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Research article

A multi-benefit framework for funding forest management in fire-driven ecosystems across the Western U.S.

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ABSTRACT

Forests across the Western U.S. face unprecedented risk due to historic fire exclusion, environmental degradation, and climate change. Forest management activities like ecological thinning, prescribed burning, and meadow restoration can improve landscape resilience. Resilient forests are at a lower risk of high-intensity wildfires, drought, insects, and other disturbances and provide a wide range of benefits to ecosystems and communities. However, insufficient funding limits implementation of critically needed management. To address this challenge, we propose a multi-benefit framework that leverages the diverse benefits of forest management to engage a suite of stakeholders in sharing project costs. We take a three-pronged approach to develop our conceptual model: examining existing frameworks for environmental project implementation, conducting a literature review of forest management benefits, and evaluating case studies. Through our framework, we describe the steps to engage partners, starting by identifying benefits that could accrue to potential public and private beneficiaries, and moving through an iterative and collaborative process of valuing benefits, which can accrue over different spatial and temporal scales, in close consultation with potential beneficiaries themselves. The aim of this approach is to stack funding streams associated with each valued benefit to fully fund a given forest management project. The multi-benefit framework has the potential to unlock new sources of funding to meet the exceptional challenges of climate and wildfire disturbances. We apply the framework to dry forests of the Western U.S., but opportunities exist for expanding and modifying this approach to any geography or ecosystem where management provides multiple benefits.

Kimberly Quesnel Seipp: Conceptualization, Methodology, Writing, Project administration, Tessa Maurer: Conceptualization, Methodology, Writing, Micah Elias: Conceptualization, Methodology, Writing, Phil Saksa: Conceptualization, Methodology, Writing, Funding Acquisition, Catherine Keske: Conceptualization, Methodology, Writing, Supervision, Funding Acquisition, Kirsten Oleson: Conceptualization, Methodology, Writing, Supervision, Funding Acquisition, Benis Egoh: Conceptualization, Methodology, Writing, Supervision, Funding Acquisition, Rachael Cleveland: Conceptualization, Methodology, Writing, Charity Nyelele: Conceptualization, Methodology, Writing Nicolas Goncalves: Conceptualization, Methodology, Writing Kyle Hemes: Conceptualization, Methodology, Writing, Funding Acquisition, Peter Wyrsch: Conceptualization, Methodology, Writing, David Lewis: Conceptualization, Methodology, Writing, Min Gon Chung: Conceptualization, Writing Han Guo: Conceptualization, Methodology, Writing, Martha Conklin: Conceptualization, Methodology, Writing, Supervision,

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1. Introduction

Forested lands cover a significant portion of the Western U.S. and are largely publicly owned (Fig. 1a–b), providing important benefits to natural and human systems (Ciccarese et al., 2012). In particular, dry forests (Hessburg et al., 2005), which cover approximately 25.5 million hectares of the Western U.S. (W. L. Baker, 2015), provide a multitude of key services: they comprise important habitat (Jones et al., 2016; Kelly et al., 2020); are key to maintaining water security (N. Liu et al., 2021; Kittredge, 1953; Stevens, 2017); and provide critical carbon storage capacity (Coop et al., 2020) .

Forests across the Western U.S. now face widespread and high wildfire hazard potential (Fig. 2), andcatastrophic wildfire, insect, and drought-related mortality events threaten the capacity of dry Western U. S. forests to provide these critical services (Hagmann et al., 2021; Vose et al., 2016; Fernández et al., 2012). Legacy management approaches have reduced the ability of forest ecosystems to recover after disturbance (Stephens and Moghaddas, 2005; Malcolm P. North et al., 2019; Coppoletta et al., 2019). Fire exclusion policies over the past decades ignored centuries of indigenous burning practices, resulting in dramatically higher fire risk due to increased altered forest structure and species composition within these forests (Marks-Block and Tripp, 2021; Pyne, 2017; Covington, 2000; Moritz et al., 2014). Warming due to climate change exacerbates this risk through more prolonged and severe droughts and increasingly volatile fuel conditions (Abatzoglou and Park Williams, 2016).

There is broad scientific evidence that active and intentional management of dry Western U.S. forests can increase landscape resilience, especially when interventions focus on forest structure and the reintroduction of key ecosystem processes (Stephens et al., 2010; Hessburg et al., 2021; Steel et al., 2021). Although isolated perspectives promoting passive management persist in the literature (Jones et al., 2022), the weight of scientific evidence demonstrates that contemporary wildfires are far outside the historical range of variation (Hessburg et al., 2005; Falk et al., 2011; Hessburg et al., 2019) and agrees that active management is necessary (Prichard et al., 2021; Hessburg et al., 2021). The specific prescriptions needed on each landscape varies but may include mechanical thinning, prescribed burning, meadow rehabilitation, and riparian restoration (M. P. North et al., 2021; Starrs et al., 2018).

Despite the acute need for active management, the pace and scale of implementation is inadequate. Implementation challenges include workforce capacity constraints, conflicting goals of land managers/owners and local stakeholders, and operational and governance hurdles (Davis et al., 2021). Underlying all these issues is a perennial lack of funding for large-scale forest management work.

Funding needs relate to both project planning and implementation

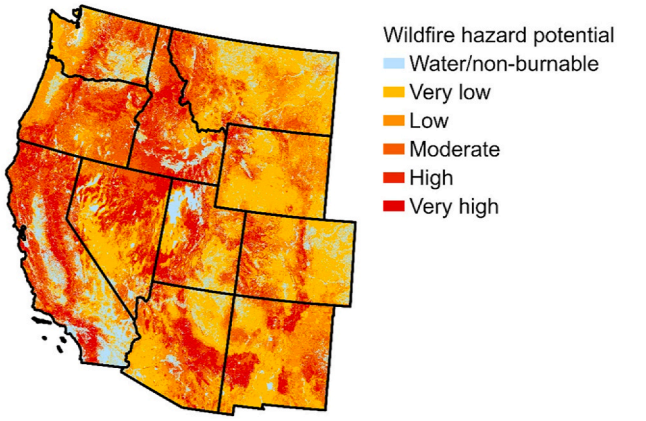

Fig. 2. Wildfire hazard potential as of 2018 for the Western U.S. Data source: Forest Service Research Data Archive (Dillon, 2018).

across both public and private land. Land managers are typically solely responsible for planning and funding work on the lands they manage or own (M. P. North et al., 2015). However, the need is possibly most acute on public land due to shortcomings in historical funding mechanisms, including those related to timber sale receipts. Timber receipt revenue for the U.S. Forest Service (USFS) has declined substantially during recent decades (to levels less than $400M annually) compared to historic levels (greater than $3 billion annually) and is not likely to recover to anywhere near historic levels (Belavenutti et al., 2021). Congressional appropriations have not compensated for this decline, much less the shortfalls necessary to address the full need, estimated at around $50 billion nation-wide (U.S. Forest Service, 2022). Moreover, recent high-impact fires have shifted attention and funding towards fire suppression, which has further decreased attention and resources dedicated to preventative management. Nationally in the U.S., spending on wildfire suppression has increased by more than 350% since 2000 (Fig. 3).

Given these challenges, a paradigm shift in funding approaches is required. Funding and financing mechanisms that leverage project benefits are increasingly being used, including: direct and indirect investments by governments and utilities; voluntary donations by the private sector; as well as market-based mechanisms including municipal bonds, voluntary surcharges, mitigation banks, and carbon markets, among others (Gartner et al., 2013). Several academic frameworks have been proposed in the literature to leverage the known benefits of healthy ecosystems, largely related to water and carbon, for monetary investment.

However, these frameworks have not been widely adopted in practice and none have been applied in the context of dry Western U.S. forests. Moreover, many frameworks in the literature focus on the planning process; however, frameworks to support implementation,

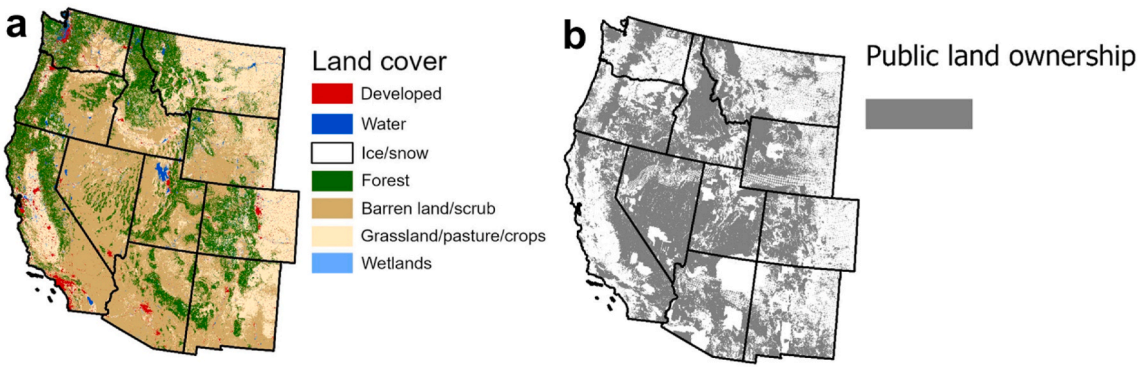

Fig. 1. (a) Land cover of the Western U.S. Data source: National Land Cover Database (Jin et al., 2019) and (b) Public (federal, state, and local) lands in the Western U.S. Data source: Protected Areas Database of the United States (U.S. Geological Survey (USGS) Gap Analysis Project (GAP) 2018).

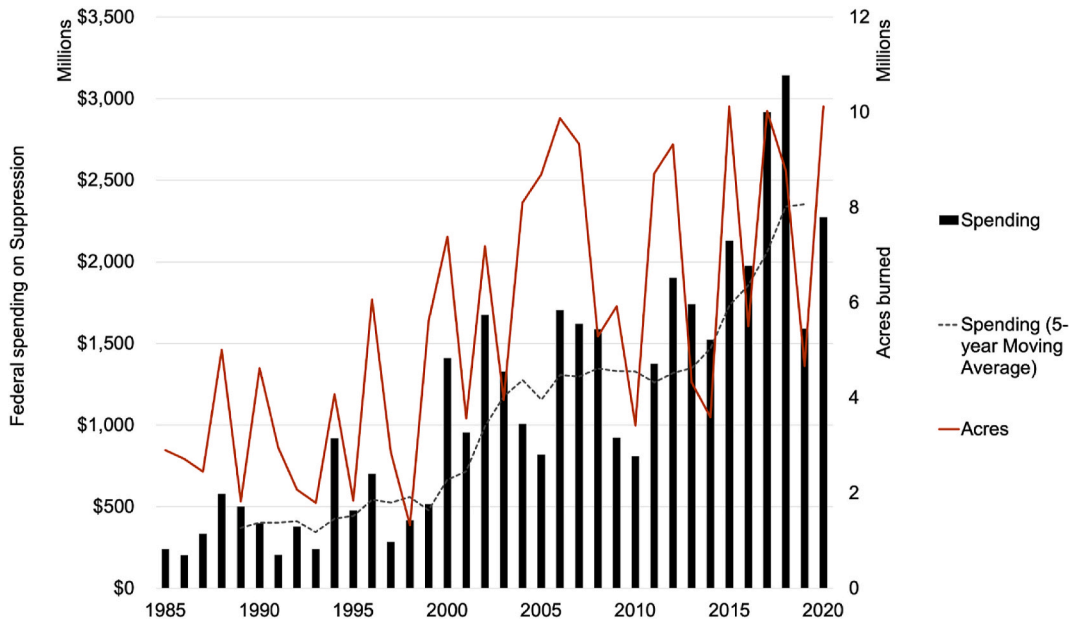

Fig. 3. Annual federal spending on fire suppression and total burned acreage. Data source (National Interagency Fire Center, 2021).

especially with a focus on increasing funding are less prevalent. Few forest management projects to date have successfully leveraged the benefits of resilient forests to break out of traditional funding structures (i.e., timber sales and Congressional appropriations on public land or solely landowner funding on private land). Thus, there is an opportunity to examine the gap between literature and on-the-ground projects and to look at how novel funding streams can be developed based on known forest benefits. The focus of our work is largely on public lands, partly because all identified case studies were at least partially on public land and also due to the scale of those areas in need of management and relative lack of public funding to perform the work (Fig. 1b and 3). The work here refers to "benefits" of resilient forests rather than ecosystem services or other terms to allow for the broadest interpretation of how individuals or entities interact with forests.

1.1. Research Questions

This study aims to answer the following questions

1. How can elements of existing environmental management frameworks be utilized to create a framework for implementation of projects in forested ecosystems? How can gaps in existing frameworks be addressed to catalyze and accelerate forest management?
2. What are the suite of benefits provided by resilient forests and how can they be leveraged to increase funding opportunities for forest management projects?
3. How have successful multi-benefit forest management projects overcome the logistical, operational, and social barriers to leverage project benefits?

In answering these questions, we propose an iterative and collaborative multi-benefit framework as a pathway for land managers, project developers, and partners to identify the multiple values of resilient forests for diverse beneficiaries, with an aim to expand funding streams and increase overall financial support for implementing management actions. Our goal is to develop an approach to stimulate investment and increase pace and scale of action.

2. Methods

We followed three steps to develop our framework:

In the first step, we explored existing multiple use frameworks broadly across the environmental sector to identify themes and recommendations that are relevant for designing a forest management framework. We identified shortcomings or disconnects between the existing literature and case studies that may explain why multi-use frameworks have not been more widely adopted in practice.

In the second step, we surveyed potential forest management benefits. Developing a list of potential benefits (also called co-benefits, performance metrics, or project goals in the literature) and incorporating them into the framework is critical for making conceptual models useful and informative (Gordon et al., 2018; Harris-Lovett et al., 2018; Serra-Llobet et al., 2022). Similar to the concept of "Benefit-Relevant Indicators" (Olander et al., 2018), we focused on benefits which might be of specific interest to potential beneficiaries, including both potentially monetizable and non-monetizable benefits. The goal was not to create an exhaustive list of every potential benefit, but rather to provide a collection of benefit groupings that could be further investigated on a project-specific basis. First, we searched peer-reviewed literature and reports for the terms forest management, forest restoration, and resilient forests and made a list of all benefit categories mentioned. Then, we reviewed existing literature for each specific benefit category, iteratively refining the list while developing a deeper understanding of each benefit.

In the third step, we examined case studies that have successfully incorporated the benefits of forest management to increase the number of sources and/or scale of funding. Testing and validating frameworks with existing case studies is a key aspect of making sure conceptual models are grounded in reality (Shanks et al., 2003; Gregory et al., 2012). Throughout the Western U.S. there are a number of forest management projects that have used some sort of multi-benefit approach. From here on, these projects and corresponding benefits are referred to as "non-traditional".

The lessons learned from the first three steps were then codified into a replicable but flexible process. The proposed framework aims to incorporate successful methods for identifying non-traditional benefits and project specific beneficiaries, defining the evaluation processes used to measure success, and stacking funding sources to increase total available project funding.

3. Findings

3.1. Literature review findings

Multi-benefit, multiple use, or co-benefit frameworks are common across the environmental literature. Traditional multiple use forest management approaches (Bowes and Krutilla, 1985) acknowledge the importance of co-benefits (those benefits beyond the original intent of the project), with respect to both planning and management. They usually assume fixed funding streams for forest management, which for projects on public lands implies a combination of congressional appropriations and timber sales. Reliance on public funding is common in other multi-benefit frameworks as well, including those developed for agriculture (Bryant et al., 2020; Lazurko and Venema, 2017), urban green infrastructure (Gordon et al., 2018; Demuzere et al., 2014), floodplain projects (Serra-Llobet et al., 2022), and water management (Everard and McInnes, 2013; Diringer et al., 2019; Harris-Lovett et al., 2018).

Each of the reviewed frameworks highlight the importance of incorporating novel project co-benefits when analyzing project impacts, specifically when examining cost-effectiveness or conducting a cost-benefit analysis. Incorporating co-benefits in the literature has largely been to optimize existing public funding or, occasionally, justify the increase of existing public expenditures. As public funding is not likely to ever fully cover large scale forest management in the Western U.S., frameworks must explicitly aim to unlock new funding streams.

Either explicitly or implicitly, the frameworks reviewed incorporate the concept of ecosystem services (Daily et al., 2009; Costanza et al., 1997) into the broader assessment of co-benefits. While there is a large body of literature and success encouraging publicly funded projects for multi-benefit forest management, private sources of funding to secure ecosystem services remain limited (Daily et al., 2009; Mandle et al., 2020), with the notable exception of carbon markets, which are uniquely transactable and global in scope (Robertson et al., 2014; Salzman et al., 2018), as well as some watershed payment for ecosystem services programs (Bremer et al., 2018).

Issues hampering the ability to leverage private payments for ecosystem services include: incomplete accounting of the full ecosystem service value chain from producer to consumer, lack of consideration of how ecosystem service benefits are distributed across beneficiary groups, and underspecification of where ecosystem services benefits are valued (Mandle et al., 2020). The typical valuation approach used in ecosystem services is landscape-level aggregation of benefits, which risks conflating several interrelated characteristics of ecosystem service benefits that are relevant for decision makers. For example, the full value of a benefit may be irrelevant to a beneficiary if they are contributing to a project that results in only a marginal change in benefits. Aggregate landscape-level benefit analyses also do not account for different motivations among beneficiaries, especially comparing public, user-financed, and compliance-based funding schemes (Salzman et al., 2018). This gap calls for a framework that adequately characterizes how benefits are captured and to whom the benefits accrue (Mandle et al., 2020).

Finally, existing frameworks largely do not unpack the connection between identified project benefits and potential funding sources. It is common for papers to draw a connection between a certain benefit and a certain beneficiary, sometimes for the purposes of illustration of a particular methodology (e.g. (Aburto-Oropeza et al., 2008)). However, there is little emphasis on the beneficiary engagement process to determine if the methods, metrics, and even the identified benefits themselves match beneficiary priorities. This limits the practical usefulness of these frameworks by ignoring social and organizational realities and may also result in important benefits going unidentified. As beneficiary groups may have different concerns, or value benefits differently, a framework is needed to operationalize a flexible, collaborative, and iterative process to uncover new sources of funding from government financed, user-financed, or compliance sources.

Based on these findings from the frameworks examined, we identified the following requirements for our multi-benefit framework: (a) ability to leverage private and other non-traditional funding sources; (b) sector- and beneficiary-specific analysis of benefits, and (c) an opportunistic and beneficiary-driven approach to funding in order to maximize new and existing funding streams.

3.2. Review of benefits

We identified eleven common benefit categories of forest management through the literature review, spanning biophysical (*e.g.* tons of CO_2e), socio-cultural (*e.g.* non-use values), and economic (*e.g.* income from wood products) metrics (Table 2). These 11 benefits include: habitat and biodiversity, wood products, water security, recreation, infrastructure, restoration economy, carbon stability, public health, local climate, non-use values, and sense of place.

The benefits we identified are not meant to be comprehensive. Instead, these benefits are those which may be of greatest interest to beneficiaries and therefore most readily leveraged for funding. For example, snowpack retention is not included directly because most beneficiaries are likely interested in the downstream impacts linked to water security, such as additional water quantity, colder water, and higher base flows. In theory, however, a project beneficiary such as a ski resort could be interested in the snowpack itself. Table 2 depicts the 11 benefits identified during the literature review and includes key points about the effect that management has on the benefit, what risks might be avoided through management, what aspects of the benefit may be enhanced through management, and the conditions required to realize the benefit.

Together, the 11 identified benefits contribute to an overall more sustainable world as evidenced by their collective contributions to 10 of the United Nations' Sustainable Development Goals (SDGs) (United Nations Environment Programme, 2020) (Fig. 4). These benefits are widespread in forest management projects in dry Western forests and are frequently mutually reinforcing. For example, protecting habitat and biodiversity often means performing thinning and prescribed burns to reduce competition and the risk of catastrophic fire (Stephens et al., 2020; Knapp et al., 2017; M. North et al., 2009). These management actions usually also have the effect of boosting long term carbon stability, providing raw material for wood products, and enhancing water security (Saksa et al., 2017; Springsteen et al., 2015; Liang et al., 2018).

3.3. Case studies

We examined case studies of multi-benefit forest resilience projects that (1) are still funded through traditional land agency budgets and timber sales (Table 1a) and (2) have successfully leveraged non-traditional sources of funding and paying beneficiaries, such as water utilities, local cities, state governments, Tribes, corporations, and federal grant programs (Table 1b). The Ashland Forest Resiliency (AFR) Stewardship Project in Oregon, Denver's Forests to Faucets partnership in Colorado, the Flagstaff Watershed Protection Project, and the North Yuba Forest Partnership (NYFP) are all examples of these non-traditionally funded projects that incorporate a diversity of organizations to help plan, coordinate, and implement forest management activities, largely in response to, or in order to prevent, catastrophic wildfire. The success of these projects have been enabled by effective collaboration, clear identification of benefits, and engagement of well-resourced and forward-thinking beneficiaries.

Each non-traditionally funded multi-benefit project used an iterative process of collaboration which created buy-in from stakeholders. This trend is also identified for successful forest collaboratives in the literature (Davis et al., 2018). In all four projects we evaluated, the USFS worked with Tribes, non-profits, and other state and federal agencies to catalyze action in addition to other local partners: local water agencies

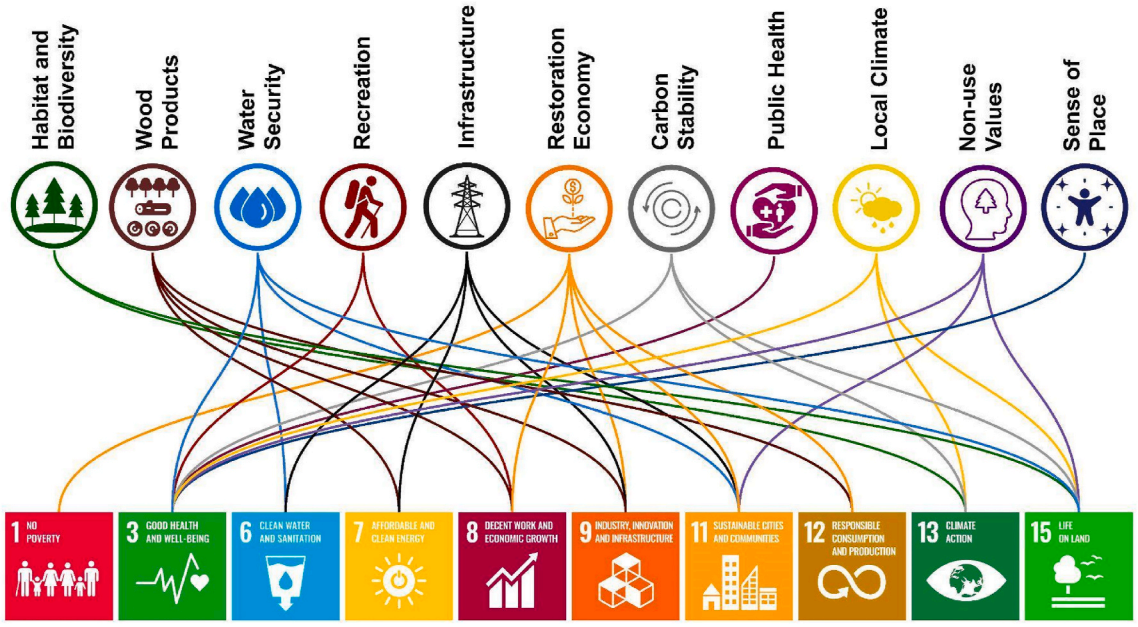

Fig. 4. The 11 benefits of a resilient forest achieved through management and how each supports 10 of the United Nations' Sustainable Development Goals (SDGs).

Table 1a
Examples of Multi-Benefit Forest Resilience Projects on USFS land with traditional funding sources from the sale of timber and the U.S. Forest Service.

Project	Starting Year	Location	Size	Benefits Leveraged	Paying Beneficiaries
Quincy Library Group	1993	California	85,000 Acres	● Habitat & Biodiversity ● Wood Products	USFS
Mill Creek A to Z Project	2013	Washington	54,000 Acres	● Habitat & Biodiversity ● Wood Products	USFS Vaagen Brothers Timber Company
Four Forests Restoration Initiative	2010	Arizona	2,400,000 Acres	● Habitat & Biodiversity ● Wood Products	USFS

Table 1b
Examples of Multi-Benefit Forest Resilience Projects on USFS Land leveraging benefits for new funding sources.

Project	Starting Year	Location	Size	Benefits Leveraged	Paying Beneficiaries
Ashland Forest Resiliency (AFR) Stewardship Project	2010	Oregon	53,000 Acres	● Habitat & Biodiversity ● Water Security ● Infrastructure & Operations ● Public Health	USFS USDA-NRCS City of Ashland State of Oregon
Forests to Faucets	2010	Colorado	100,000 Acres	● Water Security ● Infrastructure & Operations	USFS Denver Water
Flagstaff Watershed Protection Project	2012	Arizona	10,544 Acres	● Infrastructure & Operations	USFS City of Flagstaff
North Yuba Forest Partnership (NYFP)	2018	California	275,000 Acres	● Habitat & Biodiversity ● Water Security ● Infrastructure & Operations ● Public Health	USFS Yuba Water Agency State of California Corporations

for the North Yuba Forest Partnership and the Forests to Faucets collaborations and the cities of Ashland and Flagstaff for those respective projects. Fundamentally, success accessing non-traditional funding was correlated with strong collaborations, connections, and facilitation roles played by different partners.

Another key characteristic of these four projects was clear identification of relatively quantifiable and monetizable benefits. These benefit evaluation processes were based on actionable, scientifically sound metrics of avoided risk and/or an enhanced benefit from forest restoration. Each of the non-traditionally funded projects leveraged water benefits in some way, either protected critical reservoirs from sedimentation and debris or the potential to increase water yield after forest thinning. Although other benefits such as biodiversity benefits and recreation were important to stakeholders in each of the forest collaboratives, water security benefits were used in all cases to engage non-traditional payors and increase the number of funding sources.

Finally, each project engaged forward thinking, urban, or otherwise well-resourced beneficiaries. Local cities including Denver, Flagstaff, and Ashland as well as the Yuba Water Agency all provided sources of funding that had not previously been accessed for forest management. Forests to Faucets used a ballot measure to leverage funds from the Colorado Forest Service as well as the NRCS (Adams, 2018), Flagstaff passed a bond measure to fund $10 million worth of work ("Flagstaff Watershed Protection Project" 2023), and Yuba Water was able to provide funds from hydropower electricity revenue. Each of these payors represented large numbers of individual beneficiaries, either water or electricity customers.

These four case studies reinforced certain findings from the literature

review (Section 3.1). First, the benefits of a project may not be obvious at the outset: successful projects limited *a priori* assumptions about what specific benefits or beneficiaries would be most effective in leveraging non-traditional funds. In each of the case studies, significant effort was made early in project development to build buy-in from stakeholders and beneficiaries around the project benefits. In all cases, trusted scientific analysis of the benefits underpinned engagement by quantifying benefits to a degree of certainty acceptable to beneficiaries. Second, the success of the non-traditionally funded multi-benefit project speaks to engagement that responds to beneficiary concerns, further confirming the need for disaggregated benefit analysis and no *a priori* assumptions around benefit importance. Third, all projects had in common the presence of well-resourced, frequently urban, beneficiaries. In all cases, the projects were close to or directly impacted resources for significant population centers. At the scale of the Western U.S., not all projects or regions may have such a connection, which could make it challenging to leverage non-traditional payment sources. Such projects could still benefit from corporate or other off-site engagement, but there is no guarantee that would always result in sufficient resources.

Based on the findings from the case studies, we identified the following requirements for our multi-benefit framework: (a) flexibility handle a variety and combination of payor types (including public, private, compliance, etc.), (b) explicit identification of the benefits and description of to whom they accrue, at what point in the value chain, and what value they have to beneficiaries, and (c) inclusion of participatory approaches to create support and buy-in from a range of beneficiaries.

4. A multi-benefit framework for forest management

The resulting framework describes the process of 1) identifying the benefits of a given set of management activities and the beneficiaries to whom those benefits accrue, 2) determining the value of each benefit to each beneficiary through an iterative and collaborative process, and 3) stacking those values to match the full sum of the project cost (Fig. 5).

The central feature of the framework is the emphasis on how an iterative and collaborative evaluation process with beneficiaries can overcome shortfalls of traditional project valuation approaches like cost-benefit analysis, which may not fully address environmental impacts of climate change, leave out certain beneficiaries or stakeholders, and/or exclude certain non-market or non-monetary costs and benefits (Brand et al., 2021; Bennett et al., 2014). The evaluation approach is designed to disaggregate benefit assessments and identify appropriate benefit value while providing flexibility for incorporating multiple types of benefits, beneficiary types, and funding sources (e.g., public appropriations, grants, private entities, philanthropic donations).

4.1. Identifying benefits

The first step in the framework is to identify a broad suite of potential project implementation benefits by assessing the expected outcomes of the proposed activities (Fig. 5). The benefits in Table 2 can serve as a starting point for conversations, but project developers should not assume that any specific benefit will resonate with beneficiaries. Benefits need not be quantifiable or monetizable in a common unit; rather, a broad set of benefits should be identified. Benefits not initially identified may also come to light during the beneficiary engagement process, in which case this step can be repeated. In order to maximize potential funding streams, project developers should consider many angles of positive project outcomes, in terms of either the direct enhancement of a benefit or reduced risk of losing those benefits.

While project benefits usually coexist or mutually reinforce each other, they may also conflict. As such, even though these 11 benefits (Table 2) showcase many positive outcomes, forest management actions may not be viewed positively by all communities and stakeholders. For example, forest thinning may affect the sense of place or visual appeal of the forest for individuals or communities that have become familiar with the dense forest structure more typical of recent decades (Gosnell et al., 2006). Similarly, communities may be wary of prescribed burning, both due to smoke emissions and to perceived risk that the burn becomes uncontrollable. While smoke from prescribed fire presents fewer negative health impacts than the wildfires it is designed to protect against (Schweizer et al., 2019), local communities may not be aware of these differences. Crafting public awareness, outreach, and communication materials and identifying community needs can help address potential concerns about project trade-offs and pave the way for public support. Additional strategies for managing trade-offs that have been previously identified in the literature include: explicitly identifying and recognizing the trade-offs, understanding and including multiple stakeholders in the process, accounting for trade-offs across multiple spatial and temporal scales, learning from past experiences, and ensuring continuous monitoring as implementation progresses (Rodríguez et al., 2006; Zheng et al., 2019).

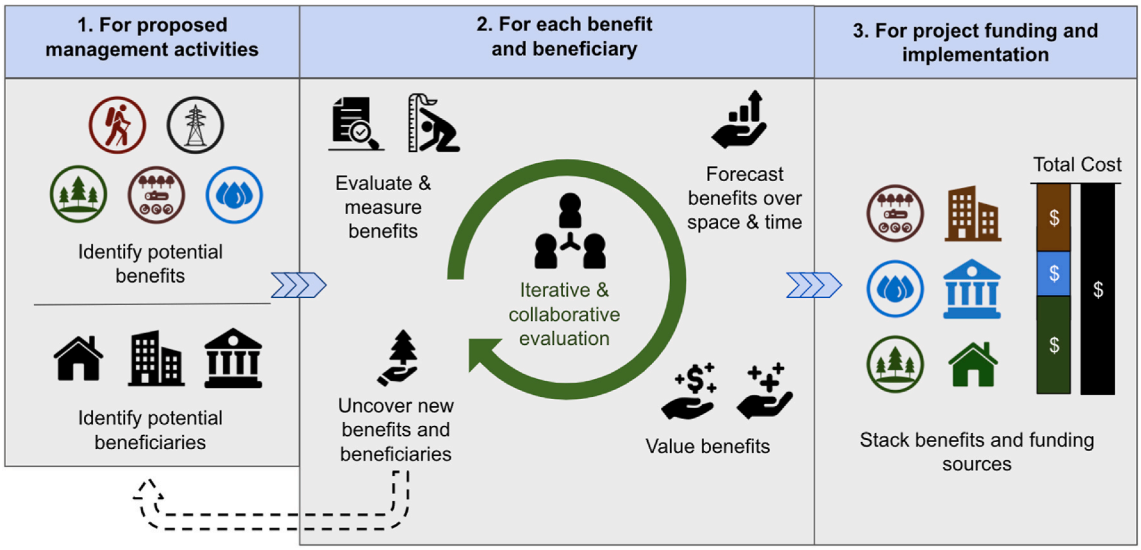

Fig. 5. Multi-benefit framework for funding forest management.

Table 2
Benefits from resilient dry forests achieved through management activities.

Benefit	Key Points	Risk Avoided	Enhanced Benefit	Conditions Required	References
Habitat and Biodiversity 	The overarching goal of forest management is to increase forest resilience, or the ability to withstand shocks to the system (fire, pest, drought, etc.)	● Forest ecosystem & habitat loss from severe wildfire	● Resilience to climate & wildfire disturbance	● Achieving resilience is highly specific to forest type, region, and threats	(Malcolm P. North et al., 2019; McWethy et al., 2019; Thompson et al., 2009)
Forest Products 	Transforming non-merchantable biomass into a feedstock for bio-power plants, biochar, and wood products. Other forest products may include: First Foods, edible, and medicinal plants and terrestrial/aquatic species, which may be of particular interest important to Tribes.	● Biomass waste is burned or decomposes, releasing carbon emissions ● Edible and medicinal plants, especially native species, are lost due to disturbance and encroachment of non-native species	● Carbon sequestration and storage ● Displacement of more carbon intensive products and energy ● Sources of sustenance and cultural value are protected for Tribal and local communities	● Sufficient infrastructure ● Consistent supply of material ● Market demand ● Profitable electricity rates for bio-power plants ● Appropriate local climate conditions, sufficient seed stock, ongoing maintenance, especially burning, to maintain habitat	(S. Baker et al., 2019; Campbell et al., 2018; Gildart and Others, 2005; Natcher, 2006; Adlam et al., 2022)
Water Security 	Management can enhance water supply, protect water quality, protect aquatic habitat, and protect water & hydropower infrastructure	● Contaminated water supply ● Reservoir sedimentation ● Flooding ● Poor aquatic habitat ● Soil stability and decreased risk of erosion ● Reduced fish populations and wetland plants important to Tribes	● Supply increase benefits local communities, hydropower production, irrigation and municipal utilities ● Species of high cultural value to Tribes are protected	● Forest-dominated watershed ● Existence of water supply infrastructure: reservoir, intake, etc. ● Catchment is upstream of a drinking water source or reservoir	(Bales, 2016; Ice et al., 2004; Simonit et al., 2015; Sun et al., 2015)
Recreation 	Forests provide many recreation opportunities including fishing, camping, hunting, trails, and boating	● Loss of access or reduced visitation ● Reduce local economic activity	● Maintain or increase visitation and local economy	● Highly specific to attribute, location, and condition	(Fish et al. 2016; Hermes et al., 2018; Hilger and Englin, 2009)
Infrastructure and Operations 	Wildfires in the wildland urban interface (WUI) can damage housing, transportation networks, utility pipelines and other infrastructure	● Liability of starting wildfires in the WUI ● Damage to houses and other infrastructure ● Avoided wildfire suppression costs	● Resilience to disturbance	● Management (fuels treatments) must occur close to infrastructure and development to have an impact on decreased fire risk to the WUI	(Bertolotti et al., 2019; McMahan and Gerlak, 2020; Fraser et al., 2020; Mueller et al., 2018; Schulze et al., 2020)
Restoration Economy 	Local jobs are created in implementing management activities, project management, and the forest products industry, while indirect economic benefits accrue to rural and Tribal communities	● Displacement of investments in less climate friendly industries like oil and gas ● Unemployment	● Job creation and new business opportunities ● Increased business to business spending	● Forest management contractors ● Processing facilities (bioenergy, wood products, etc.) ● Consistent supply of work and material	(BenDor et al., 2015; Cunningham, 2002; Standiford and Henderson, 2020; Nielsen-Pincus and Moseley, 2013)
Carbon Stability 	Resilient forests result in long-term carbon stability, through reduced emissions from high-intensity severity fires	● Management decreases carbon in the short term, to decrease the risk of carbon loss from high-intensity severity fire.	● Long term carbon stability and climate change mitigation	● Need to calculate change in fire risk, vegetation growth, and average carbon stocks over time	(Earles and Hurteau, 2014; Liang et al., 2018; Hurteau et al., 2019)
Public Health 	Wildfire smoke causes negative health impacts, anddisadvantaged communities are disproportionately affected	● Adverse health impacts: respiratory illness, cardiovascular disease, and more	● Protected recreation & physical activity opportunities	● The closer the community is located to the wildfire, the higher risk of associated health impacts ● This risk can be mitigated by policy and/or individual behavior change	(Cascio, 2018; Epa, 2019; Fann et al., 2018; J. C. Liu et al., 2015; Reid et al., 2016; Burke et al., 2021)
Local Climate 	Climate regulation services occur through biophysical mechanisms	● Increased extremes in land surface temperature	● Better conditions for forest growth, recruitment, and biodiversity	● Local communities must be principal beneficiaries to realize benefits	(Bonan, 2008; Anderson et al., 2011; Cooper et al., 2017; Z. Liu et al., 2019; Lawrence et al., 2022)
Non-Use Values 	Existence, cultural, bequest, and option values are grouped together and derived from knowledge that healthy forests will exist now and into the future	● Degradation of natural cultural heritage & traditional homelands, parks, national monuments, natural areas etc ● Inability to access	● Access to cultural resources ● Increased visitors ● Increased funding ● Increased quality of parks and other natural areas	● Beneficiaries must know its existence ● Accessibility to future generations or for later use ● These values are hard to quantify or qualify	(Bamwesigye et al., 2020; Chopra, 1993; Diafas et al., 2017; Rezende et al., 2015; De Groot et al., 2010; Walsh et al., 1990; National Ecosystem Services

(*continued on next page*)

Table 2 (*continued*)

Benefit	Key Points	Risk Avoided	Enhanced Benefit	Conditions Required	References
Sense of Place 	Sense of place is a multidimensional construct used to describe human belonging to a specific location	● Loss of available natural resources ● Potential risk to place identity and place attachment	● Strengthen place identity and attachment ● Enhances community environmental behavior ● Individual physical, mental, and psychological well-being	● Public places of interest should be accessible by the community	Partnership, 2016; Middleton, 2014) (Bergstén and H. Keskitalo 2019; Cross et al., 2011; Cheung and Dennis, 2018; Nielsen-Pincus et al., 2017; Masterson et al., 2017; Stedman, 2003)

4.2. Identifying potential beneficiaries

The next step in the framework is to determine potential project beneficiaries. Resilient forests deliver benefits to both public and private beneficiaries (Table 3). How and why a beneficiary is interested in a benefit has implications in terms of measurement and quantification, valuation, the funding mechanisms available, and the need for monitoring and/or reporting. It is critical to approach and communicate with each beneficiary individually throughout the valuation process (Olander et al., 2018). While examples of potential benefits can help start conversations with potential beneficiaries, engagement should allow for iterative feedback and conversation to understand beneficiary priorities and potentially uncover new or different relevant benefits.

Public beneficiaries, such as federal, state, or local governments or Tribes, may be motivated by protecting or enhancing benefits they identify as public goods. This can include harder-to-quantify benefits like regulating local climate, preserving cultural heritage, and protecting habitat and biodiversity. The public goods from healthy natural systems have historically - and will continue to - provide much of the logic for public funding appropriated to restoration and conservation. Equity considerations are also key when rationalizing public expenditures for forest management, for example, as marginalized and vulnerable communities disproportionately feel the negative effects of wildfire smoke (Reid et al., 2016).

Private beneficiaries will often be interested in the quantification, monetization, and allocation of the benefit (Bennett et al., 2014). A private beneficiary might be unfamiliar with the ways in which forest management can positively impact their economic bottom line or help achieve their goals. This makes thoughtful engagement and trust-building critical to understanding beneficiary motivation. Private entities interested in forest management outcomes may include investor-owned utilities looking for direct revenue enhancement (e.g. increased water yield following vegetation thinning) or risk reduction (e.g. infrastructure and liability protection from fire risk reduction). Corporations with environmental, social, governance (ESG) goals to reduce their climate impact may also be interested in contributing to forest management projects based on both internal (e.g. sustainability goals, financial outcomes, or employee pressure) and external (e.g. customer desires, regulations, or marketing) factors (Collins and Schultz, 2021). Philanthropies have historically played a key role in wildfire recovery for community support (Rosenthal et al., 2021), indicating that they could also be potential funders for proactive forest management as an avenue for community protection, for current and future generations.

Many benefits fall on a spectrum between fully private (excludable and rival) and fully public (non-excludable and nonrival) goods and services (Araral, 2014; Choe and Yun, 2017), and therefore most will be of interest to both public and private beneficiaries, although potentially for different reasons. For example, the health outcomes associated with decreased smoke from severe wildfires may be of interest to both local and state public health agencies who are interested in protecting their citizens. At the same time, health insurance companies could see decreased wildfire smoke in terms of decreased emergency room visits, which could lead to financial benefit.

Not all public beneficiaries are similar in not needing robust measurements and not all private beneficiaries need robust measurement. Public water agencies, governed by boards of directors, may still need to see forecasted financial savings to their bottom line to make the economic case for participation. There are also private beneficiaries, like philanthropies, who have a mission to support public goods like clean water, protected habitat, and equitable access to forested recreation facilities, and therefore want to see quantifiable outcomes. The complexities of site- and beneficiary-specific engagement highlight the need for benefit valuation in close collaboration with the beneficiaries themselves.

4.3. Leveraging benefits through an iterative and collaborative evaluation process

Once project benefits and associated potential beneficiaries have been identified, the iterative and collaborative process of valuing those benefits begins. This involves evaluating or measuring the projected incremental changes or impacts from project activities, forecasting the benefit over space and time, and using that information to value benefits. Collaboration and trust-building is critical for appropriately valuing benefits because beneficiaries may differ in terms of evaluation methods they are willing to accept, uncertainty ranges they are able to tolerate, and benefits they wish to prioritize; some beneficiaries may even see something as a benefit that other stakeholders perceive as a cost. A beneficiary generally must perceive the value of the forecasted benefit to be greater than any feasible alternatives, including the no-action or business-as-usual scenarios, to make the case for action.

4.3.1. Evaluating and measuring benefits

A first, critical distinction to make jointly with beneficiaries is whether they are interested and willing to pay for *outputs* or *outcomes* of a particular action (Brand at al., 2021). When evaluating for outputs, success is defined simply as project actions being implemented. The implicit assumption in an output-oriented approach is that, based on the best available scientific projections, project implementation will lead to forest resilience and result in the benefit of interest. Output-oriented metrics, like the number of acres restored, can be particularly useful for leveraging hard-to-quantify and measure values like non-use values and sense of place. As a result, evaluation for output-oriented approaches frequently use proxy metrics to determine success: for example, miles of roads decommissioned may be the proxy for protected aquatic habitat, under the assumption that the work will lead to reduced sediment transport.

On the other hand, many beneficiaries, particularly entities requiring an economic justification for participation, may be focused on outcomes, the measurable changes resulting from the management. In this case, project actions must be tied to projected outcomes based on statistical or

Table 3
Public and private beneficiaries of a resilient forest achieved through management.

Benefit	Public Beneficiaries	Private Beneficiaries
Habitat and Biodiversity	● Governments: Local, State, Federal, and Tribal ● Federal and State land owners and managers	● Local and regional recreational visitors ● Land owners and managers
Forest Products	● Governments: Local, State, Federal and Tribal	● Bioenergy facilities ● Wood products companies ● Carbon credit developers
Water Security	● Government agencies, including Tribal, for aquatic habitat & species protection ● Municipal water, flood district, and hydropower utilities	● Private hydropower and utilities including agriculture and irrigation districts ● Corporations directly (e.g. bottling companies) or indirectly (e.g. as utility customers) dependent on supply
Recreation	● Local towns and counties ● Federal and State land owners and managers	● Recreation visitors and users ● Hunting and fishing groups
Infrastructure and Operations	● Federal and state departments of transportation ● Municipal water and energy utilities ● Local governments in high-fire-risk areas ● Federal and state land managers	● Insurance companies ● Homeowners Associations ● Road/Rail managers and trucking companies ● Private water and energy utilities
Restoration Economy	● Local, State, Federal, and Tribal Departments of Commerce ● Local economies	● Unions ● Wood products companies ● Forestry contractors
Carbon Stability	● Local, State, Federal, and Tribal climate initiatives	● Carbon credit developers
Public Health	● Public health agencies ● Public hospitals ● The public (from air quality standpoint)	● Health insurance companies ● Health care networks ● Private hospitals ● Local businesses, especially open-air enterprises ● Recreation and tourism industries
Local Climate	● Local, State, Federal, and Tribal governments	● Groups interested in climate benefits to seedling regeneration ● Private businesses and households using indoor climate-control
Non-Use Values	● The public ● Tribes and First Nations ● Individuals and entities placing cultural value on the land ● Future generations	● Philanthropic organizations with environmental stewardship and community support missions ● Environmental and cultural organizations
Sense of Place	● Local communities, including Tribes ● Communities with attachment to place	● Philanthropic organizations with environmental stewardship and community support missions ● Environmental and cultural organizations

physical modeling. For example, a water supply enhancement outcome could be tied to acres thinned via a forest water use reduction model (Roche et al., 2020; Saksa et al., 2017). Transparency in benefit measurement is critical, and beneficiaries should have buy-in to the methods selected for evaluation and be comfortable with the likely range of uncertainty of the results. All parties - beneficiaries, project developers, and any third-party modelers - should prioritize an impartial environmental-economic analysis of the project actions. Depending on the project, a particular outcome and associated benefit may not be guaranteed, so beneficiaries must trust they are receiving a sound analysis in order to make a decision on participating in a project.

The scientific expertise and human resource requirements for doing outcomes-based analyses have traditionally been a barrier to leveraging certain benefits given ;the time and resources required to pay for on-the-ground sensor networks or expensive tools. New approaches using non-traditional and emerging approaches that are both robust and easy to use have changed this paradigm. For example, remote sensing has emerged as a relatively inexpensive way to capture landscape-scale conditions (e.g., the California Forest Observatory (Salo Sciences, Inc., 2020), InVEST (Daily et al., 2009), eMapR products (Hooper and Kennedy, 2018), and Lema (Ohmann and Gregory, 2002)) and to provide forecasted benefit modeling and monitoring. Web-based and social media platforms provide other newly accessible novel data sources, such as housing prices from Zillow, Redfin, or Trulia that allow for more rapid evaluation of infrastructure value in fire-risk zones (Garnache, 2020). Citizen science data and online data gathering tools are other inexpensive, novel data collection methods gaining traction (Strobl et al., 2019; PurpleAir, 2020).

Finally, these new datasets lend themselves for use alongside artificial intelligence and machine learning techniques which are increasingly becoming popular in the ecology field (Peters et al., 2014; Saia et al., 2020). These models require buy-in from stakeholders as these novel approaches move from theory to practice (Saia et al., 2020). Despite these new data and computational resources, certain benefits are still significantly under-studied. For example, more research is needed on public health impacts of wildfire smoke (Wilmot et al., 2021) to more explicitly link decreased wildfire risk to positive public health outcomes in a way that incentivizes public health agencies and health care systems to fund management. Additionally, developing new methodologies or engaging existing methodologies which leverage the carbon benefits of resilient forest management will help access funds from carbon markets (van Kooten and Johnston 2016; Kurz et al., 2016). Until more robust or widely accepted evaluation techniques are developed, engaging beneficiaries around these benefits may require a greater tolerance of uncertainty.

4.3.2. *Considering benefits across space and time*

Although forest management itself takes place over distinct spatial and temporal extents, the benefits often extend far beyond those boundaries. This misalignment of scales is both an opportunity and a challenge for monetizing benefits and incentivizing participation.

Spatially, the distance from forests to some beneficiaries can make benefit attribution from a specific project to non-local beneficiaries challenging. Recreation benefits, reduced health impacts from wildfire smoke risk reduction, and many non-use values may be realized by both local rural communities and urban users located sometimes hundreds of miles from the forest itself. It may be difficult to identify the benefit value of one given project to an urban beneficiary, when many beneficiaries exist and/or work must be done at a spatial extent relevant to non-local beneficiaries.

Despite these spatial challenges, the ability to engage urban and state-level beneficiaries may be imperative for many projects to overcome the fact that local, usually rural, communities are frequently resource-constrained. One avenue for successful urban-rural funding collaboration is by leveraging the carbon benefits of management projects which help to avoid greenhouse gas emissions associated with catastrophic wildfire. Due to the global nature of atmospheric carbon, local, national, and international entities benefit from the carbon benefits of projects regardless of the location. Although there has been limited success engaging urban beneficiaries to pay for forest management, this is an active area of research and beneficiary engagement

across many of the 11 benefits of resilient forests (Table 2).

The temporal heterogeneity of benefits further compounds the challenges associated with the differing spatial scales. Certain benefits may accrue slowly and over long time periods while others materialize quickly. As a result, benefits may not begin to accrue to specific beneficiaries until after work has been done or only under certain conditions (e.g. in high precipitation years). In such cases, it can be difficult for beneficiaries to commit funds upfront even if they benefit from the project in the long term. Here, conservation finance tools like environmental impact bonds may help beneficiaries with limited cash to participate in projects (Brand at al., 2021). Other payees may be reluctant to pay upfront for benefits that are realized over decades, like non-use values (specifically bequest values), which are important for future generations, particularly since estimating benefits typically grows more uncertain over longer time horizons. This highlights the importance of discounting future project benefits and the impact of different discount rates when estimating the impact of a project. Discount rates are key, even if only conceptual, when considering the long-term costs and benefits of a project (Arrow et al., 2013). Clear benefit forecasting tools may help convey the need to invest in management today to ensure the continuation of benefits through time.

Management which maintains a resilient forest structure related to density, species composition, and stand age is key for extending the temporal timescale of benefits of a resilient forest. Importantly, maintenance must be undertaken at the landscape scale to provide some of the benefits that are not realized until activities are implemented on a significant portion of the project area. Meanwhile, delaying upfront implementation means greater expense in the future due to growing impacts of climate change, encroaching pressures of human infrastructure, and cumulative environmental degradation. Thus, the substantial upfront costs for management, which increases forest resilience, are significantly lower over time than the status quo of non-resilient forests when environmental impacts of forest management projects are incorporated (M. North et al., 2012).

4.3.3. Valuing benefits

A key feature of the multi-benefit framework is understanding how beneficiaries value forecasted benefits. Co-producing value estimates alongside beneficiaries is critical for understanding how value is considered, how value accrues, and where value is captured (Mandle et al., 2020). Assessing specific characteristics of the value through a transparent, iterative, and participatory process ensures beneficiary buy-in and that the final assessed value is meaningful to the paying entity (Bos et al., 2015). For example, a water utility may value protected water quality in terms of avoided sedimentation risk to their reservoir over 5 years, a downstream agricultural beneficiary may be interested in the post-fire flood risk reduction, captured as economic risk mitigated, over 10 years, and a state department of commerce might value the job creation associated with the work.

A beneficiary can perceive a benefit to have a use value, non-use value, and/or intrinsic value (Turner and Daily, 2008). Translating these values into monetary values can be needed for adequately funding conservation or restoration work (Turner and Daily, 2008). The ease of estimating the monetary value of a benefit is largely dependent on whether the value of the benefit is market-based or rooted in ethical values (The Economics of Ecosystems and Biodiversity, 2008). Aside from understanding how the benefit is monetizable (assigning a financial value to the benefit change), it is also critical to determine if the value of the benefit is transactable (ie. if the beneficiary is willing to pay for that change). It is important to note that, while monetizing a benefit usually makes it more transactable, it is possible for benefits to be transactable without being monetized. For example, a beneficiary concerned about an output metric may pay for the forest management work on the basis of existence values or retaining sense-of-place due to decreased wildfire risk, making these transactable without being monetizable.

To gain a better understanding of how the 11 identified forest management benefits could be leveraged, we developed a simple, conceptual typology based on relative monetizability and transactability (Fig. 6). How each benefit fits on the two scales has direct implications for valuation and therefore funding. Benefits were grouped into three categories based on their relative locations on monetizability and transactability axes: (1) benefits that can be monetized and transacted - those that are most promising for leveraging financing for both public and private beneficiaries; (2) benefits that can be monetized but more challenging to transact - those that are promising but more research and new policies are needed to understand the value and create a market; and (3) benefits with low monetizability and transactability - those that are the most challenging to monetize but could be leveraged for funding through outputs-based participation from public funds or entities with ESG goals.

Progressing through Fig. 6, identifying the most easily transactable and monetizable benefits may encourage engagement of water utilities and hydropower companies for water security benefits, governmental agencies and municipalities interested in protecting recreation assets, wood products companies focused on wood products or carbon values, or governmental and non-profit groups invested in preserving habitat and biodiversity. As benefits become less monetizable and transactable, identifying public and private beneficiaries willing to provide funding may become more challenging, highlighting the continued need for stakeholders historically willing to fund projects based on outputs and not outcomes. Working alongside public and private beneficiaries simultaneously can encourage participation and unlock previously untapped funding sources by leveraging a full suite of benefits (Table 2).

The synergies between benefits often means that harnessing monetizable and transactable benefits as value streams can support benefits that are less monetizable and transactable (for example, existence values) without the need for explicit payments. One common benefit interaction is the intersection between wood products (highly transactable and monetizable), the restoration economy (somewhere transactable and monetizable), and sense of place (challenging to transact and monetize). A beneficiary who is interested in seeing a project happen because of the wood products generated would also be supporting the local economy , while simultaneously enhancing connection to the local forest from the community that benefits from the work. An important feature of the multi-benefit framework is that it can draw awareness to additional benefits that are valuable but not easily monetizable or transactable. The integrity of the forest ecosystem is intrinsically connected to the other benefits, so as a project improves ecosystem integrity, other benefits will naturally accrue. For example, the capacity of a forest ecosystem to sequester carbon relies on the healthy function of that ecosystem.

4.4. Uncovering new benefits and beneficiaries

During the evaluation process, new project benefits will likely be uncovered by working with beneficiaries. Collaborative assessment with potential payors facilitates identification of possible benefits and ensures that benefits are conveyed in a meaningful way, for example in risk-reduction terms or in terms of direct benefit enhancement. Collaborative exploration of the benefits important to beneficiaries is key to ensure that benefits are not misconstrued, misinterpreted, or projected onto a beneficiary. For example, a project developer might assume that a county government is most worried about the risk to their built infrastructure if a wildfire occurs, but instead the local government priorities may be oriented towards the impact that a fire would have on the local recreation economy or its implications for local climate.

In addition, new beneficiaries will likely emerge, including those interested simply in participating in the collaborative process. Engaging this broader suite of beneficiaries may facilitate engagement with new potential payors, either organizations with whom they share resources or those they view as recipients of project benefits. This phenomenon is

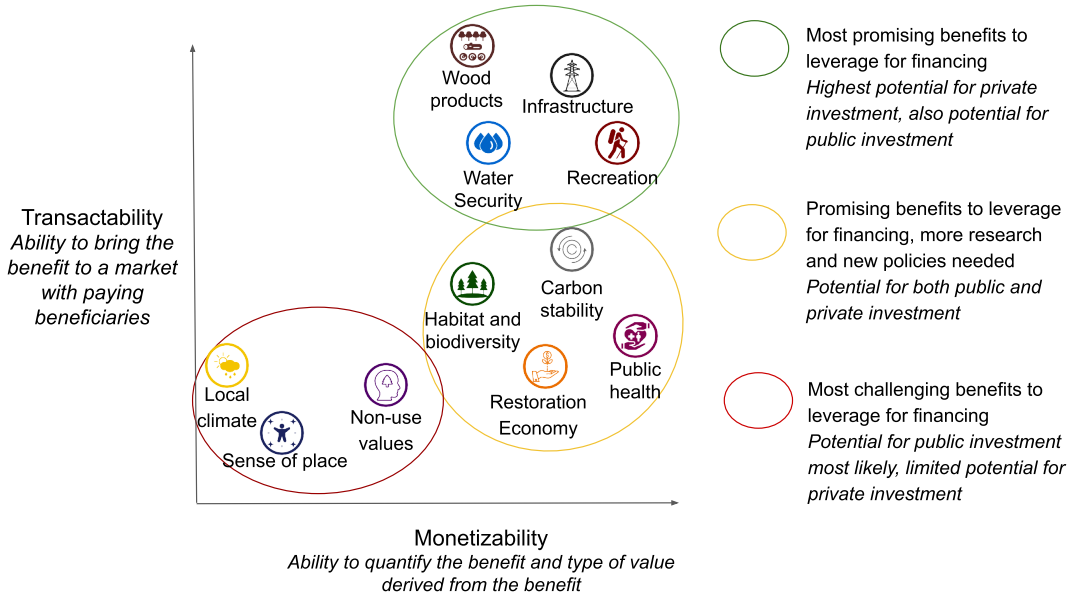

Fig. 6. Conceptual diagram showing the relative monetizability and transactability of each identified benefit of a resilient forest achieved by forest management.

particularly true on the local to regional scale, where land management, environmental, and utility organizations likely have a history of contact and are well known to each other. Using the tools and strategies described previously (Section 4.3.1) to collaboratively value project outputs and outcomes should be repeated for each new benefit and beneficiary.

Additional benefits and beneficiaries usually strengthen a project rather than weaken it, since the interactions between benefits are mostly mutually enhancing and additional potential beneficiaries widens the pool of potential funding. Beneficiaries may also be more likely to engage if they are not the sole payor. As such, it is important to continually iterate when new benefits and beneficiaries are identified by bringing new entities into project management discussions (Fig. 5).

Stakeholder engagement is important during both the planning and implementation phases of a project, though this framework focuses explicitly on implementation. During this phase, payors do not have influence over investment decisions other than their own decision to contribute, at what level, and over what time scale based on the benefits that they value. Stakeholders do not contribute funds towards specific project actions, but towards the total project cost. Stakeholder involvement catalyzed by benefit-related funding can help new participants take ownership of natural infrastructure in ways that are currently mostly applied to gray infrastructure. Participation can support not only individual projects, but lead to broader collaboration on a given landscape, which can, for example, allow land managers to plan future projects at larger scales with greater confidence that they can be implemented. Given the cyclical and iterative nature of forest management, engaging beneficiaries during implementation positions those beneficiaries to be active members of planning for the future forest management work.

4.4.1. Stacking benefits and funding sources

Regardless of impetus, multi-benefit forest management projects effectively bundle funding sources to pay for these multiple, spatially overlapping ecosystem services provided by different project outputs and outcomes (Robertson et al., 2014). Although stacking ecosystem services can pose accounting challenges and often necessitates clearly understanding how management affects ecosystem function (Robertson et al., 2014; Robert and Stenger, 2013), stacking provides a conceptual path to increasing project funding. Stacking ecosystem services is a theme in the literature which explores dynamics when multiple, spatially overlapping ecosystem services generate benefits which may be monetized. Discussion of stacking has grown rapidly over the last decade given the growing multi-billion dollar international market in carbon, habitat, and water credits (Robertson et al., 2014). These multi-benefit projects also demonstrate the power of blending funds from both public and private beneficiaries: seeing funding streams from public entities can motivate private sector participation and vice versa.

Multi-benefit public-private funding partnerships can help address possible free rider problems, a situation when an entity benefits from forest management which is funded and undertaken by others (Hardin and Garrett, 2020). However, the goal of the multi-benefit framework is not to identify all freeriders or aim for financial contributions to be proportional to the projected benefits. This is in part because: (a) it will be difficult, if not impossible, to identify all the benefits and beneficiaries of proposed management; (b) there is inherent and often high levels of uncertainty in spatial and temporal benefit projections; (c) a beneficiary may not be able to contribute proportional amounts of their benefit for funding; (d) institutional arrangements may make contributions difficult or impossible (e.g. asking “the public” to collectively pay for the air quality benefits), and; (e) there are many intrinsic benefits of the forests that are not valued in quantitative or monetary terms. Instead, the goal should be for all participating beneficiaries to understand the order of magnitude return on their individual investment to make an economic justification.

This approach, where beneficiaries value benefits individually, means that the cost to implement a project may be more or less than the perceived benefits. However, when truly accounted for, it is likely that forest management even to achieve a single benefit can outweigh the cost of the entire project. For example, from a water quality benefit perspective, treating just a small portion of a watershed can lead to benefits for a water utility that outweigh the cost of treatment (Bladon et al., 2014).

5. Discussion

5.1. Opportunities and barriers for framework deployment

There are both opportunities and barriers for framework deployment across the Western U.S. From an opportunity standpoint, there is a widespread, urgent need for a framework that can help increase the pace and scale of forest management activities. Since forests in the Western U.

S. are multi-use resources, providing, among others, water, energy, recreation, and public health benefits, they are ideal settings for a multi-benefit framework. Large, continuous tracts of these ecosystems, meanwhile, fall under the management of a single (usually federal) agency (Fig. 1b), easing the logistics around large-scale management activities. Furthermore, the Western U.S. is a region of significant resource and economic interconnectedness (e.g. (Wang et al., 2020)), which can increase the feasibility of using a co-benefits model. For example, water supplies and hydroelectric generation that originate in forested regions may travel hundreds of miles and serve large population centers, which expands the geographic scope of potential beneficiaries for projects.

Another major benefit of applying this framework to forest management is the relatively clear science around management best practices (Hessburg et al., 2021). While all projects will need to be assessed for specific impact and benefits within the framework, general consensus on the importance of resilient forests and how to achieve that is a strong foundation for beginning conversations with stakeholders.

Finally, the framework as presented here is designed to allow participation from all stakeholders, including land managers, implementation partners, government agencies, and third-party beneficiaries, within the existing governance structures for each party. This can significantly shorten the lead time for deployment, as significant policy, legal, or other efforts are not usually required to lay the groundwork. The exact form of the funding vehicle is flexible, but could reflect any of several existing examples of successful, transparent arrangements (e.g. water funds or the Forest Resilience Bond (Madeira and Gartner, 2018)).

However, barriers also exist. There are land ownership, functional, organizational, and conceptual boundaries that must be navigated (Davis et al., 2021). In addition, dry Western U.S. forests cover highly variable montane terrain, meaning that benefits that vary in complex ways over time and space and measurement availability across and between landscapes may be uneven at best and non-existent at worst.

The most critical challenge to implementing the framework is the existence of interested third-party beneficiaries to help meet project costs. Some geographies may not have well-resourced beneficiaries who are able to meaningfully contribute, and withoutadditional funding streams, this approach is not possible. Assuming potential beneficiaries do exist, the major challenge becomes engaging potential beneficiaries around a novel approach to valuing nature. Cost sharing in forest management can seem at best new and perhaps even tangential to the primary goals of many organizations. It can be challenging to gain trust with these potential beneficiaries, build understanding of the importance and relevance of forest management to them, define metrics of success (e.g. (Collins and Schultz, 2021), and work through the valuation process. Often, relationships with potential beneficiaries are the longest to build, but trust-building can be supported by the iterative and collaborative approach laid out in Fig. 5. Other ways of building trust and confidence with beneficiaries include grounding benefit quantification in the best available science and, if desired, implementing a pay-for-performance repayment structure where contributions are contingent on follow-up monitoring of benefits.

The process of beneficiary engagement can also be greatly aided by a local partner organization with one to two individuals willing to act as project "champions." These groups and individuals are uniquely positioned to help build stakeholder and community support for the project, thereby creating a social license for beneficiary participation that is complementary to the valuation of benefits process.

However, having a local partner organization is usually critical for other reasons as well. These groups can provide an understanding of the broader ecosystem and community context for projects, lead implementation activities, and support grant applications to state and federal agencies. As in many sectors, new frameworks for land management can face hurdles from institutional and collective inertia alone; a local partner organization is well positioned to advocate for the additional upfront effort that implementing a new framework requires.

5.2. The potential role of project developers and financing

The multi-benefit framework depends on a collaborative and iterative process of valuing benefits. . Each beneficiary is unique, and defining the outputs and/or outcomes that define success requires site-specific analysis and deep, meaningful engagement. A project developer who can serve as an intermediary with technical and project management expertise is often critical for beneficiary engagement, benefit analysis, and bringing together multiple diverse stakeholders in a joint effort towards catalyzing management. Project developers can also bring facilitation, additional human resource capacity and technical expertise, and serve as a central hub for collaboration by many different parties (Brand, 2021). Ensuring trust and transparency between potential beneficiaries and the project developer is key for buy-in and success.

Making the economic case to beneficiaries can require not only benefit valuation, but also innovative funding and financing mechanisms that operate at various temporal scales. For example, a financing solution where private capital covers upfront costs of the project, which is then repaid by beneficiaries as benefits accrue, could be an effective way to enable management (Brand, 2021). The Forest Resilience Bond, part of the North Yuba Forest Partnership (Table 1b), is an example of a case study where financing played a key role in both accelerating implementation and beneficiary engagement of a local water utility (Madeira and Gartner, Todd, 2018).

5.3. Stakeholder engagement, environmental justice, and equity

There is an opportunity to include a broad set of stakeholders, who may or may not ultimately be paying beneficiaries, in this process. Including diverse groups with different values is critical to addressing issues of well-being, equity, and environmental justice, particularly in relation to issues of empowerment, engagement, access, and benefit sharing (Farley and Costanza, 2010; Potschin et al., 2015). The timing and manner of engagement and subsequent implementation of forest management projects has implications for marginalized groups including Tribal Nations, rural communities, and communities of color. In certain instances, these groups may not have monetary resources to contribute to projects and/or financial contributions are not appropriate, but have a strong interest in implementation and may also be able to participate in other ways.

For example, many management activities, including prescribed burning, water quality protection, and habitat restoration, have important cultural implications for Tribes, who may wish to be involved in the management of their traditional homelands (Vinyeta, 2022). Rural communities in the WUI, meanwhile, face greater risks than urban communities in the event that management activities are not carried out in a timely and responsible way, and with a disproportionate share of that risk falling on people of color, low-income residents, and the homeless in those communities (Greenberg, 2021; Mehta et al., 2020).

Failure to recognize and engage beneficiaries and other stakeholders in an equitable manner can lead to suboptimal and sometimes unethical outcomes (Chazdon and Guariguata, 2018). For projects on public lands, this inclusion of diverse groups is partially done through the U.S. federal permitting requirements during the planning phase, although barriers exist for actually incorporating environmental justice into this process (Ulibarri et al. 2022). By the implementation phase of a project, which is the focus here, stakeholder and partner engagement is critical for keeping the local residents engaged in activities happening in their community and sense of ownership to prevent unethical outcomes.

6. Conclusion

The need and urgency for landscape-scale forest management across the Western U.S. is increasing as human impacts, climate change, and legacy land management practices have left fire-prone dry forests vulnerable to multiple stressors. The need for action far exceeds the

funding available, however, and the traditional means of funding this critical work, where the land manager alone is responsible and often relies on timber sales, is no longer adequate. Fortunately, management actions that increase forest resilience yield multiple benefits to diverse entities beyond the land manager, providing an opportunity to spur collective action to share the costs of these critical projects. In order to address the issue of inadequate funding, we propose a multi-benefit framework which was developed by examining frameworks in other fields, reviewing a range of potential benefits of healthy forests, and examining case studies of projects which successfully deployed non-traditional funding. We identified both 11 potential benefit categories as well as potential public and private beneficiaries that could share in the cost of management to achieve.

By bundling the value of a diverse set of benefits to bring in many value streams, resources can be leveraged at the landscape scale required to effectively achieve forest resilience. This approach has the potential to fundamentally change the current paradigm of siloed land management efforts to increase the pace and scale of action. This multi-benefit framework can help solve a critical challenge of forest management across the Western U.S. and provides several avenues for future work, including further development of forest benefits, measurement and distribution of benefits, as well as different methods for valuing benefits. As climate change and other environmental disturbances are projected to increase future costs of environmental management, such a multi-benefit approach may be critical to meeting funding needs for this work in the 21st century.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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