. These were determined using the Extract Multi Values to Points tool in ArcGIS Pro where the values from the DF probability layers were extracted from reserved validation points for aspen and conifer respectively. Using summary statistics, the mean value for each model year was calculated and applied accordingly.

	Aspen PT	**Conifer PT**
2000	0.58	0.61
2002	0.56	0.63
2003	0.60	0.65
2004	0.58	0.61
2005	0.55	0.64
2006	0.58	0.68
2007	0.55	0.65
2010	0.63	0.68
2011	0.58	0.67
2013	0.59	0.65
2015	0.63	0.65
2020	0.63	0.68
2023	0.62	0.65
2024	0.60	0.67
2025	0.62	0.68

Conversion of Model Outputs to Vector and Acreage Calculations

To calculate the model-predicted acreage for aspen and conifer for each model year, the vectorized layers described above was intersected iteratively with (1) the FSA boundary, (2) the HUC08 watersheds layer, and (3) the BLM regions of interest (roi) layer. Each set of intersected layers was Dissolved accordingly using either (1) FSA, (2) HUC08, or (3) BLM rois with the create multipart features option enabled. Using the Export Table to Excel tool, each set of outputs were exported into Excel and acreage was graphed over the study period for both aspen and conifer cover classes at each of three scales (1) FSA, (2) HUC08, and (3) BLM roi scale.

Determination of Model Years to Include in Trend Analysis

To determine which model years to include in trend analysis, the following factors were investigated: 1) availability of cloud-free, smoke-free growing season imagery, 2) alignment of scene footprints and resulting image georegistration, 3) date of imagery acquisition, 4) and comparison of vegetation indices.

Several years did not have any useable imagery within the target temporal window (2000 through 2025) and were not included in this study. These were 2001, 2008, 2009, 2012, 2014, 2016, 2017, 2018, 2019, 2021, and 2022. Furthermore, the years 2000 through 2003 were removed because of footprint mismatch and potential loss of image-to-image georegistration. The years 2010 and 2015 were removed because the only useable imagery was from September. Inclusion of these data would cause excessive phenological variation as all other years' imagery were acquired in July and August. In four instances, the resulting vegetation indices (NDVI, MSAVI2) resulted in anomalously high or low values compared to other years even when precipitation and temperature patterns were comparable. The years 2006, 2010, 2013, and 2015 were removed. After all anomalous or erroneous model years were removed, trend analysis was able to proceed using the years 2004, 2005, 2007, 2011, 2020, 2023, 2024, 2025.

Historic Fires

Fire footprints from the Historic Fires Database (HFD) were intersected with modeled aspen polygons. An examination of fires intersecting with model-predicted aspen stands was conducted to determine when stands may have most recently experienced burning.

Climatic Factors

Annual and seasonal climate trend datasets were used to identify factors that could explain observed changes in aspen extent over time. To account for lag in vegetation response to climate change, data beginning in 1995 was used. Using the Batch Zonal Statistics (processed as multidimensional enabled) and Table to Excel tools in ArcGIS Pro, all climate datasets were graphed at the FSA scale and at the HUC08 watershed basin scale. This analysis was completed using visual assessment.

RESULTS AND DISCUSSION

Based on the DF model, aspen has declined in extent across the FSA by approximately 50,000 acres (32%) between 2004 (163,356 acres) and 2025 (112,320 acres) (**Figure 2**). Personal communications with land managers working in the region since 2000 indicates general agreement that while aspen has declined, the abundance of aspen modelled in 2004 is likely an overestimation and the actual loss of aspen is not as substantial as predicted by our models.

Results of watershed basin analysis show this trend is not spatially consistent however, with some watersheds exhibiting stability while others show more sharp declines.

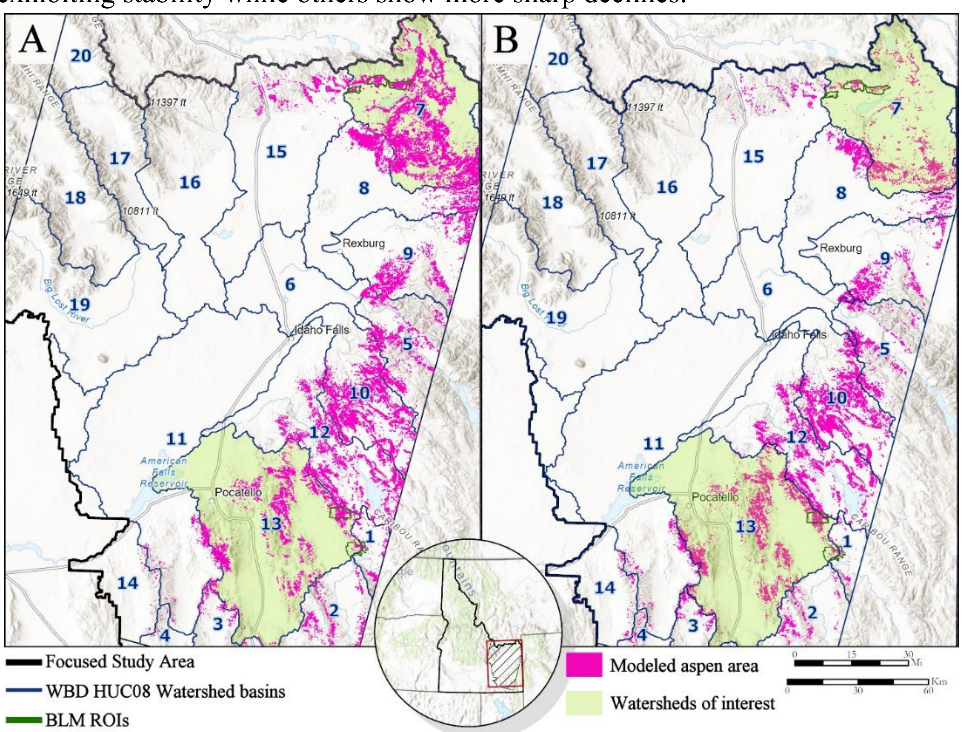

Figure 2. Model-predicted aspen with an MMU of one acre applied. Map A (left) shows modelled aspen output from 2004 and map B (right) shows output from 2025.

Landcover Trends

Trends relating to aspen and conifer cover classes are presented starting with trends at the FSA scale, then over two selected watershed basins, and finally over the five smaller BLM roi areas. The two watershed basins specifically used for comparison were selected as they exist at opposite ends of the FSA's latitudinal range and, more importantly, have been identified as priority areas by land managers at the BLM.

At the FSA scale, aspen extent appears to be declining between 2004 to 2025, whereas conifer appear to be expanding (**Figure 3**). This generally aligns with what has been observed by BLM land managers and agrees with studies conducted in Colorado and Utah. However, ecological trends often differ depending on the scale at which they are observed.

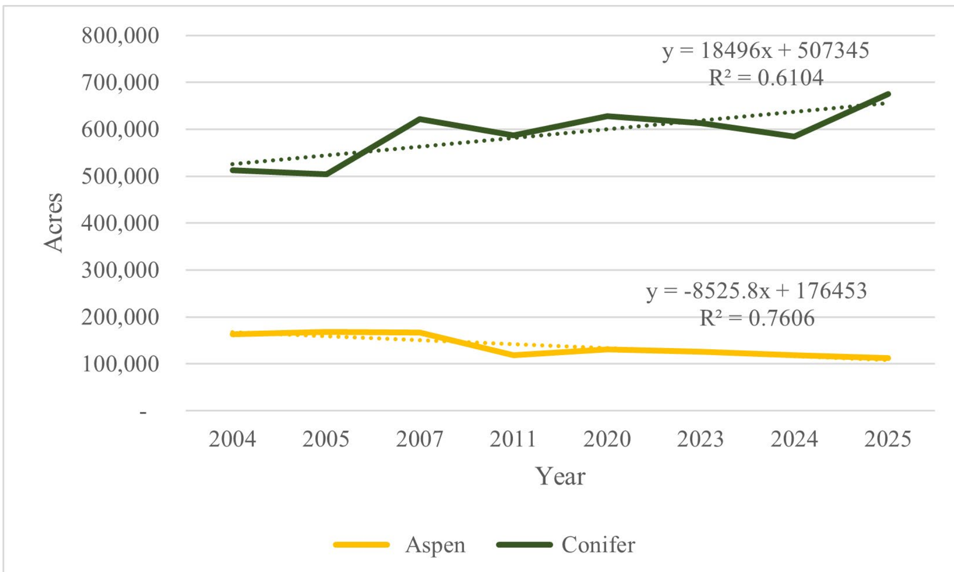

Figure 3 Acreage of modeled aspen and conifer classes for the focused study area.

At the watershed basin scale, trends in aspen extent were more variable. The watershed basins in the western half of the FSA contained very little aspen even in 2004, with subsequent years being highly variable and not particularly informative in comparison to the trends observed in the eastern watershed basins. These watersheds are more relevant to this study as these areas represent more suitable aspen habitat and contain the majority of field sites the models were trained on. Two of the 20 full or partial watershed basins were singled out as being of particular interest to BLM managers; the first contains the Pocatello and Soda Springs regions (henceforth referred to as Zone 13). The second watershed basin contains the Island Park region (henceforth referred to as Zone 7).

Zone 13 is in the southeast portion of the FSA. In contrast to the overall declining trend in aspen noted over the entire FSA, Zone 13 does not exhibit any strong increasing or declining trend and in fact, aspen extent appears to be relatively stable. Conifer cover in Zone 13 appears to be decreasing in extent which will be discussed later in this paper (**Figure 4**).

Zone 7 is located in the northeast portion of the FSA. In comparison to the more or less stable trend in aspen extent observed in Zone 13, Zone 7 exhibits a stronger declining trend in aspen extent accompanied by a steady increase in conifer extent (**Figure 5**). This suggests conifers may be outcompeting aspen in this watershed basin. Without fire (or other similar disturbance) to reduce competition from conifers and stimulate vegetative regeneration in aspen, this trend will likely continue.

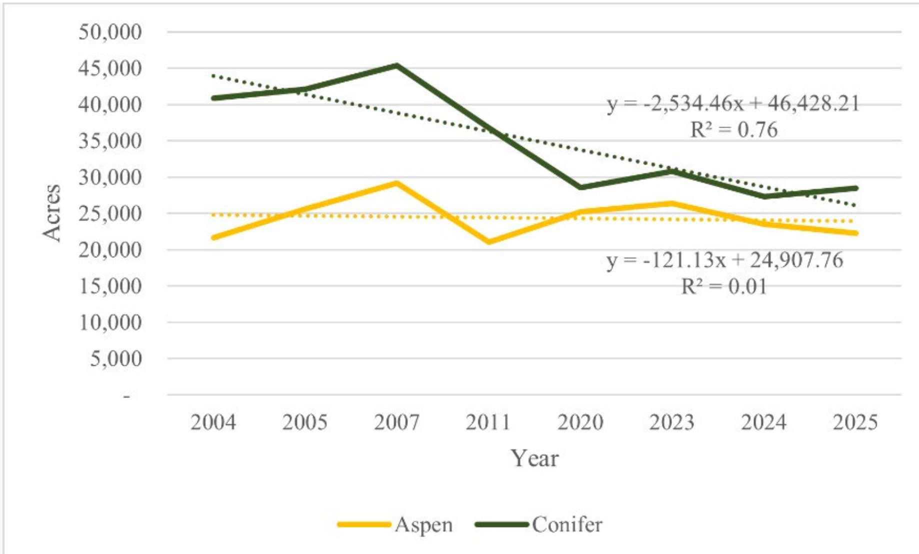

Figure 4 Acreage of modeled aspen and conifer classes for the Zone 13 watershed basin.

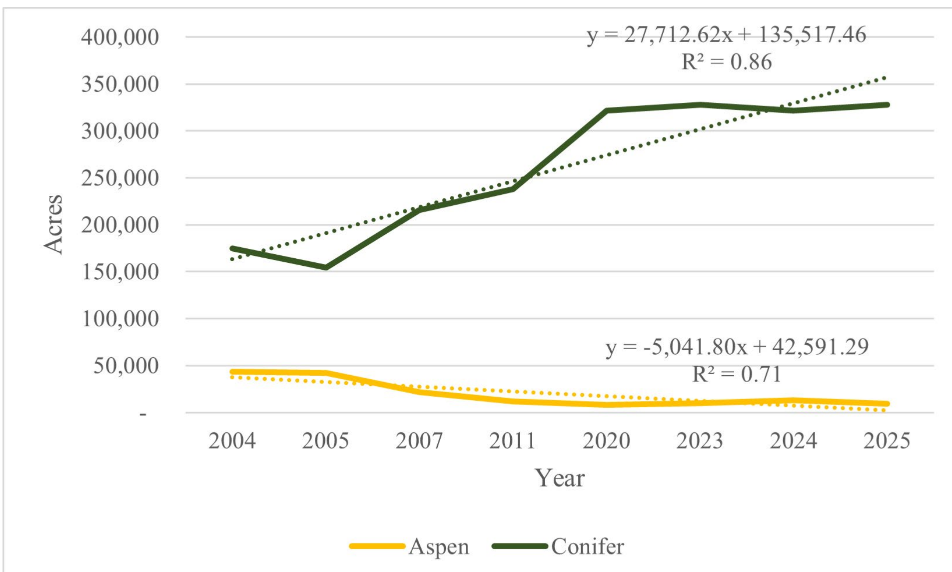

Figure 5 Acreage of modeled aspen and conifer classes for the Zone 7 watershed basin.

At the even more spatially resolved scale of BLM roi areas, similar overall trends were observed. Within the Zone 13 watershed basin, two roi's referred to as the 10-Mile area and the Soda Hills area are located. Aside from what appears to be an anomalous spike in model-predicted aspen in the year 2005, aspen extent appears to be relatively stable within the 10-Mile area which aligns well with the stable trend seen in Zone 13 overall. Conifer extent appears to be declining in this area, which also aligns well with what was observed in Zone 13 overall (**Figure 6**).

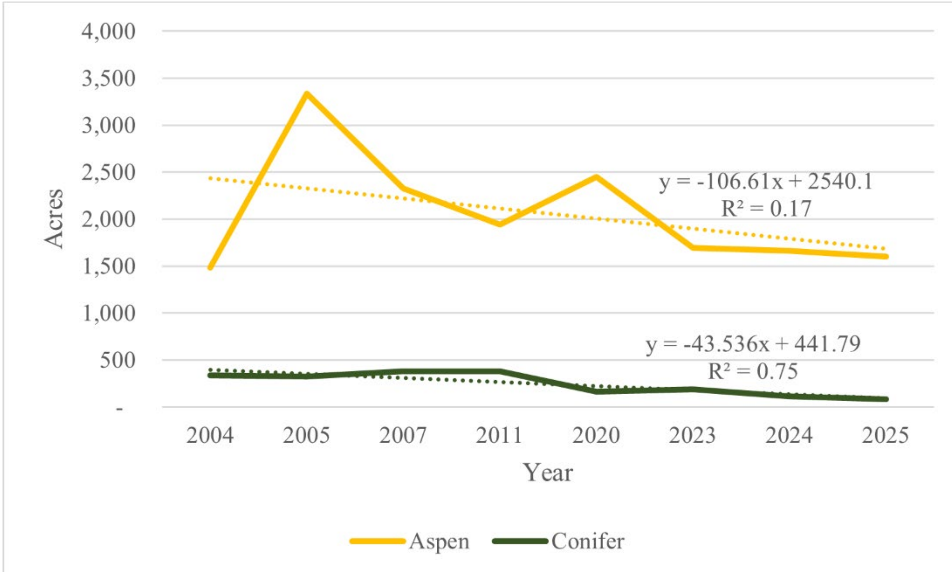

Figure 6. Acreage of modeled aspen and conifer classes for the 10-Mile BLM roi.

Similarly, the smaller extent of modelled aspen is relatively stable in the Soda Hills area. In contrast to the 10-Mile area --but in line with overall FSA trends-- model-predicted conifer extent appear to be increasing in the Soda Hills roi (**Figure 7**).

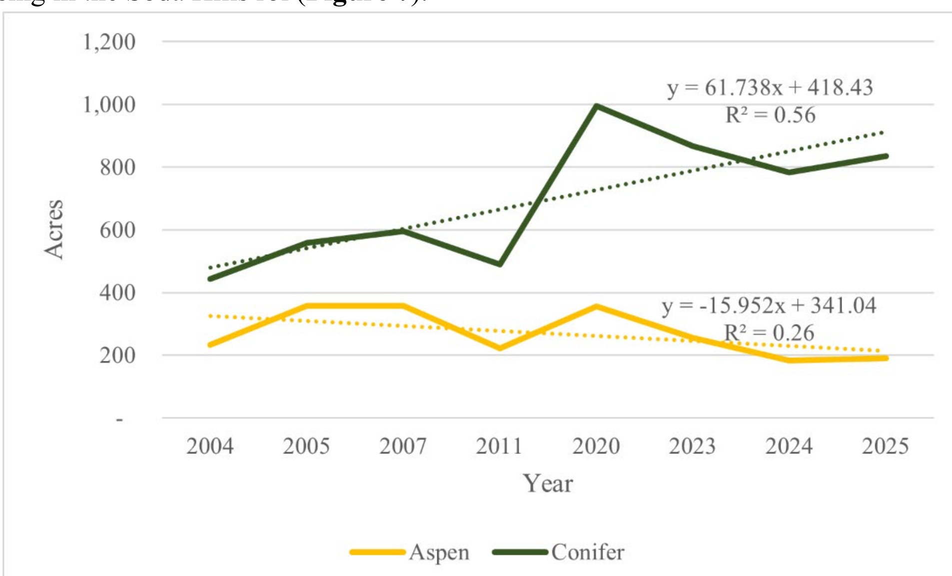

Figure 7 Acreage of modeled aspen and conifer classes for the Soda Hills BLM roi.

In the northeast section of the FSA, the Zone 7 watershed basin contains three smaller roi areas referred to as (1) Icehouse, (2) Yale-Kilgore, and (3) Sheridan Ridge areas. Modelled aspen extent in the

Icehouse area showed some variability within an overall declining trend. Model-predicted conifer extent appeared to be increasing in the Icehouse roi as well (**Figure 8**).

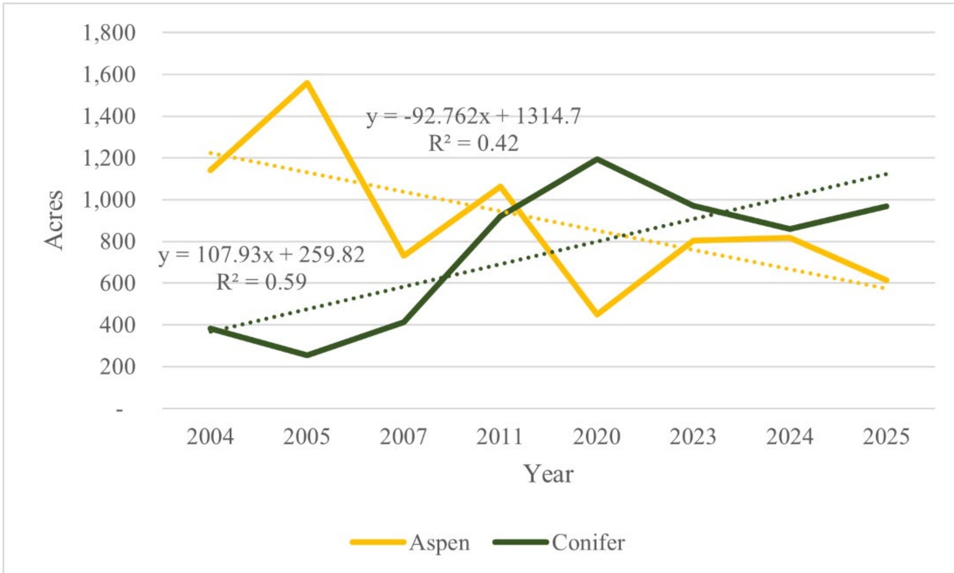

Figure 8. Acreage of modeled aspen and conifer classes for the Icehouse BLM roi.

The Yale-Kilgore roi shows a distinct decline in modelled aspen and a slight increase in conifer (**Figure 9**). This follows well with the trend seen in the larger Zone 7 watershed basin as well as in the overall FSA.

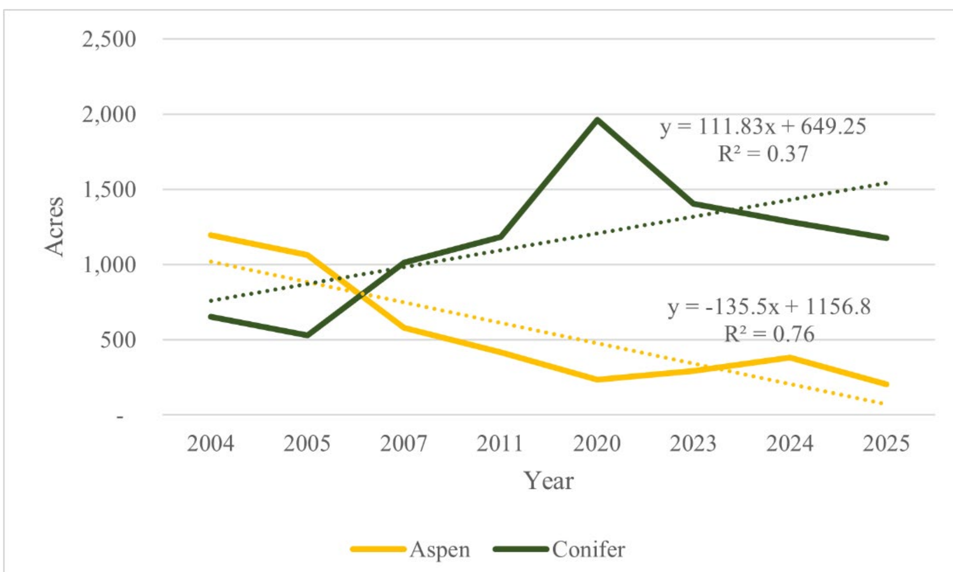

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Figure 9. Acreage of aspen and conifer classes for the Yale Kilgore BLM roi.

The Sheridan Ridge roi area also showed a declining trend in modelled aspen and an increasing trend in modelled conifer, though with lower predicted acreage and more variability as indicated by the lower R^2 value (0.50). Neither the aspen nor conifer trends are as distinct as those at the watershed basin scale or at the scale of the FSA.

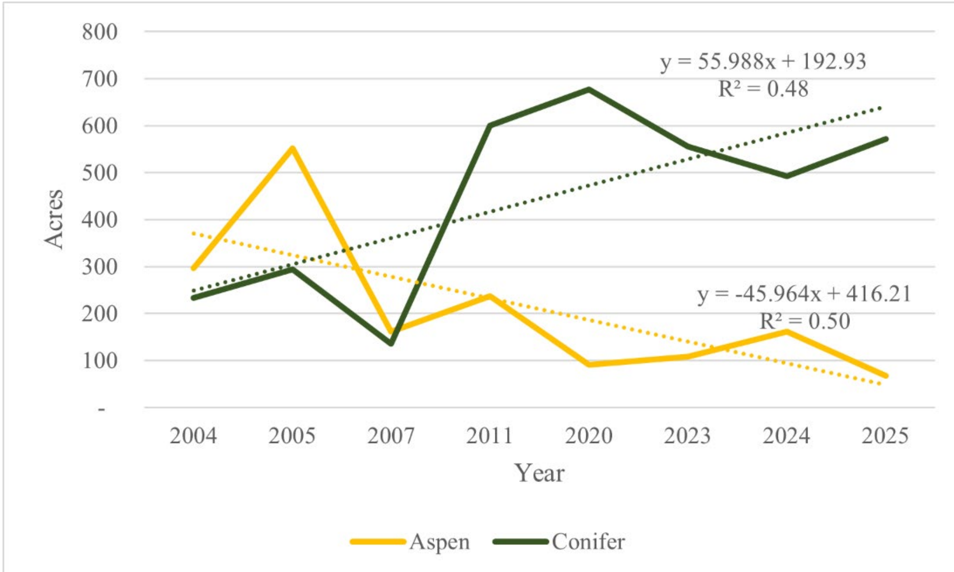

Figure 10. Acreage of modeled aspen and conifer classes for the Sheridan Ridge BLM roi.

Climatic Factors

At the FSA scale, mean annual maximum temperatures have increased slightly (0.5° C) and mean annual minimum temperatures have increased even more (1.5°C). In addition, mean maximum and minimum temperatures across growing seasons has also increased (0.7°C and 1.5°C, respectively). While precipitation, including the sum of annual precipitation, sum of growing season precipitation, and snow water equivalent (SWE) oscillate quite a bit on multiyear cycles, they all exhibit a weak declining trend over the study period. Growing degree days (GDD) and frost-free days (FDD) have increased at the FSA scale, which may result in aspen being stressed for longer periods of time when under droughty conditions, subsequently leading to more susceptibility to damage from secondary disturbance agents like pests and pathogens under these specific circumstances. At the FSA scale, trends in FFD, GDD, growing season Tmax/Tmin, and winter Tmin were all statistically significant based on Mann-Kendall analysis, while precipitation and SWE trends –while suggesting overall declines-- were not strong and not considered significant.

Trends at the Watershed Basin Scale

The trends described above were also seen at the watershed basin scale, but with several key differences. While Zone 7 is seeing less precipitation annually over time, growing season precipitation has remained largely stable over the study period. However, SWE has decreased more dramatically than seen in Zone 13. In Zone 7, FFD, GDD, growing season Tmax/Tmin, and winter Tmin were all considered statistically significant trends based on Mann-Kendall analysis. In Zone 13, only FFD, GDD, growing season Tmin, and winter Tmin were considered significant. Precipitation and SWE did not exhibit statistically significant trends in either watershed.

Aspen Decline

Overall, the results of this study suggest a declining trend in aspen over the FSA, and from these data it may be inferred that a similar trend exists across the larger, initial study area (**Figure 1**). However, without an abundance of aspen in the northwest portion of the study area, the stands that do exist appear to be small and mixed with coniferous forest, making it more difficult to detect using remotely-sensed imagery.

A sharp decline in modeled aspen acreage was seen in the Island Park watershed basin. Rising minimum temperatures, declining growing season precipitation, and declining snow water equivalent may be at least partially responsible for these changes resulting in increased stress for aspen due to their relatively shallow roots and high-water requirements. This in turn may leave aspen susceptible to secondary disturbance from pests and pathogens. Reduced SWE also leaves young aspen suckers exposed to winter herbivory, resulting in lower recruitment rates. However, it should be noted that precipitation and SWE did not exhibit a strong significant trend over the study period within the FSA or either of the watershed basins used in analysis and these results should be understood accordingly. Rising trends in predicted conifer acreage suggest aspen may be experiencing notable competition from conifer encroachment. Given that aspen typically require a disturbance --like fire or clearcutting-- to stimulate root suckering the lack of disturbance helps explain why aspen are declining.

Model outputs suggest aspen are relatively stable in the Pocatello/Soda Springs watershed basin. This can likely be attributed to more recent stand-stimulating wildfires in this area and less dramatic shifts in climatic conditions in comparison to the trends seen in higher elevation sites and higher latitude watershed basins like Island Park. This does not necessarily mean that land managers should cease management and monitoring of aspen in these areas as few stands visited during the field season demonstrated the vigorous regeneration in the under- and mid-stories that is representative of a healthy, mixed-age stand. Further south in Utah, studies report declines in aspen as well. This indicates the potential drivers of observed decline in eastern Idaho are more likely attributable to disturbance patterns rather than climatic factors at this time. Given the relative stability of predicted aspen acreage over the study period, a lack of notable conifer encroachment, more recent wildfire disturbance, and more subtle climatic shifts in key variables like minimum temperature, growing season precipitation, and snow water equivalent, there may be more time to prepare for shifts that could trigger more substantial levels of decline.

Uncertainty

This study was not without its challenges. Given the large geographic area of the original study area (73,778 km^2) and limited availability of smoke-free, cloud-free, snow-free Landsat imagery over the growing season for each year, results from the analysis of the original study area were inconclusive. The decision forest classifier simply did not perform well across such a spatio-temporally diverse study area with high levels of phenological variability and broad elevational and latitudinal gradients. Even with the smaller FSA (41,498 km^2) the understory of aspen field sites was highly variable making it difficult to define consistent spectral signatures of aspen sites.

Future Direction

For future explorations of aspen populations at the landscape scale in southeast Idaho, researchers could explore 1) a smaller, even more focused study area; 2) conducting analyses with more spatially resolved commercial imagery; and 3) phenological date synchronization of imagery across the study area (Weber, 2001)).

Given phenological variation across the study area and high variability of understories at aspen field sites, it was difficult for the decision forest model to define a consistent spectral signature across the FSA. More targeted studies of smaller areas with reliably ground-truthed field sites would improve model accuracy and reliability while providing land managers with more relevant localized information. Keeping future study areas small enough to fit within a single Landsat scene or within a single selection of alternative satellite imagery would eliminate some of the challenges faced in this study.

For a more detailed modeled inventory of aspen stands in a more focused study area, researchers and land managers could consider looking into finer spatial resolution commercial imagery like from SPOT 6 at 1.5-meter spatial resolution. Ten-meter Sentinel-2 data were used as inputs for an exploratory decision forest model over a portion of the study area for this project and results were compared to a model trained using comparable Landsat imagery at 30-m spatial resolution to see if the model would perform better and be able to detect smaller aspen stands without grossly overpredicting. This brief exploration showed that the Sentinel-derived Decision Forest Model (SDDFM) did not perform as well as the Landsat-derived Decision Forest Model (SDDFM) when compared on the basis of mean probability values at reserved field sites. The SDDFM also predicted 51% more aspen within the study area when compared to the LDDFM which appeared to be overpredicting aspen as well. These results suggest that for studying general trends in aspen extent at a broad landscape scale, Landsat's 30-meter spatial resolution is adequate. However, detecting individual aspen trees or small stands for precise inventory is not possible at this resolution. The 10-meter spatial resolution of the SDDFM did not improve model accuracy and predicted nearly twice as much aspen overall. This suggests Sentinel-2 imagery is also not able to provide small stand detection.

Additionally, for future studies of aspen at a large landscape scale, researchers could attempt to phenologically synchronize data across a study area. For example, phenology on June 1st in the southeast section of the study area may be equivalent to the ecology of the northwest portion on July 1st. This would need to be done not only across the study area, but also across the study period. Greenup is highly dependent on climate drivers like minimum and maximum temperatures, snowpack/snow water equivalent (SWE), timing and amount of snowmelt, and precipitation. Peak gold color of aspen leaves in fall and senescence is also dependent on variables such as precipitation, maximum and minimum temperatures, and number of daylight hours. To do a phenological synchronization of data, one would need reliable climate data over the period of study for the entire area of interest. This would allow for more targeted acquisition of imagery and perhaps a more reliable classification over a large study area. However, another limiting factor would be the availability of unobstructed imagery on or near the phenologically synchronized dates, which can be challenging when satellites only collect imagery every 8-16 days regardless of possible obstructions like cloud cover, wildfire smoke, snow, and ice.

CONCLUSIONS

The results of this study indicate aspen are declining across eastern Idaho. The pattern of decline is not spatially consistent however as aspen stands in the northern portions of the study area show a stronger declining trend than that observed in southern portions of the study area which exhibit more or less stable trends between 2004 and 2025. Personal communications with land managers working in the region since 2000 indicates general agreement that aspen has declined, however, the abundance of aspen modelled in 2004 may be an overestimation and the actual loss of aspen is not as substantial as modelled.

It is of interest that in areas where aspen extent is declining, conifer extent appears to be concomitantly increasing. This suggests the cause of aspen decline may be due to a lack of recent disturbance such as wildfire or clear cutting/thinning. However, the impact of interacting climatic factors should not be overlooked. In particular, both growing season and winter mean temperatures have increased across the study area ($P < 0.05$) and the length of the growing season as indicated by both frost-free days and growing degree days has also increased ($P < 0.05$) across the focused study area as well as within the two specific watershed basins explored in this study. The increasing temperatures and longer growing seasons could add stressors to aspen especially when coupled with conifer competition and drought conditions.

Though results at the original study area scale were inconclusive due to data limitations and high levels of phenological, elevational, and latitudinal variation, this study provides insight into generally declining trends in aspen extent across eastern Idaho, which aligns with observations from regional land managers. Based on findings from this study, disturbance-simulating treatment options like prescribed fire, clearcutting, and selective harvest to stimulate root-suckering, combined with post-treatment exclosures should be considered in the watersheds investigated, but would potentially have the greatest impact on aspen stands in Zone 7. While model results indicate more stable aspen stands in Zone 13, perhaps due to more recent fires, active treatment, and less competition, further monitoring is encouraged.

Future research should consider taking this work a step farther by modeling over smaller, study areas using more spatially resolved, phenologically synchronized imagery to produce more reliable inventories of local aspen stands. Land managers may also consider conducting focused modelling efforts over specific treatment areas modelling aspen extent before treatment, shortly after treatment, and at multiyear intervals post treatment as a resource-efficient complement to field surveys.

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