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Carbon monitoring and above ground biomass trends: Anchor forest opportunities for tribal, private and federal relationships

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ABSTRACT

There are more than 300 million hectares of forested land within the conterminous United States essential to sustaining the myriad social/cultural, economic, and ecologic benefits society enjoys from these lands. Nationwide, millions of forested hectares, both private and public, are disappearing functionally and physically through serve wildfire fire and land conversion. On many of these lands, management, centered on fire suppression, has led to reductions in forest resilience to wildfire. Lands, overstocked with accumulated fuel and faced with a changing climate, are expected to continue this legacy of fire and deteriorating health. A paradigm shift is needed to face the challenges confronting forests and enhance collaborative efforts across multiple forest ownerships. Our ability to leverage emerging technologies and pair them with the knowledge of indigenous peoples presents new opportunities for success. The objectives of this study were to 1) assess the Anchor Forest concept as a framework to leverage collaborative motivations and leadership by indigenous peoples (Tribes) in eastern Washington State to improve forest ecosystem health across legal and political boundaries, 'cross-boundary' management, and 2) demonstrate how the NASA carbon monitoring system (CMS) mapping products of regional forestland above ground biomass (AGB) density and temporal trends can provide information that supports decisionmakers in their efforts to collaboratively approach improving forest health conditions through management activities.

Introduction

There are more than 300 million hectares of forested land (minimum of 10% tree canopy) within the conterminous United States (Krist et al., 2014). These forests are essential to sustaining the myriad social/-cultural, economic, and ecologic benefits society enjoys from these lands. Healthy forests can provide employment and recreational opportunities as well as forest products and a broad spectrum of ecosystem services (Donovan et al., 2015). Forests of the western U.S. alone provide nearly 65% of the clean public drinking water for nearly 64 million people (American Forest Foundation, 2015). The ability of forests to continue to provide these benefits and others into the future remains at risk (O'Laughlin, 2013; United States Department of Agriculture Forest Service, 2011).

Nationwide, millions of forested hectares, both private and public, are disappearing functionally and physically as exemplified within the National Forest System (NFS) (ITC, 2013). Management on many of these lands has centered on fire suppression for most of the 20th century (Mason et al., 2012; O'Toole, 2007) leading to reductions in forest resilience to wildfire. Longer fire seasons and larger fires generate both greater fire costs and increased associated expenditures (Abatzoglou et al., 2017; Kane et al., 2015; Morgan et al., 2017). This is exemplified by the trend of U.S. Forest Service (USFS) wildland fire expenses (in 2020 dollars), from less than $500 million in the 1980s to $1.4 billion in

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the 2000s (Ingalsbee, 2010), to more than $2.7 billion in 2020 (United States Department of Agriculture Forest Service, 2015; USDA Forest Service, 2015). Many NFS lands, overstocked with accumulated fuel and faced with a changing climate, are expected to continue this legacy of fire and deteriorating health (Krist et al., 2014). Many of these NFS lands boarder forestlands owned or managed by nongovernmental entries such as Tribal Nations, U.S. companies, or private citizens (ITC, 2013).

A paradigm shift is needed to improve and sustain ecosystem function on these lands (Coop et al., 2020; Franklin, 1993; Franklin and Johnson, 2012; Hessburg et al., 2019) as well as reduce the potential for landscape-altering fires that jeopardize societal well-being and human safety with significant near- and long-term costs (Brown et al., 1999; Wu and Kim, 2013). Land fragmentation (Bradley et al., 2009), administrative inconsistencies (Butler et al., 2015; Franklin and Johnson, 2012; Predmore et al., 2011), agency personnel turnover (ITC, 2013), litigation (Keele et al., 2006; Mortimer and Malmsheimer, 2011; Winkel, 2014), and a weakened support of the general public understood as a 'social license' (Bradley et al., 2007; Gambino-Portuese et al., 2009; Kittler, 2014; Miner et al., 2010) create many of the challenges facing economically-viable and ecologically-functional forests recognized by Tribal Nations as 'working forests' (Corrao and Andringa, 2017). These 'working forests' are an important part of improving overall forest ecosystem health (Schmid, 2015; Schultz et al., 2012; USDA Forest Service, 2010). Furthermore, the management of these lands is significantly influenced by pro-active collaboration (Case et al., 2020; Reo et al., 2017; von der Porten and de Loë, 2014) and heavily reliant upon accurate and actionable information (Hessburg et al., 2019).

Many of the challenges confronting our forests have become too large and complex to be addressed by any single forest ownership (Zenner, 2014). Thus, proactive collaborative efforts, must come together to address challenges across legal and political lines 'cross--boundary' while remaining focused at the landscape scale (Butler et al., 2015; Corrao and Andringa, 2017; GAO, 2007; Jacobson, 2020). Recent wildfire seasons have continued to demonstrate the risks and consequences of failing to address forest health issues at this landscape scale (NIFC, 2015), and changing climate patterns threaten to further alter the distribution of forest cover types, species, and natural disturbance patterns, such as bark beetle outbreaks (Littell et al., 2010; Snover et al., 2013).

The need for a collaborative solution is made clear by increasing trends in wildfire spending, restoration costs, and fire risk across multiple forest ownerships. Operational forest-inventory technologies in the forest management sector such as ForestView® (Keefe et al., 2022; Sparks and Smith, 2022) and the active inclusion of indigenous peoples (Case et al., 2020) present new opportunities for success when paired with policies such as Stewardship Contracting, Shared Stewardship, Good Neighbor Authority (Mattor, 2013; Mattor et al., 2020); funding by programs for carbon accounting (Huang and Sorensen, 2011; Patterson, 2011; Sleeter et al., 2018); and, combined with collaborative frameworks such as the Anchor Forest concept (Corrao and Andringa, 2017; Jacobson, 2020).

Understanding collaborative structures and the elements of collaboratives further emphasized the value of these tools. Elements of collaboratives have been described as: "(1) the pooling of appreciations and/or tangible resources, e.g., information, money, labor, etc., (2) by two or more stakeholders, (3) to solve a set of problems which neither can solve individually" (von der Porten and de Loë, 2014). And from a social science perspective common themes important to the formation of collaborative environments are said to include: face-to-face interaction, inclusiveness or a desire for representation, consensus, deliberation as the basis for decision making, the presence of enduring relationships between collaborators, and the pooling of resources to address common problems (von der Porten and de Loë, 2014). Therefore, the understanding of research centered on the foundational aspects of collaborative efforts (e.g., problem-setting, direction-setting, and structuring) between differing disciplines and divergent interests (Gray, 1985) offer insights into the constructs of frameworks such as the Anchor Forest Concept and the potential to demonstrate improvements in forest health and/or decreases wild fire risk on forested acres, not owned or currently managed by Tribes, but adjacent to Tribal lands thereby representing cross-boundary management cases.

The Anchor Forest Concept

An Anchor Forest would be a multi-ownership land base of any size able to support sustainable long-term wood and biomass production levels backed by local infrastructure and technical expertise and endorsed politically and publicly to achieve improved forest health and reduced fire risk conditions through management objectives of multiple interests. The Anchor Forest concept is founded on the premise that these tracts of forestland under long-term stewardship, inclusive of commitments for commodity production, can economically incentivize cross-boundary collaborative management (Corrao et al., 2016a; ITC, 2013).

These "Anchor Forests" would then provide functioning exampling for how investments in ecological services through Tribal Nations and the infrastructure needed to address forest health, sustain working forests, and improvements in ecosystem resiliency (DNR, 2014; IFMAT, 2013). The Anchor Forest concept draws upon three attributes exemplified by tribal forests that foster stewardship (e.g., capability, commitment, and vision), embody sustainability (Fig. 1) (IFMAT, 2013), and increase collaborative forest management. Collaborative forest management efforts are those that result in the 'social license' needed to implement the "Shared Stewardship" management of the forested landscape (USDA Forest Service, 2010) through the collective ability of many working toward a unified goal.

The Anchor Forest assessment surveys were constructed to provide insights into maintaining and/or expand forest management efforts across national landscapes. The Anchor Forest surveys were completed to assess the potential for a forest collaborative, founded by tribal values and leadership, to increase forest management activities, improve forest and ecosystem health, and offer a social structure that promotes equitable social, economic, and ecologic outcomes, generally defined as ecosystem services within the study. Similarly, within the Anchor Forest concept, ecosystem *processes* have been described as the naturally occurring functions describing biophysical relationships that exist whether humans benefit from them or not, whereas ecosystem *services* represent the goods or processes of an ecosystem that contribute to human well-being, and as such, would not exist without the existence of people and societies (Fig. 2) (Corrao et al., 2016a).

Available Resources and Technology

The impacts of climate change on many indigenous peoples of North America (Cordalis and Suagee, 2007), and the ecosystem services they derive from natural landscapes (Case et al., 2020), outlines the importance of forest health and managing forested environments through collaborative efforts that leverage the traditional ecological knowledge (TEK) of Tribal Nations and indigenous peoples. Collaboratives founded by objectives focused on forest health and TEK may have a mitigating effect for some landscapes with regard to changing climatic conditions and a reduction in the severity of wildfire (Marks-Block et al., 2019; Marks-Block and Tripp, 2021). Additionally, the ability of Carbon (C) credit programs to provide subsidies and financial value to forestlands accepted into a program is well recognized (Andrew Stainback and Alavalapati, 2002; Huang and Kronrad, 2001; West et al., 2020), including specific opportunities for sovereign nations (Huang and Sorensen, 2011; Manning and Reed, 2019). Capital resources available through C credit programs are one significant opportunity available to address forest health for collaboratives inclusive of sovereign nations already managing forest and woodland landscapes for the promotion of forestland health or resilience (Dubois, 2006).

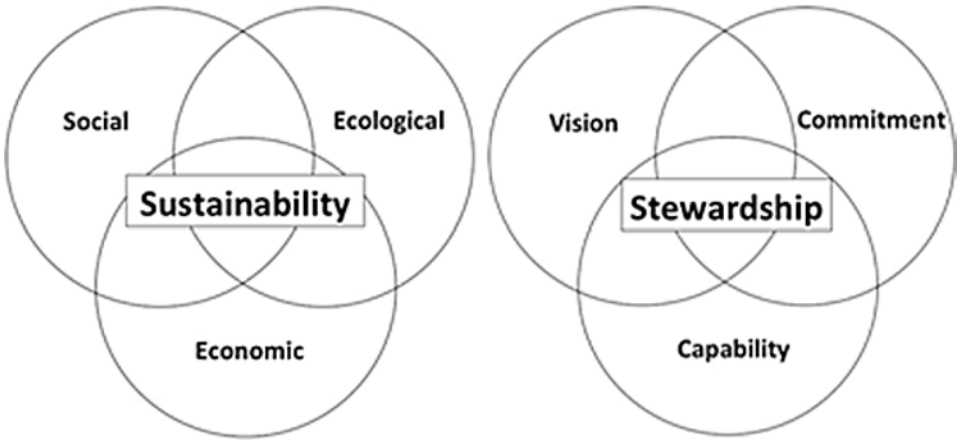

Fig. 1. The "triple bottom line" of sustainability combining social, economic, and ecologic dimensions inextricably coincides with the foundation of stewardship. Stewardship for sustainability has been described as the intersection between vision, commitment, and capability. *Vision* represents the ability to establish and convey a shared sense of "what can be", *Commitment* represents relationships that maintain respect, trust, and collaboration over the long-term, and *Capability* represents the availability of competent interdisciplinary staff with the information and resources to implement multiple-use, multiple-resource management plans (IFMAT, 2013).

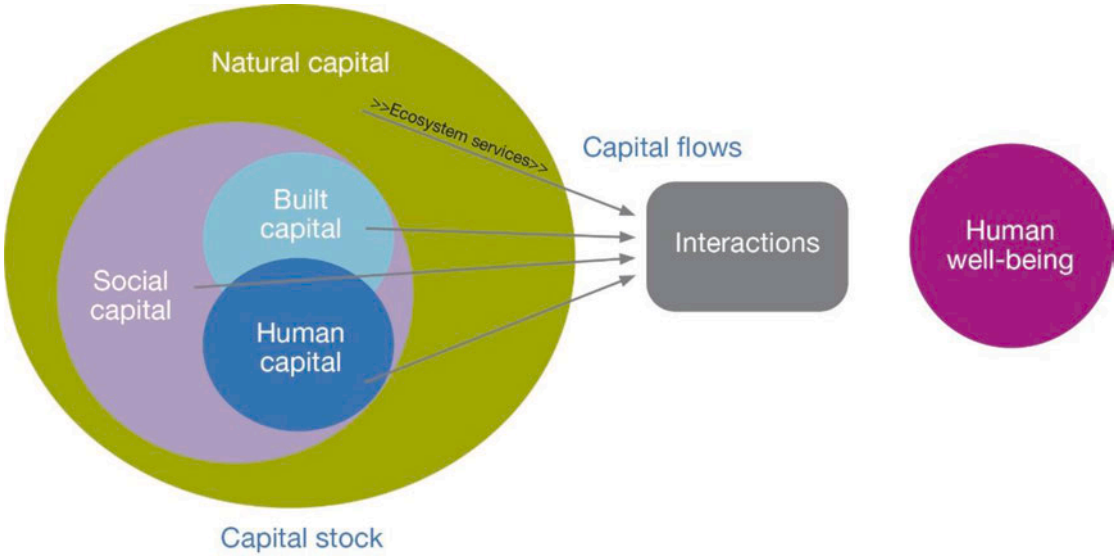

Fig. 2. Human-environment interactions are formed between built, social, human and natural capital and collectively contribute to human well-being. Built (including economy) and human capital are embedded in society which is enveloped within the rest of nature. Ecosystem services are the relative contribution of natural capital to human well-being; they do not flow directly to create well-being and need the other sources of capital to exist. It is therefore imperative to incorporate all facets of capital within collaborative landscape-scale management actions such as those of an Anchor Forest. *(Figure reproduced with permission from (Turner et al., 2015)).*

The Confederated Tribes of the Colville Reservation (Colville Tribes), within the northeastern portions of Washington State currently participate in an Improved Forest Management (IFM) C credit project through the California Air Resource Board (CARB) on approximately 183,333 hectares of their reservation. The protocol of CARB for an IFM project is similar to that applied in other areas of the world to incentivize responsible management and does not prohibit harvest, but does require that carbon inventories be maintained for the life of the project (De Jong et al., 2000; Griscom and Cortez, 2013). This flexibility allows the Colville Tribes to carryout their cultural objectives across the forested landscape to provide timber products and jobs as well as improve species composition, forest structure dynamics, and reduce fire risk while adapting management practices in beneficial ways to offer C credits to off-reservation markets. In addition to participation in a C credit market the Colville Tribes participate in multiple forest-collaboratives within eastern WA (e.g., Northeast Washington Forestry Coalition (NEWFC) and North Central Washington Forest Health Collaborative (NCWFHC)). Participation in these groups provides insights to the collaboratives that would otherwise be under-developed in their planning efforts to support active management across the landscape to accomplish multiple objectives. Programs like CARB provide monetary value for management efforts through an incentive-based approach founded on C accruals above an established scientific standard (Blanc et al., 2019; De Jong et al., 2000).

Advancements in the processing and applications of remote sensing data, specifically light detection and ranging (LiDAR) for forestry applications (e.g., ForestView® and FUSION) and the availability of LiDAR sensors on different platforms (e.g., tripods, UAVs, helicopters, and fixed-wing aircraft) has increased the availability of tools and uses in the past decade (Benson et al., 2020; Hojo et al., 2020; Ni et al., 2019; Sparks and Smith, 2022; USPTO, 2021). These technological resources combined with collaborative efforts inclusive of tribal rights offer a foundation for the Anchor Forest concept to influence forestland management on neighboring off-reservation forestlands within the U.S. (Dockry, 2020). Use of available technology to quantify aboveground C (Gómez et al., 2014; Hudak et al., 2012), map biomass (Hudak et al., 2020), or enumerate discrete forest structural attributes (He et al., 2019; Mohan et al., 2017; Sparks and Smith, 2022; Wang et al., 2020) on manageable forestlands will be foundational to successful collaborative efforts by providing accurate and actionable information for assessment

and planning purposes.

For example, the NASA Carbon Monitoring System (CMS) aboveground biomass (AGB) density mapping efforts offer free raster products derived from multiple remote sensing and empirical data sets that can be leveraged by those in forest landscape and wildfire risk planning, as well as climate change mitigation, or as a spatiotemporal indicator of forest change. With respect to collaborative relationships focused on forestland health and wildfire mitigation, these products offer pixel-level ($30m^2$) insights into estimations of reduced wildfire expenses associated with forest management. Reductions in fire risk and severity can capture per-hectare savings ranging from $1,497 for moderate, to $3,464 for high-risk forest lands (Lippke et al., 2005; Mason et al., 2006). These C estimation maps help inform decision makers of high-risk or high-value hectares across a landscape during planning of silvicultural-prescription or resource-investment locations, similar to the methods applied by Case, Kim, and Kerns (2020), to assess climate change vulnerability of tribally important ecosystem services.

NASA's Carbon Monitoring System (CMS) Initiative has been funding projects that use a broad range of NASA satellite observations, modeling/analytical capabilities, and commercial off-the-shelf technologies to develop products that can support management activities. For instance, the Fekety and Hudak (2019) wall-to-wall AGB density maps (Fig. 3) developed at 30-meter spatial resolution for the Northwestern United States, and the airborne lidar-based AGB density maps from which they were derived (Hudak et al., 2020), are two freely downloadable CMS map products well-suited for regional and local AGB density assessments, respectively. These wall-to-wall AGB density maps provide valuable information for regional analysis and planning and are intended to help the U.S. Forest Service develop Five-Year-Action-Plans, as well as inform forest health, biomass accrual planning, conservation applications, and annual forest change mapping.

Therefore, the objectives of this study were to 1) assess the Anchor Forest concept as a framework to leverage collaborative motivations and leadership by indigenous peoples (Tribes) in eastern Washington (WA), State to improve cross-boundary forest ecosystem health, and 2) demonstrate how the NASA CMS mapping products of regional forestland AGB density and trends may provide information that supports decisionmakers in their efforts to collaboratively approach improving forest health conditions through management activities.

Methods

Collaborative Analysis Survey

Within WA, three management areas were delineated for the Anchor Forest assessment based on available forestry infrastructure, presence of NFS forest lands bordering Tribal lands, and Tribal lands with active forest management programs and/or infrastructure (Fig. 4). Tribal representatives from the Yakima Nation, the Colville Tribes, the Spokane Tribe, and the Kalispel Tribe were contacted to discuss participation in, and development of, a survey for stakeholder engagement. Initial scoping and planning meetings were conducted during October 2013, November 2013, and January 2014 to develop a list of agencies, organizations, private industries, and other stakeholders these sovereign nations believed would add value through participation. A paper survey was developed to include questions regarding respondent assessments of current timber supply, existing institutional structures, and capacity (e.g., staff, equipment, facilities, and internal support), willingness to participate, and availability of informational resources in relation to the Anchor Forest concept as was provided in an outline. Surveys were mailed to all participants 1 April 2014, and survey results were presented at a series of focus group meetings beginning 28 April 2014 and throughout the year to gauge understanding, and interest in implementation, of an Anchor Forest pilot project. Follow up interviews with engaged stakeholders focused on institutional capacity, existing or needed, in support of an Anchor Forest pilot project. These interviews were conducted both in-person and over the phone throughout 2014. Survey responses and stakeholder participation are available in M. Corrao, Dolsen, and O'Laughlin (2016) for the three focus areas included in this analysis; the Northeast (NE), North Central (NC), and South Central (SC) management regions, respectively.

Survey results from each region were grouped by similarity and ranked by potential to support an Anchor Forest concept collaborative approach, support and/or challenge the Anchor Forest concept, or serve as a barrier to collaboration or implementation of an Anchor Forest. Ranked survey responses were then compared to a proposed

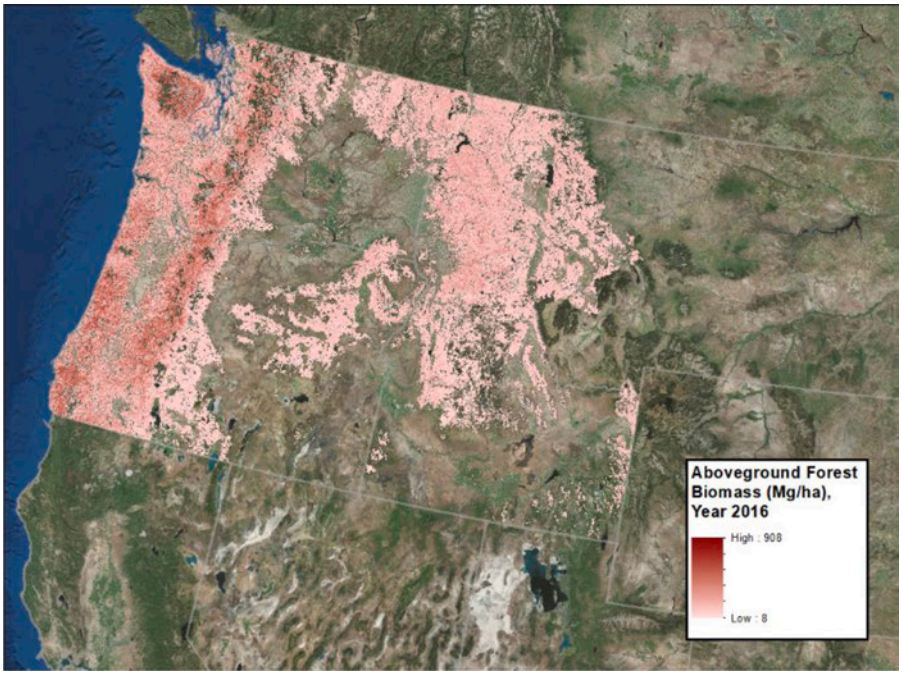

Fig. 3. 2016 AGB density map predicted from climate metrics, topographic metrics, canopy height (Simard et al., 2011), and Landsat time series (2000-2016) processed through LandTrendr (Kennedy et al., 2018) and publicly available (Fekety and Hudak, 2019).

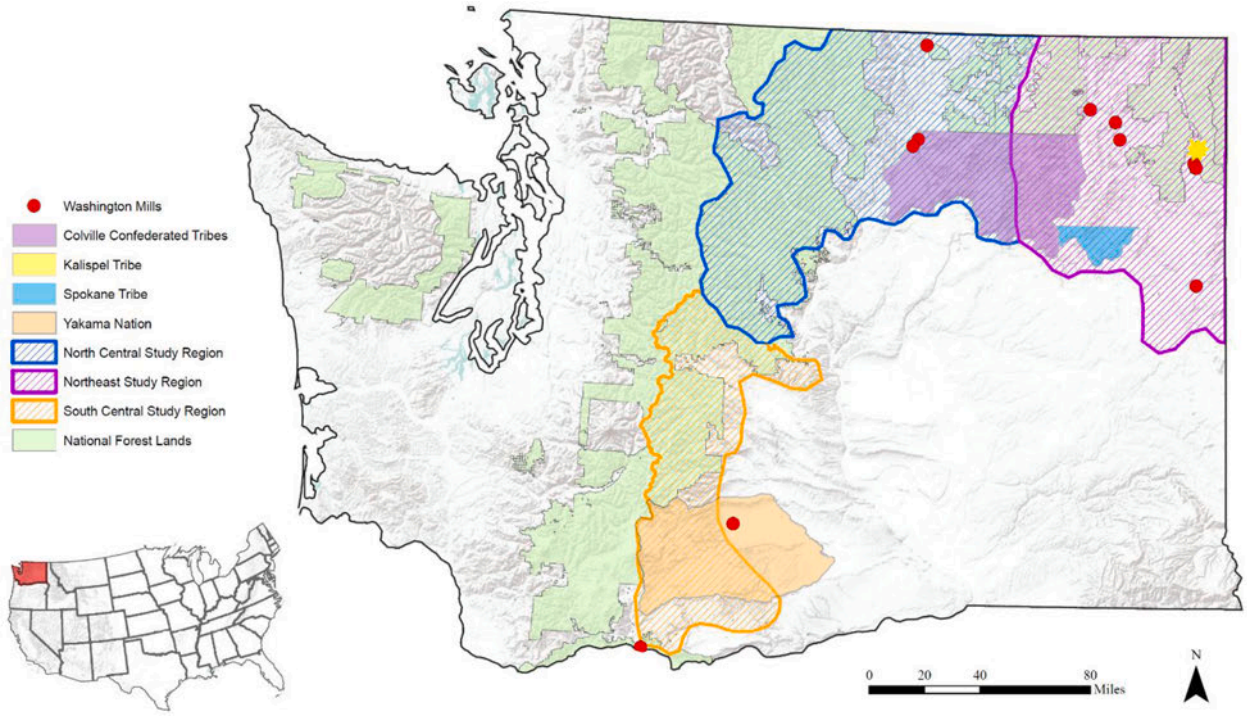

Fig. 4. The Anchor Forest assessment project management areas, participating Sovereign Nations, National Forest lands, and forest product processing facilities within Washington State, USA, east of the Cascade Mountain range.

organizational structure for an Anchor Forest collaborative working group. The proposed structure was developed through review of the governance of the Tapash Sustainable Forest Collaborative, the Northeast Washington Forestry Coalition's Colville National Forest "Blueprint", and the North Central Washington Forest Health Collaborative. These reviews were then blended with findings regarding the cultural and structural pathways of participating Tribes within the framework to assess collaborative capacity as presented by Cheng and Sturtevant (2012). Additional contributing factors included the progression of remote sensing data uses in forestry (e.g., Hudak et al. 2020) and innovative mapping applications using lidar data by the Colville Tribes, and the use of lidar for development of a single-tree forest inventory across their ~260,000ha of operational forest lands by the Yakama Nation. Commitments by participants and sovereign nations provided the foundation for this research to further develop and assess the Anchor Forest concept and the potential to demonstrate improvements to forestland health and resilience at a regional and/or national level.

Forest Aboveground Biomass Assessment

CMS maps of annual AGB provided spatiotemporally consistent estimates upon which to base assessments of changing forest conditions. For this study, AGB density estimated from project-level field plot and airborne lidar collections and upscaled at 30m resolution using climate, topographic, and annual Landsat image variables (Hudak et al. 2020) from 2000 to 2016 provided a CMS mapping product (Fekety and Hudak 2019) visualization of changing AGB conditions across the study area of WA and the three management regions in eastern WA within the Anchor Forest concept survey. The CMS analysis for AGB was analyzed equitably on federal, state, private, and tribal lands from 2000 to 2016 wherever possible, given differing management objectives and practices.

Public ownership vector data, separated by Forest Service (FS), other federal, and state-owned lands, were downloaded from the WA Department of Natural Resources (DNR) (https://data-wadnr.opendata.arcgis.com/ accessed on 6 Jan. 2021). The WA DNR also provided private industrial versus private non-industrial (non-commercial entity-owned) ownership vector data. Forest treatment vector data were available only for FS and Colville Tribal lands. Treatment data on Forest Service lands were acquired from the Forest Service Activity Tracking System (FACTS) database (https://data.fs.usda.gov/geodata/edw/datasets.php accessed on 14 Jan. 2021); FS lands were grouped into two classes; treated (areas inclusive of timber harvest, stand improvement (release and thinning), and/or fuel reduction activities), and untreated (all other lands classified as 'forested' within the State. Treatment vector data of timber harvest on the Colville Reservation was provided by the Colville Tribes. Ownership and treatment vector data were reprojected and overlaid on the annual AGB density maps of Fekety and Hudak (2019). For each ownership, treatment, and year (2000 to 2016), AGB pixel values were extracted and zonal AGB density means and total forested area were calculated. Non-forested pixels were masked in the AGB density maps of Fekety and Hudak (2019) and hence were not included in the calculation of AGB density zonal means or total forested area. Processing was performed using the 'terra' R package (Hijmans, 2021).

Results

The Anchor Forest Concept Survey

Focus group discussions within each of the three study regions revealed many insights facing implementation of the Anchor Forest concept (Table 1,Table 2, and Table 3). Discussions of collaborative ecosystem management included topics such as the belief that currently deteriorated forest conditions should be the greatest priority, and that some legislation, local laws, and policies are often unreasonably time consuming and too slow to effectively achieve the actions needed on these forestlands. Participants also acknowledged the value of partnerships between stakeholders with differing opinions, and the importance of leadership from tribal members and agency personnel to unite stakeholders and move actions forward with well-defined objectives. Concerns regarding the need for a measure of 'protection' for the

Table 1
Participant feedback for the South Central region provided through survey responses and during focus-group meetings.

South Central Region - Predominantly Tribal and Federal Sector presence with Active Forest Management on Tribal Lands	
+	A collaborative process lead by tribes and the U.S. Forest Service is preferred.
+	There is a desire to include more stakeholders from a broader audience in the already formed collaborative processes, and would carry over to an Anchor Forest.
+	There is a focus on forest health and sustainable ecosystem function and services in this region equal to or more so than timber production.
+	There is a significant active tribal presence with a background in active forest management and a large contiguous land base.
+/-	Forest treatment capacity is more limited than funding for some ecosystem restoration activities. There is a need for additional personnel training.
+/-	There is a need for more participation and cooperation from the U.S. Forest Service in active land management or adjacent forest lands to minimize threats to management tribal lands.
+/-	U.S. Forest Service funding and resources are tied up in planning not in action.
-	Tribes identified mismanagement as the largest threat to forest health and the occurrence of uncontrollable wildfire due in part to conditions on adjacent lands has impacted water quality, fishery resources, cultural sites and whole ecosystem functions in general.

+ Represents an opportunity for an Anchor Forest Project.
+/- Represents an opportunity as well as a challenge for an Anchor Forest Project.
- Represents a challenge or a barrier for an Anchor Forest Project.

Table 2
Participant feedback for the North Central region provided through survey responses and during focus-group meetings.

North Central Region - Predominately Federal and State Sector presence with Limited Forest Management	
+	There is support for a collaborative process from the U.S. Forest Service in support of an Anchor Forest
+	Collaboration and communication are needed and generally support by all participants within the study region.
+/-	There is limited milling capacity for forest products and substantial investment would be required to increase capacity.
+/-	There is limited timber supply due to restricted forest management and agency resources.
+/-	Tribal participants have limited resources within this area.
+/-	Private landowners within this region are concerned that Anchor Forests would "add another layer of regulation to forest activities".
+/-	There is lacking infrastructure and markets in general for wood products especially "large wood".
+/-	There is a lack of logging personnel across all business sectors.
+/-	This region has the greatest number of hectares designated as unhealthy forest conditions. The majority of hectares are on federal lands and many are not restricted from treatment by wilderness or roadless designations.

+ Represents an opportunity for an Anchor Forest Project.
+/- Represents an opportunity as well as a challenge for an Anchor Forest Project.
- Represents a challenge or a barrier for an Anchor Forest Project.

collaborative process to discourage non-participant appeals, litigation, and delay were raised with the intent to move collaborative projects forward more effectively when parties, unwilling to participate, challenge the decisions of collaboratives.

Institutional Capacity

Survey responses across multiple industry sectors were gathered over a multi-year process (Corrao et al., 2016b) regarding the overall institutional capacity available to support a collaborative forest management effort like the Anchor Forest concept (Fig. 5). Capacity to contribute was primarily driven by budget constraints, staffing requirements, and collaborative trust in the sharing of responsibility. Willingness and capacity to participate were greatest within the tribal and private sector respondents. State sector respondents indicated a similar willingness,

Table 3
Participant feedback for the Northeast region provided through survey responses and during focus-group meetings.

Northeast Region - Predominantly Industry and Private Sector presence with Active Forest Management	
+	Collaboration was preferred for forest management based on experience.
+	There is a focus on timber supply and forest product utilization through active management.
+	Goals are support for local communities through jobs and use of a diversity of forest products.
+	There is well established private sector milling capacity and marketing.
+/-	The majority of unhealthy forest conditions are on federal lands and many are not restricted from treatment by wilderness or roadless designations.
+/-	There is a need to define "sustainability" in support of active forest management for communication purposes.
+/-	The public perception of forest health needs modification and attention needs to be drawn toward the implications for non-management.
+/-	There is lacking infrastructure and reduced markets for "large wood".
+/-	There is a lack of Tribal milling capacity and a general lack of logging personnel across all business sectors.
+/-	There is a lack of U.S. Forest Service support and leadership regarding active forest management.
+/-	U.S. Forest Service funding and resources are tied up in planning not in action.
-	Tribes identified mismanagement as the largest threat to forests - noting management for "Desired Future Conditions" can be an obstacle for adaptive management.

+ Represents an opportunity for an Anchor Forest Project.
+/- Represents an opportunity as well as a challenge for an Anchor Forest Project.
- Represents a challenge or a barrier for an Anchor Forest Project.

but limited capacity given time and staffing resource needs. Federal respondents were on average less willing to participate and indicated similar constraints in capacity by staffing and financial resources. The overall readiness to collaboratively participate in an Anchor Forest type collaborative varied by participants, indicating sharing of resources, staff, expertise, and equipment would be based upon leadership support as well as the availability and timing of resources. Readiness across all participants was constrained by an un-clear understanding of the actionable goals and objectives, concerns regarding a downsized workforce, reduced milling infrastructure, and limited time, staffing, and financial resources.

Governance within the Anchor Forest Concept

Within eastern Washington, the Tapash Sustainable Forest Collaborative (Tapash), the North Central Washington Forest Health Collaborative (NCWFHC), and the Northeast Washington Forestry Collation (Coalition) which developed the Colville National Forest “Blueprint” represented organizations operating under governance structures founded by objectives to improve forestland management decisions and investments. The importance of linking collaborative efforts through shared narratives (Mistry et al., 2016) suggests that the ‘Executive Team’ and ‘Working Group’ structure of the Tapash provides one opportunity for a successful implementation of the Anchor Forest concept. This structure was adapted following survey responses and is presented as a template for applying the Anchor Forest concept (Fig. 6).

Forest Infrastructure and Value

With more than 404,700 hectares of forest land being impacted annually by insects and disease within the State of Washington (Krist et al., 2014; Tidwell, 2015), and annual increases in the frequency of wildfire across the Western U.S. (NIFC, 2015), federal land treatment recommendations from the USFS (287,916 hectares) (Tidwell, 2015) and Washington Governor Jay Inslee (~291,373 hectares) (USDA, 2015) suggest management has fallen short of planned and approved objectives every year since 2000 (Corrao et al., 2016a) within the three regions of this study.

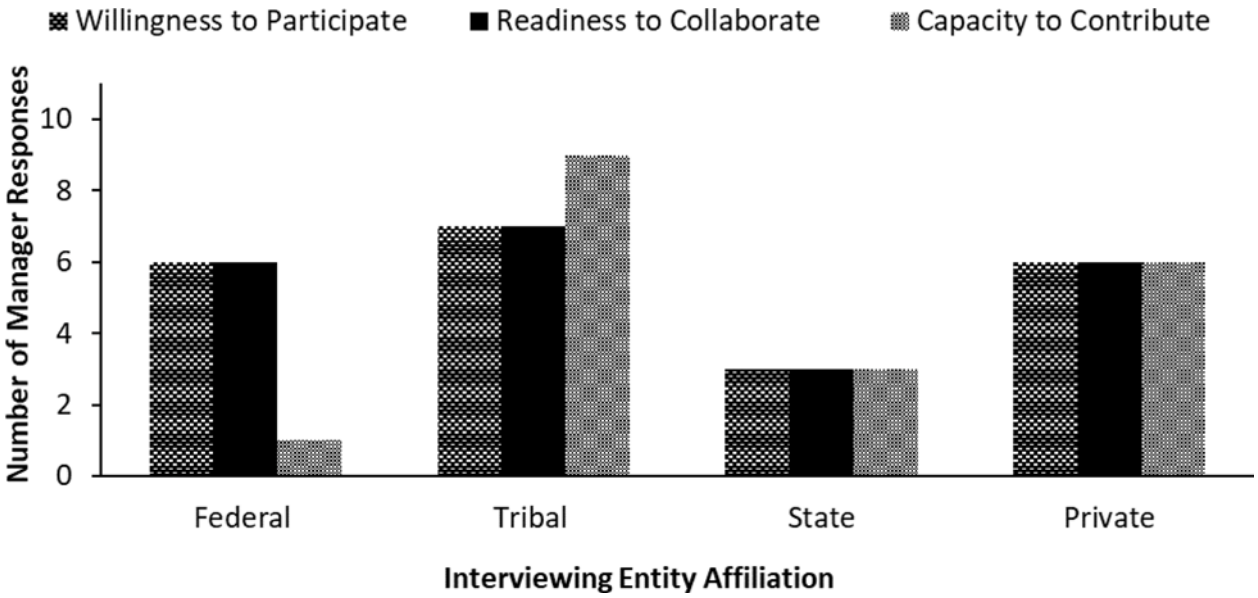

Fig. 5. Responding entity managers (n = 30) are presented together due to an overlap of interview participants between regions. Respondents in all regions indicated an overall willingness, readiness, and capacity to participate in an Anchor Forest collaborative, with the federal participants indicating limited capacity and state respondents indicating an overall uncertainty in their readiness or capacity.

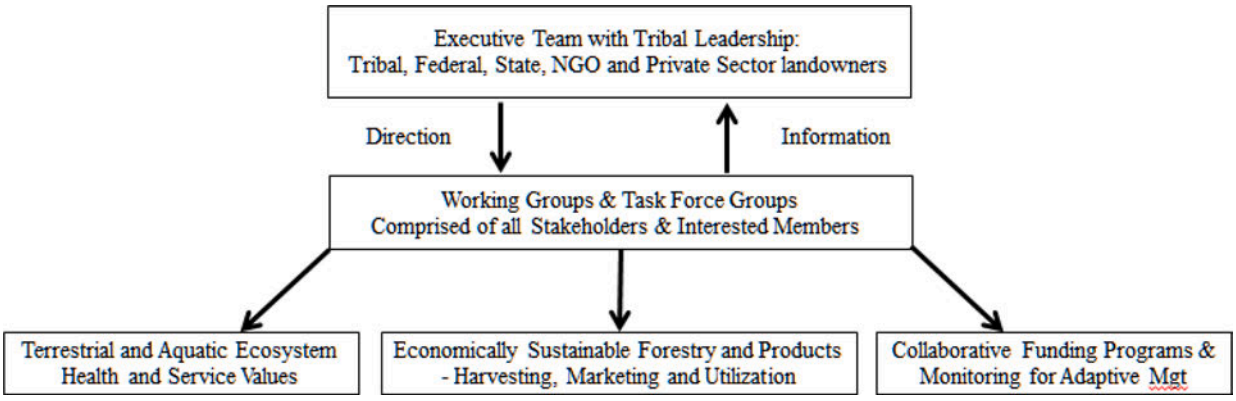

Fig. 6. This flow chart provides one example of a modified governance structure from the Tapash Collaborative, inclusive of tribal leadership and the balanced social/cultural, economic, and ecologic principals, that could be a representative governance structure for an Anchor Forest project resulting from the presented concept.

This is exemplified within the SC study region where there are 953,430 forested hectares with an estimated 182,100 operable hectares (Table 4) at an increased risk of additional tree mortality and damage by insects, disease and wildfire (DNR, 2014). Three sawmills in the region generate an average of 1,536,353 metric tons annually and 487,185 bone-dry tonnes (BDT) of biomass (Table 4). In socioeconomic terms (Table 5), the three sawmills provide the equivalent of 4,782 jobs, approximately $107.2 million in wages, and $649.6 million in the sales of goods and services (Haugo et al., 2015; Perez-Garcia et al., 2012). If current forest management within that region (17,702 hectares per year) was increased by 913 hectares annually (~5%), the identified 183,100 operable hectares could be treated in approximately 10 years, and any revenue from timber harvesting could serve as a funding source to accomplish additional treatments through supporting legislation such as the opportunities provided by the Good Neighbor Authority (Hoover, 2014).

Forest Above Ground Biomass Assessment

The size of forested land ownerships varied greatly in the three study areas, from only 1,875 ha on Kalispel Tribal lands restricted to a single parcel in the NE study area (Fig. 4), to FS lands that occupied >400,000 ha in the NE and SC study areas and >1,000,000 ha in the NC study area (Table 6). Tribal lands comprised the second largest land ownership per study area. The Colville Tribe has three times more forested land than the Spokane Tribe in the NE study area. The Colville Tribe and Yakama Tribe are the exclusive tribes in the NC and SC areas respectively, each managing >300,000 ha of forestlands. Forested state lands ranged from 134,337 to 206,501 ha across the three study regions, while private lands, separated into private industrial and non-industrial (non-commercial entity-owned) for this analysis (Table 6), ranged from 193,627 to 764,962 ha across study regions. Forest treatment polygon data were available only on FS and Colville Tribal lands, hence forest AGB density on these lands was partitioned between treated (hectares of observed decreasing AGB change 2000-2016) and untreated lands (hectares of observed increasing AGB change 2000-2016), but not on the other federal, tribal, state, or private ownerships. A total of 97,209 ha (4.9% increase from 7.5% in 2000) of forested FS lands were treated across the three study regions from 2000 to 2016, which equates to 5,718 ha per year. In the Northeast and North Central study regions, a total of 75,499

Table 4
Summary information for the three study regions within eastern Washington are presented showing total forested lands, current annual treatments by land ownership, and the estimated biomass produced and used for each region. Operable areas (hectares) are those available to forest management exclusive of wilderness, inventoried roadless areas, and other federally protected lands (Haugo, 2015).

Regional Conditions and Target Treatments	South Central	North Central	Northeast
Forested (ha)	953,439	1,325,750	731,671
Operable Areas (ha) Needing Treatment[1]	182,100	189,393	393,759
Operable Areas (ha) by Ownership			
Federal (ha)	21,448	93,887	105,622
Tribal (ha)	46,134	28,327	67,987
State (ha)	40,873	29,137	31,565
Industrial Private (ha)	43,301	6,880	67,178
Non-Industrial Private (ha)	30,351	31,161	121,405
Current Areas Treated Annually (ha)	17,702	11,733	28,516
Current Annual Timber Harvest (tonnes)	667,375	178,430	690,548
Estimated Annual Biomass from Harvest (BDT) [2]	211,628	56,581	218,976
Estimated Utilized Biomass (BDT)[3]	35,753	9,559	36,994
Eastern Washington Forest Products Produced by Region	43%	12%	45%

[1] Haugo et al. 2015 (Haugo et al., 2015; Haugo, 2015)
[2] Estimated annual biomass production was calculated using a conversion factor of 0.73482 bone-dry tonnes of biomass per thousand board feet (US) of timber harvest (Perez-Garcia et al., 2012).
[3] Current statewide biomass utilization is 452,232 BDT (Perez-Garcia et al., 2012), with 18.2% (approximately 82,306 BDT) being attributed to eastern Washington. It was assumed biomass production for each study region was the same as percent-harvested timber volume, 43%, 12%, and 45% of the 81,647 BDT for the South Central, North Central, and Northeast study regions respectively.

Table 5
A summary of potential benefits and avoided costs following an increase of <10% of managed forest lands in each of the three Washington State study regions. Avoided cost estimates were calculated based on implementing fuels treatments to reduce associated wildfire expenses as provided in the literature (Lippke et al., 2005; Mason et al., 2006; Rasmussen et al., 2012).

Estimated Benefits from Proposed Treatment	South Central	North Central	Northeast
Additional Forest Products Generated (tonne)*	25,490	81,105	162,209
New Jobs[1]	198	630	1,260
Wages[1]	$5,808,000	$18,480,000	$36,960,000
Product Sales[1]	$35,200,000	$112,000,000	$224,000,000
Avoided Cost per Hectare High-Risk Conditions[2]	$3,464	$3,464	$3,464
Estimated Total Avoided Costs	$3,164,314	$9,825,216	$19,677,070

[1] Research has shown average of 18 jobs, $528,000 in wages, and $3.2 million in sales are generated per 2,317 tonnes (million board feet U.S.) of harvest within the Pacific Northwest (Cook et al., 2015).
[2] An assessment of avoided costs using management costs, and benefits derived from, associated with investments in forest fuel removals and fire risk reduction (Mason et al., 2006).
* Calculated based on an assumed harvest of 28.64 tonnes per hectare.

ha (4.8% increase from 9.2% in 2000) of forested FS lands were treated from 2000 to 2016. On Colville lands in the Northeast and North Central regions, 49,036 ha (8.9% increase from 9.3% in 2000) of forest were treated from 2000 to 2016, equal to 2,884 ha per year.

Forest AGB density summarized from the Fekety and Hudak (2019) annual CMS maps gradually accrued from 2000 through 2016 (Fig. 7), although rates of accrual varied considerably between land ownerships. With the exception of the isolated Kalispel tribal land parcel (much smaller relative to other ownerships, Table 1) in the NE area, with ~180

Table 6
Total forested area (ha) by land ownership and study region for the years 2000-2016.

Land ownership (ha)	Northeast	North Central	South Central
Forest Service (untreated)	348,616 - 375,461	990,711 - 1,039,365	381,233 - 402,942
Forest Service (treated)	82,906 - 109,752	60,473 - 109,127	3,594 - 25,303
Federal (non-Forest Service)	72,645	93,919	7,601
Colville (untreated)	178,501 - 191,545	272,928 - 308,921	
Colville (treated)	27,132 - 40,176	24,044 - 60,036	
Spokane	64,730		
Kalispel	1,875		
Yakama			325,718
State	134,337	182,786	206,501
Private Industrial	207,702	36,895	80,105
Private Non-Industrial	557,260	272,426	113,522

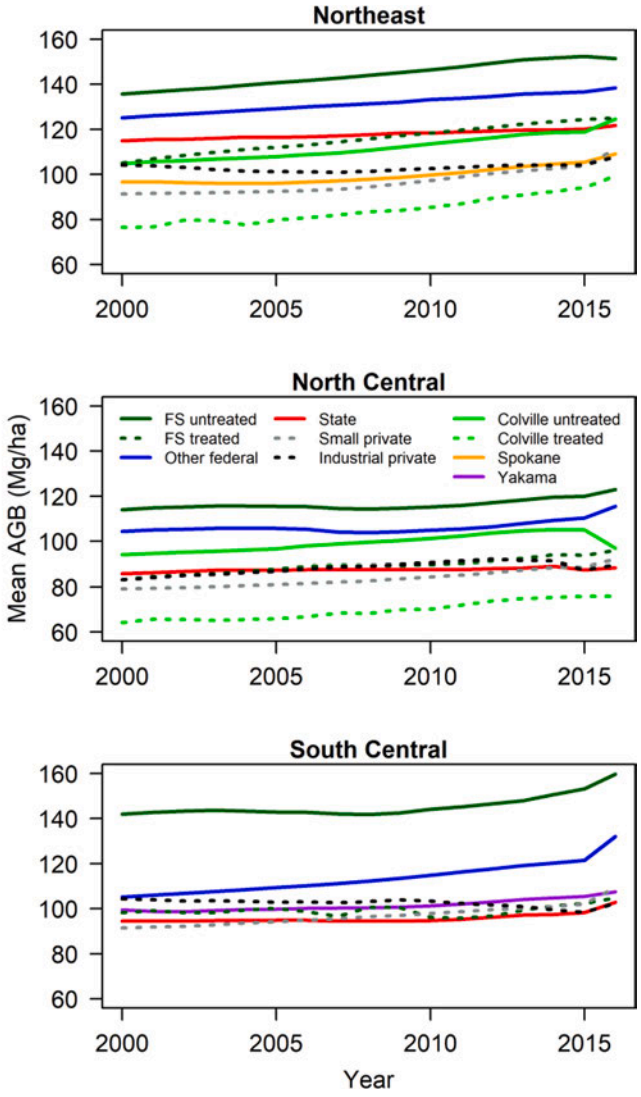

Fig. 7. Mean forest aboveground biomass (AGB) density (Mg/ha) by land ownership in the three study regions for the years 2000-2016.

Mg/ha, FS untreated lands held the densest AGB stores across all three study areas, while other federal land ownerships ranked second, ahead of state, tribal, or private ownerships. AGB density trends varied most in the NE study area, where state lands in 2000 ranked slightly ahead of Colville Tribal lands and FS treated lands. However, by 2016 these three trajectories converged. Meanwhile, lower AGB density on Spokane Tribal lands and on private lands (industrial and non-industrial) similarly converged from 2000 to 2016. Treated Colville Tribal lands had the lowest AGB density observed across all three study areas throughout the 17-year record. In 2000, AGB density on treated FS lands was similar to those on private industrial lands in all three study areas but diverged higher in the NE study area by 2016, while converging lower in the NC and SC study areas during the same period. AGB density and trends on Yakama Tribal lands in the SC study area tracked similarly to those on state, private, and on FS treated lands as opposed to FS untreated lands.

Discussion

Through the survey results and assessment of the Anchor Forest concept, numerous tribal nations and individuals outlined conversations and needs defining the importance of overcoming instances where collaborative institutions fail to recognize tribal political standing as sovereign nations, and instead treat them as stakeholders which has been observed in previous work (Jacobson, 2020). Acknowledgement of Tribal Nations and indigenous peoples as sovereign nations within collaborative processes, and recognition of indigenous governance and self-determination, are key understandings necessary when working together toward overcoming a common socio-ecological challenge (Reo et al., 2017). The tribal centric foundation of the Anchor Forest concept may help overcome this and increase the tools and resources available to collaborative groups.

While one governance structure may not be appropriate for all collaborative groups, the Tapash Collaborative's landowner-based Executive Team and working group/task group structure (Fig. 6) may be applicable to implementation of an Anchor Forest project if led by a tribe or tribal nation. An Anchor Forest project would require direct decision-making authority from various landowners and land management agencies however, the mandates and goals of the individual participants would be inclusive of the sovereign rights of participating Tribes and their unique government-to-government relationship to the United States within this type of structure. With tribal inclusion and leadership, the opportunities to improve the development of landscape level restoration projects, support the socio-economic needs of communities, maintain restoration infrastructure, and the tracking of restoration, wildfire, and climate change, may be better realized given the spiritual significance of natural landscapes and sovereignty of indigenous peoples.

The integration of contracting and funding programs such as Shared Stewardship, the Good Neighbor Authority, the Collaborative Forest Landscape Restoration Program (CFLRP), and the Tribal Forest Protection Act (TFPA) with guidance from decisions such as the Tribal Trust Doctrine (Wood, 2014) offer specific opportunities for increased tribal consultation and cross-boundary forest management for those federal lands adjacent tribal reservations. Whether designated as an "Anchor Forest" or under collaborative management following the Anchor Forest concept Federal forestlands adjacent to tribal lands provide immediate opportunities to test the findings of this research. Inclusive of Tribal guidance and collaboration these landscapes may support long-term contracted commitments to active management necessary to encourage the capital investments needed in some areas such as the NC Region of the study, to outpace deteriorating forest ecosystem conditions.

In support of these efforts, projects require a leader or "champion" in each participating agency and sovereign nation to collaboratively prioritize and direct management of efforts intended to leverage available funding and data products. Stakeholders in these projects could then utilize the organizational partnerships such as that between NASA, the USDA Forest Service and the Colville Tribes to leverage remotely sensed data products such AGB maps to further address land management objectives (McAndrew et al. 2019; Watts et al. 2020). A monitoring component would be necessary for each project to evaluate measures of environmental performance and the practices applied as well as assess new opportunities to sustain and expand activities that may increase sucsses throughout Washington State and the West.

The wall-to-wall AGB maps used in this study (Fekety and Hudak 2019) provided a corollary for forest C storage information that is spatially consistent across the full extent of the three study regions, at an annual time step and 30m spatial resolution that is conducive to regional forest monitoring and planning. Moreover, the mapped AGB estimates leverage available lidar datasets which adds an unquantified element of confidence in structural estimates. Technological advancements that leverage increasingly informative datasets such as those produced from lidar are becoming more available (Fekety and Hudak, 2019; USPTO, 2021), and can be useful for collaborative efforts between tribal, private, and federal government actors in informing priority areas and management efforts. However, in some applications airborne lidar-based submeter structural products may be desirable over an area-based 30m pixel/grid (Marinelli et al., 2019; Paris et al., 2016; Strub and Osborne, 2021). As higher resolution ($\geq$16 pulses/m^2) lidar and other remote sensing data become available and processed into products that meet focused project-level objectives (Borgogno Mondino et al., 2020; Keefe et al., 2022; Sparks and Smith, 2022) it is anticipated that AGB maps and other analyses will continue to increase in operational value.

The needs and objectives of forest managers should remain local, centered on the lands they are charged to manage. The depth of information available from lidar and other remote sensing platforms (imagery) across multiple natural resource management objectives, suggests we can expect demand for these products to continue to increase, regardless of political priorities and other externalities. The ability to prioritize and rank treatment areas using measurable metrics focused on social, environmental and economic goals from these emerging technologies, is anticipated to increase the effectiveness of collaborative natural resource efforts. The processes applied in the assessment of AGB temporal change in this research supports the Anchor Forest concept by providing metrics that assists in quantifying ecosystem services within areas to be managed, describing current conditions, planning for potential benefits from forest management, and monitoring changes that provide feedback for adapting future actions.

Eastern Washington and many areas throughout the Western U.S. are experiencing significant forest health issues. Without strategically planned ecological management such as that proposed by the Anchor Forest concept and landscape-level information such as provided by the NASA CMS AGB products, these issues are likely to continue, further impacting communities and forest ecosystems. Addressing forest resilience is complex and when forest management is practiced within the confines of property boundaries, isolation, fragmentation, and a lack of collaboration have resulted (Bertaina et al., 2006; Butler, 2013; Reo et al., 2017). Furthermore, as land conversion occurs to support a growing population culturally removed from natural resource management, amenities on private lands are lost and public lands are expected to replace them (United States Department of Agriculture Forest Service, 2011).

Conclusion

Colville Tribal land managers have markedly reduced forest AGB on treated lands compared to untreated lands and similar to FS lands, with respect to temporal reductions in AGB density for the time period of 2000-2016. Colville Tribal forest management efforts have treated hazardous fuel loads on a greater proportion of their lands than have the FS, however they share mutual objectives for reducing fire risk, enhancing forest health, and sustaining economic productivity of forest

lands for both raw materials and carbon sequestration. Successes in achieving forest health objectives within dynamic forestland environments will continually require active stewardship of forested hectares across ownerships in order to address forest health conditions, reduce wildfire threats, conserve water quality and wildlife habitat, increase public safety, and improve overall ecosystem function as well as provide the jobs, wages, and taxes needed to support local communities and maintain working forests.

There are a number of tools available for prioritization of investments and management opportunities that increase forest ecosystem resiliency. This research outlines one conceptual opportunity that could bring landowners, communities, agencies, and tribes together to address increasing forest health. Efforts spanning multiple ownerships are likely to provide support for participation in carbon sequestration, ecosystem resilience, and alternative energy markets that can plan for and potentially supply fiber at larger scales than previously available.

The objectives of the Anchor Forest concept are intended to accrue shared benefits for all willing to work together in a trust-based atmosphere to develop balanced social/cultural, economic, and ecologically collaborative solutions. The conceptual structure presented in this study may enable landowners and stakeholders to more effectively utilize technology and tools such as regional biomass mapping products to monitor changing vegetative conditions, and support local communities in their efforts to effectively prioritize and apply resources in a dynamic and complex environment.

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Declaration of Competing Interest

The authors agree and submit this statement confirming there are no known conflicts of interest related to the research performed, or writing of, this manuscript as submitted.

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