Final Report: Sage-grouse hate trees: A range-wide solution for increasing bird benefits through accelerated conifer removal

WAFWA Contract Number: SG-C-13-03

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Project Summary

Invasive woody plant expansion is a primary threat driving fragmentation and loss of sagebrush (*Artemisia* spp.) habitats across the western United States. Expansion of native woody plants, primarily *Juniperus* spp., over the past century is primarily attributable to wildfire suppression, historic periods of intensive livestock grazing, and changes in climate. To inform and guide successful conservation and management programs aimed at reducing woody plant encroachment, we mapped invasive woody plants at regional scales to evaluate landscape level impacts, drive targeted restoration actions, and monitor restoration outcomes. Our overarching goal was to produce seamless regional products across socio-political boundaries with resolution fine enough to depict the spatial extent and degree of woody plant invasion relevant to sage grouse conservation and management efforts. We successfully mapped tree canopy cover in occupied sage-grouse habitat across a 7-state region (466,646 km^2). Conifer occupied sage-grouse habitat was variable across the range. According to our mapping products a relatively large proportion of the range (76%) was treeless (<1% conifer cover). Early to moderate levels of conifer cover (1-20%) occurred in ~19% of the mapping area, while the highest conifer cover class (>20%) was found across ~5% of the mapping area. These results indicate that a high proportion of invading woody plants are at a low to intermediate level suggesting that actions to reduce invasive woody plant dominance can be largely successful and should be undertaken with some urgency. The canopy cover maps resulting from this study provide the first and most geographically complete, high resolution assessment of woody plant expansion as a top-down threat to western sage-steppe ecosystems.

Background

In the western United States, the expansion of invasive woody plants into predominantly treeless landscapes has structurally altered these ecosystems and reduced habitat availability for many wildlife species (Brown and Archer, 1999; Engle et al., 2008, Miller et al. 2011). Expansion of native woody plants, including conifer (primarily *Juniperus* spp.) over ca. 130 years is primarily attributable to wildfire suppression, historic periods of intensive livestock grazing, and changes in climate (Brown and Archer, 1989; Miller and Wigand, 1994; Miller and Rose, 1999; Waichler et al., 2001; Miller et al., 2005; Van Auken, 2009). Woody encroachment increases surface water runoff and erosion by shading out the native abundance and diversity of herbaceous cover (Buckhouse and Gaither, 1982; Gaither and Buckhouse, 1983; Miller et al., 2011). With increased runoff and rainfall interception, encroachment can lower the water table, thus reducing water availability in the system (Baker, 1984; Heitschmidt et al., 1988, Wilcox, 2002; Throp et al., 2013). Impacts to wildlife populations from these changes in ecosystem dynamics are well known. For example, in sage-steppe ecosystems of the Great Basin, numerous studies have documented negative impacts from conifer encroachment to greater sage-grouse (*Centrocercus urophasianus*, hereafter sage-grouse; Doherty et al., 2008; Atamian et al., 2010; Doherty et al., 2010; Casazza et al., 2011; Baruch-Mordo et al., 2013; Knick et al., 2013a, 2013b), and other sagebrush obligates (Noson et al., 2006; Larrucea and Brussard, 2008; Woods et al., 2013).

Broad-scale mapping of invasive woody species was urgently needed to inform proactive management to restore habitats impacted by woody encroachment already underway through partnership efforts, such as, the NRCS-led Sage Grouse Initiative (SGI; NRCS, 2015a). To date, SGI has invested $760 million in sage-grouse conservation, including the mechanical removal of early successional conifer to restore 182,610 ha of sage-steppe habitats in and around sage-grouse population strongholds (NRCS, 2015a). Concern about the need for broad scale mapping to inform sage-grouse conservation practices ultimately led to the Western Association of Fish and Wildlife Agencies (WAFWA) to obtain $400,000 in funding from the NFWF, USFWS, and the Utah Watershed Initiative to support this work.

Regional mapping of woody invasion using remotely sensed data to inform species and ecosystem conservation has become increasingly feasible and desired, yet, efficacy depends upon the scale of the object of interest (e.g., individual or stand of woody plants), sensor-specific resolutions and spatial extent of the mapping area of interest (Coops et al., 2007; Falkowski et al., 2009). Remote sensing systems that acquire images with large spatial extents will have a lower spatial resolution, and will ultimately measure less spatial detail as compared to images acquired by higher spatial resolution sensors that provide detailed depictions of ecosystem characteristics across small spatial extents. The emergence of object-based image analysis (OBIA) techniques and VHSR data (spatial resolution < 2 m) has resulted in increased accuracy and precision of woody plant mapping. OBIA methods extract objects of interest from digital imagery by first grouping together neighboring pixels with similar spectral and spatial properties and then classifying these pixel groups into objects of interest (e.g., trees). When using VHSR data for mapping woody plants, OBIA outputs are typically polygons delineating specified objects of interest (e.g., woody plants or patches of woody plants; Poznanovic et al., 2014). OBIA approaches such as spatial wavelet analysis (SWA) produce detailed output that can be used to calculate metrics including, canopy cover, tree density, canopy configuration, and crown diameter distributions; many of which have been identified as important drivers of sage-grouse lek activity (Baruch-Mordo et al., 2013).

In this project, we mapped invasive woody plants at regional scales to facilitate evaluations of threat impacts, aid spatial targeting of restorative actions, and support quantification and tracking of restoration progress and outcomes. Our overarching goal was to produce seamless regional products across political and administrative boundaries with a resolution fine enough to allow a nuanced depiction of the spatial extent and degree of woody plant invasion. Towards this end, our mapping framework meets five criteria to ensure its utility:

1. Accurate mapping of woody plant abundance at low canopy values because both sage-grouse species avoid otherwise suitable habitats at <5% tree canopy cover (e.g., Fuhlendorf et al., 2002; Baruch-Mordo et al., 2013; Knick et al., 2013a, 2013b)
2. Adequate tree-level detail (e.g., tree location and crown diameter) to provide the most flexibility for estimating multiple woody plant metrics such as canopy cover, tree density, spatial canopy configuration, and crown size distributions that could be leveraged in proactive conservation (Baruch-Mordo et al., 2013)

3. High level of consistency in derived woody plant metrics through the leveraging of freely available VHSR data that are collected in a uniform manner
4. Automated processing techniques that directly derive encroachment information from the VHSR data, avoiding methods that require empirical data for parameterization or calibration (e.g., image classification or spectral mixture analysis)
5. High level of automation (through OBIA) given the vast size of the mapping extent, that is balanced and blended with manual image interpretation to maintain consistency and accuracy

Methods

Study Areas

Conifer mapping was conducted across 466,646 km^2 of occupied habitat within the Western Association of Fish and Wildlife Agencies (WAFWA) Sage Grouse Management Zones III-V and VII. Mapped areas include priority conservation areas (PACs) and all surrounding occupied non-PAC habitats regardless of ownership (Figure 1).

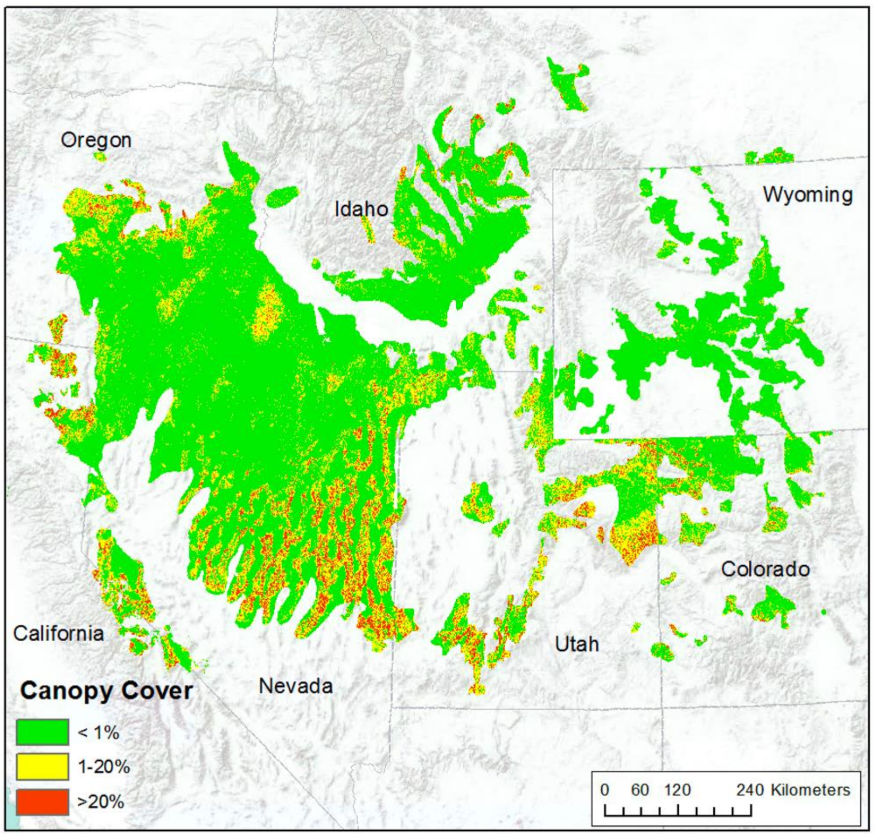

Figure 1. Conifer Cover Mapping Area and Classified Conifer Canopy Cover

Remotely Sensed Data

Digital orthophotos from the National Agriculture Imagery Program (NAIP) were leveraged for mapping woody invasive plants across the SGI and LPCI mapping extents. The NAIP program consistently collects aerial imagery across the U.S. during the growing season on a three year repeat cycle (USDA FSA, 2016). NAIP imagery data are typically four band (red, green, blue, and near infrared) with a spatial resolution between 0.5 - 1.0 m. For the purpose of our study, we obtained the most recent NAIP data available (from project onset) from a variety of sources.

NAIP data were obtained as digital images tiled on a USGS quarter quadrangle basis. Once obtained, NAIP data were processed to generate several image products suitable for woody invasive mapping. These products included vegetation indices such as the Normalized Difference Vegetation Index (NDVI), which highlights photosynthetically active vegetation, and image derivatives such as the image complement (a digital image inversion). These image products were derived to increase contrast between woody invasive plants and background image components (e.g., grass, shrubs, soil, etc.).

Conifer Detection and Mapping - Spatial Wavelet Analysis
We employed an OBIA technique, termed spatial wavelet analysis (SWA), to extract individual conifer locations and crown diameters from the NAIP images. The SWA algorithm is often used to estimate the size and location of individual trees from remote sensing data including both LiDAR data and high resolution imagery such as NAIP (e.g., Falkowski et al., 2006, 2008; Strand et al., 2006; Smith et al., 2008; Poznanovic et al., 2014). SWA uses a dynamically scaled, wavelet-based image filter to decompose digital images into individual objects or features, which in this case correspond to individual woody plants. The principal advantage of SWA over traditional OBIA techniques is that it is not restricted to analyzing features of a characteristic scale (i.e., often the operator or kernel size), which allows extraction of image features that have a characteristic shape but lack a characteristic size (e.g., tree crowns of multiple sizes).

Following previously published methods (e.g., Falkowski et al., 2006; Strand et al., 2006; Poznanovic et al., 2014), we convolved a series of 2D Mexican hat wavelets of progressively larger sizes with NAIP derived NDVI images. Mexican Hat wavelet was chosen because its circular shape approximates that of individual coniferous trees within a NDVI image. The wavelet algorithm records three parameters, namely wavelet size (which is analogous to tree crown diameter), object location (x, y position of the conifer tree*),* and a goodness-of- fit metric (i.e., how well the image filter matches the size of a conifer tree in the image). When conifer trees within the NDVI image are similar in both shape and size to the specific 2D Mexican hat wavelet, the (x, *y*) location of each tree and the wavelet size (i.e., tree crown diameter) associated with the highest goodness-of-fit metric for each separate tree are then retained and recorded. The 2D wavelet algorithm was coded and executed within Matlab® software. Output from SWA analysis was subsequently used to create a raster layer representing individual conifer tree locations and their associated tree crown diameters (Figures 2A-2B). Following this step, technicians performed manual image interpretation of SWA output to ensure proper detection of conifer trees and to identify false detections (e.g., non-conifer tree species, shrubs). Although SWA is effective for detecting conifer trees, it can also generate false detections along abrupt linear features in the imagery (e.g., roads, riparian areas), and will detect deciduous species in certain situations. Once areas of false detection were identified, we created image masks to remove false detections in areas with non-target tree species or cover types. Image masks were developed from multiple sources including pre-existing landcover maps, hydrography layers, as well as manual identification. When areas of under-detection were identified, SWA mapping was repeated with different object detection parameters, and in some situations alternative NAIP image derivatives (e.g., image compliment) were used that were better suited for detecting conifers given inconsistencies in ecosystem characteristics and image quality across the mapping areas

Canopy Cover Calculation and Classification
The conifer crown maps (Figure 1B) were then used to calculate canopy cover via a moving window approach. Specifically, a 64 x 64 pixel moving window approximating a 0.4-ha (1 acre) area was used to estimate percent canopy cover (0-100%) across mapped regions (Figure 2C). Continuous canopy cover output was classified into categories: 0-1%, 1-4%, 4-10%, 10-20%, 20-50%, and > 50% to inform woody plant management (Figure 2D).

Results
The proportion of treeless canopy cover (<1%) in mapped occupied sage-grouse habitats was variable across the SGI mapping extent (76% of the area had canopy cover <1%). Low to medium levels of conifer cover (<20% canopy) were most prominent in 19% of the mapped area, and conifers in the highest cover class (>20%) were scarce (5% of the mapper area; Table 1; Figure 1).

Our results show that invasive conifer cover is widely distributed across the range for sage grouse (Figure 1). However, the distribution of invasive woody plants across the mapping area does not follow an even distribution, but instead appears to be regionally localized with some geographic areas relatively free of major encroachment (Figures. 1-2). For example, in the occupied sage-grouse distribution, northern Nevada, Idaho, Wyoming, and large portions of southeast Oregon provide relatively treeless sage-steppe habitats on which grouse depend (Figure 1). Other parts of the range, however, are experiencing variable levels of encroachment including large portions of Utah, eastern and southcentral Nevada, northeast California, central Oregon, and habitats along the border of California and Nevada (Figure 1). The proportion of sage-grouse distribution supporting invasive woody plants is approximately 24% (Table 1). Additionally, the proportion of area occupied by invasive woody plants was lower inside than outside priority habitats (20% within sage-grouse

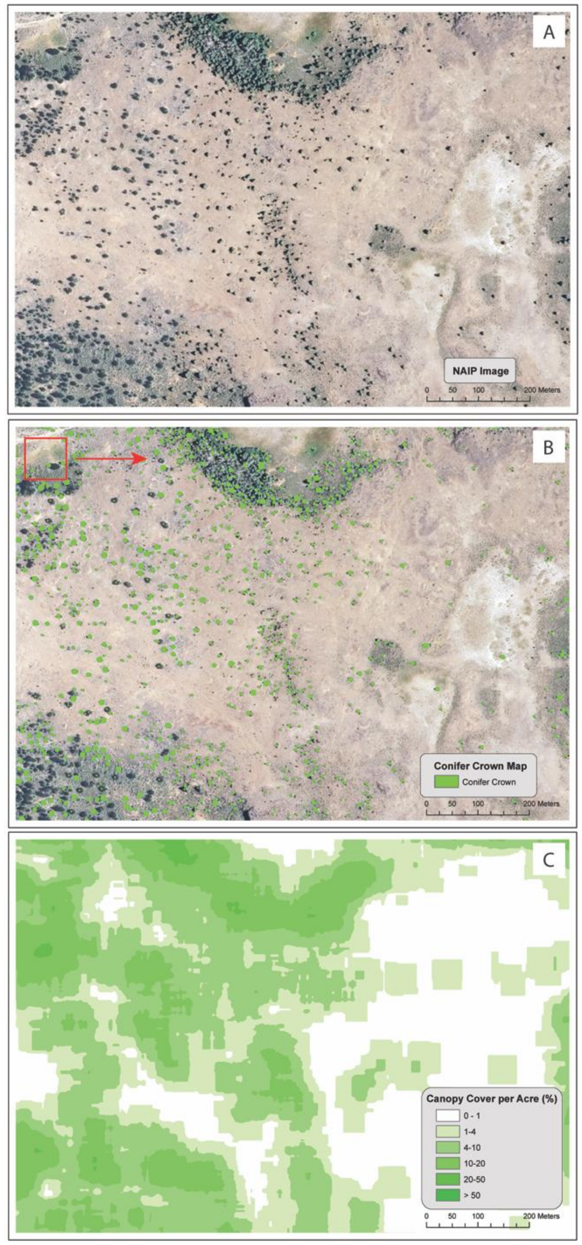

Figure 2. Canopy Cover Mapping Process first uses a NAIP image depicting an area experiencing juniper encroachment (A) and then the SWA derived conifer locations and crown diameter (B, the red square represents the moving window utilized in the canopy cover calculation) to produce the final classified canopy cover estimates for the area (C). Note: the canopy cover mapping approach is similar for mesquite, but the location and crown areas are irregularly shaped polygons outlining mesquite canopies.

PACs (Table 1). By absolute area, Nevada, Idaho and Utah hold the greatest opportunities for sage-grouse restoration inside of PACs (Table 1).

Discussion

Our study represents the most geographically complete, high resolution assessment of conifers across the western United States. The canopy products described herein measure conifer cover at one point in time, and thus are not a direct indicator of conifer expansion (i.e., measurements at two points in time would be required to directly measure expansion). However, the canopy products can be used as a general inference to where expansion may have occurred across any given landscape. The conifer canopy cover maps provide the first synoptic, geographical display of woody plant cover as a top-down threat to the western sage-steppe and prairie ecosystems (Figure 1). For the first time, the maps presented herein capture the complexity in patterns of fragmentation for both species of sage-grouse across their geographic distribution. Sage-grouse habitat connectivity is being impeded by conifer cover between mid and upper elevation habitats and between PACs (Miller et al., 2008; Chambers et al., 2014) (Figure 1).

Table 1. Estimated extent and proportion of conifer canopy cover classes by state in sage-grouse occupied range and PACs.

		Occupied Range		PAC Area (Km2)	
Canopy Cover	**State**	**Area (Km²)**	**Proportion(%)***	**Area (Km²)**	**Proportion(%)***
<1%	CA	6,860	52	4896.2273	56
1 - 4%		1,154	9	832.5497	10
4 - 10%		1,311	10	862.447	10
10 - 20%		1,512	11	871.556	10
>20%		2,421	18	1212.3091	14
CA Total		*13,258*	*100*	8,675	100
<1%	CO	18,191	71	8,307.82	87
1 - 4%		1,857	7	572.66	6
4 - 10%		1,965	8	337.91	4
10 - 20%		2,183	8	215.58	2
>20%		1,561	6	91.49	1
CO Total		*25,757*	*100*	9,525	100
<1%	ID	61,607	85	35,793	91
1 - 4%		3,795	5	1,824	5
4 - 10%		3,228	4	1,204	3
10 - 20%		2,607	4	610	2
>20%		835	1	118	0
ID Total		*72,072*	*100*	39,549	100
<1%	MT	12,685	80	5,236	87
1 - 4%		484	3	143	2
4 - 10%		642	4	176	3
10 - 20%		989	6	236	4
>20%		1,125	7	196	3
MT Total		*15,924*	*100*	5,987	100
<1%	NV	123,050	73	60,927	74
1 - 4%		9,570	6	5,308	6
4 - 10%		9,768	6	4,844	6
10 - 20%		13,526	8	5,899	7
>20%		13,607	8	5,806	7
NV Total		*169,522*	*100*	82,783	100
<1%	OR	64,484	81	23,277	88
1 - 4%		4,272	5	1,267	5
4 - 10%		4,153	5	991	4
10 - 20%		4,200	5	750	3
>20%		2,185	3	283	1
OR Total		*79,293*	*100*	26,568	100
<1%	UT	22,457	*52*	13,997	46
1 - 4%		5,398	*13*	3,721	12
4 - 10%		5,871	*14*	3,773	12
10 - 20%		8,702	*20*	5,107	17
>20%		629	*1*	3,701	12
UT Total		*43,057*	*100*	30,299	100
<1%	WY	45,603	*95*	45,603	*95*
1 - 4%		870	*2*	870	*2*
4 - 10%		698	*1*	698	*1*
10 - 20%		423	*1*	423	*1*
>20%		169	*0*	169	*0*
WY Total		*47,763*	*100*	47,763	100
Grand Total		***466,646***		***251,149***	

* Total area refers to the total area of the mapping units in each state

** Total PAC area refers to the total PAC area within the mapping units in each state

This mapping product is well suited for conservation planning but at the site level a few trees may be missed or incorrectly identified. For example, previous research on the SWA algorithm demonstrated that successful tree detection is dependent upon both tree size (i.e., crown diameter) and spatial resolution of the input imagery. Generally, SWA (or any other object-based remote sensing approach) cannot detect objects smaller than approximately two times the image spatial resolution (i.e., pixel size). In this case, because we leverage 1-m spatial resolution NAIP data, trees smaller than 2 meters in crown diameter (equivalent to 4 pixels in the NAIP imagery) were likely not successfully detected, which cloud certainty and impact end users specifically targeting restoration strategies in early phase invasion sites. Furthermore, end users should also be aware that because the digital sensors used for NAIP image acquisition are un-calibrated, radiometric properties of images vary across space and time, ultimately leading to variation in mapping accuracy. For example, variation due to un-calibrated NAIP can sometimes be seen along image seamlines or along state boundaries (Figure 1). We attempted to maintain accuracy by compensating for variation in phenology using different image derivatives such as image compliment, or by adjusting SWA detection thresholds. Two sources of variation for which we could not compensate include topographic shadowing that may have resulted in under detection or omission of trees, and the inability of OBIA mapping approaches to differentiate between woody plant species, which despite using semi-automated approaches to remove false detections, may have detected non-target species. Alternative image products such as those acquired by high resolution satellite sensors may offer an effective image base for deriving improved canopy cover estimates. For example, data from the WorldView family of satellites offer improved spatial and spectral resolution and have higher geometric and radiometric fidelity as compared to NAIP imagery, and thus may provide an opportunity to improve on the canopy cover product described herein. However, we are highly encouraged by the correspondence between the conifer maps and areas of know woody plant locations at broad scales, and encourage the application of these tools to improve the effectiveness of conservation delivery.

Implementation and Future Work

The results of our study provide wildlife and habitat managers digital maps of canopy cover of encroaching conifers within occupied sage-grouse range for each state as well as range-wide. These maps can be used to balance trade-offs between costs and benefits of various treatment techniques across the landscape. The results of this work were reported out in a webinar hosted by the Great Basin LCC on April 4th, 2016, and in a presentation to the Range-wide Interagency Sage-grouse Conservation Team (RISCT) meeting. Maps and underlying data are available using the visualization and data portals at http://map.sagegrouseinitiative.com and https://www.sciencebase.gov, as well as through the LC MAP data portal. In order to facilitate access by managers to these maps and underlying data, the Sage-Grouse Initiative (SGI) developed a SGI web map page. This page interactively displays a conifer density map, while allowing practitioners to download county-level data for use in research and targeting management actions. These maps have been the most commonly viewed and downloaded data product from the SGI site.

This new mapping information provides practitioners with direct access for planning their next project. Proactive removal of conifers during earlier phases of invasion, using mechanical techniques that minimize ground disturbance and retain shrub and herbaceous communities, are often preferred to delay-and-repair approaches in order to produce more immediate sagebrush-obligate wildlife benefits, maintain ecosystem resilience, and reduce risks of invasive annual grasses (NRCS, 2015a, 2015b; Maestas et al., 2015). Sagebrush-obligate songbird abundance increased 55-85% following shrub-retaining cuts designed to benefit sage-grouse in southern Oregon (Holmes et al., *in press*), but no such response was evident on broadcast-burned sites where juniper skeletons remained (Knick et al., 2014). Fire has approximately twice the treatment life of cutting trees at time horizons approaching 100 years, but has high up-front conservation costs due to temporary loss of sagebrush (Boyd et al., *in press*) and lowers resistance to invasive annual grasses (Miller et al., 2014). Regardless of treatment technique, early intervention to address conifers is economically prudent for livestock producers, especially when cost-shared with conservation partners, to prevent loss of available forage by up to 60% (McClain et al., *In Press*) if targeted towards more productive soils.

Digital maps used as targeting tools maximize biological return on investment by reducing cost of removal (Bottrill et al., 2009). Our high-resolution mapping provides a mechanism for quantifying and tracking threat reduction thereby increasing transparency and accountability for conservation funding. For example, map products enabled partners implementing SGI in Oregon to better estimate the extent of the early conifer encroachment threat which allowed development of a spatially-explicit investment strategy for solving the problem in and around PACs (NRCS, 2015a, 2015b; Figure 2). As a result, targeted conifer removal increased >1,400% in five years and resulted in a two-thirds reduction of the early phase conifer threat on private lands (NRCS, 2015a).

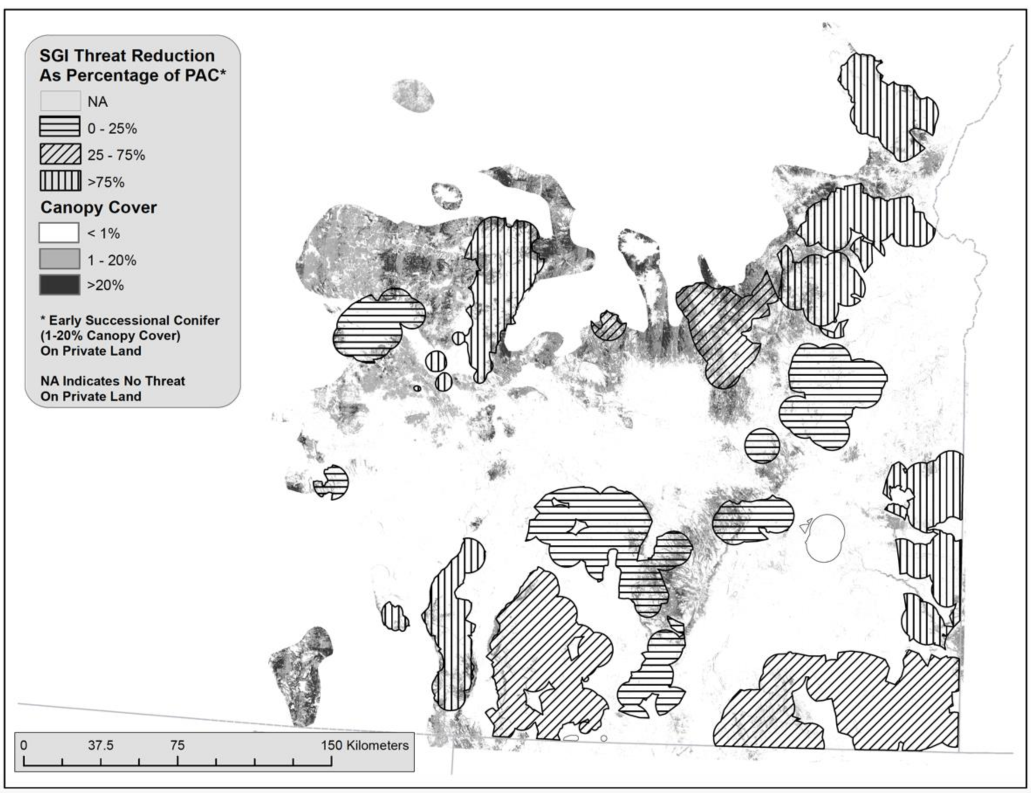

Figure 2. Tracking conifer threat reduction by Priority Areas of Conservation (PACs) in Oregon. Represented is the proportion of early-to-mid succession conifer (1-20% cover) on private lands already ameliorated by landowners participating in SGI. Conifer removal has been primarily targeted in and around PACs where the threat is greatest on private lands.

Conservation partners can now track progress towards threat reduction goals which aids future resource allocation and allows agency leadership to secure financial commitments necessary to finish the job (NRCS, 2015b).

In addition to SGI, several other partners and agencies are leveraging the conifer cover maps to support habitat management and planning. For example, Colorado Parks and Wildlife is using the conifer cover layer to support the assessment of ecosystem condition, or habitat value, of a given location on the landscape for greater sage-grouse within the Colorado Habitat Exchange, a market-based habitat mitigation program. Other partners in Oregon and Utah are using the conifer layer to better understand the impacts of conifer removal on movements and space use of sage-grouse. Finally, we are currently leveraging the conifer cover maps in a systematic landscape optimization model to identify optimal conifer removal locations based on the potential benefit to sage-grouse across a number of competing factors, including: breeding habitat enhancement, seasonal movement, and habitat connectivity. Specifically, we are employing a systematic conservation modeling approach within across the sage-grouse range to identify the most important areas for conifer removal based on optimizing specific goals including: 1) enhancing existing sage-grouse breeding, nesting, and early brood-rearing habitats, 2) facilitating movement between sage-grouse breeding and late brood-rearing habitats, and 3) improving connectivity pathways among sage-grouse PACs at the landscape scale. This type of modelling work will help land managers identify potential conifer removal areas that have the most benefit to sage-grouse at a given financial cost, and could ultimately be expanded to constrain cut locations based on habitat needs for non-target species such woodland songbirds.

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