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Mohammad Imam Hasan Reza,
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REVIEWED BY
F. Mario Andaru,
Universitas Tidar, Indonesia
Youn Yeo-Chang,
Seoul National University, Republic of Korea

*CORRESPONDENCE
Patricia N. Manley
✉ patricia.manley@usda.gov

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Return on investment applications in forest management and landscape restoration: current practices and future directions

Patricia N. Manley[1]*, Samuel G. Evans[2] and Matthew Sloggy[3]

[1]U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Placerville, CA, United States, [2]California Department of Forestry and Fire Protection, Fire and Resource Assessment Program, Sacramento, CA, United States, [3]U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Riverside, CA, United States

Maintaining and promoting forest ecosystem health and landscape management is a global challenge, given the social, ecological, and economic value of forests, the threats that they face from climate change and other stressors, and the substantial funding gap relative to the need to accomplish management objectives. The practice of calculating an economic Return on Investment (ROI) in business applications has migrated to conservation and land management planning as a means of informing and improving the positive impact of investments on forested landscapes. Forest management yields a large and complex array of benefits, each with its own spatial and temporal extent, with many being challenging to monetize. Standard ROI applications, although currently being used to represent monetizable costs and benefits of public land management options, can fall far short of representing the full suite of important, and in some cases irreplaceable, values associated with forested ecosystems. We present and discuss a conceptual framework of six key topics in ROI applications to forest management that merit attention: (1) the overarching challenge of bias from excluded benefit categories, (2) navigating uncertainty related to ROI components, (3) accounting for risk, (4) reconciling economic discounting and environmental improvement, (5) common pitfalls in summing up of benefits, and (6) the relationship between ROI and socio-ecological sustainability. Further development of mechanisms to address the complexities inherent in forest ecosystems, and to quantify and represent their diverse and substantial values would greatly enhance incentives for conservation finance and expedite forest conservation and restoration outcomes.

KEYWORDS
benefit calculation, conservation finance, ecosystem services, environmental markets, public land management, resilience, sustainability

1 Introduction

Healthy and resilient forests, and their associated ecosystem services, are facing a challenging future in light of changing climates (Dyukarev et al., 2022), the increasing prevalence of high-severity fire globally (Jones et al., 2022; Wasserman and Mueller, 2023), increased pressure from insect mortality (Sambaraju and Goodsman, 2021), and growing human demands for resources (Balatsky et al., 2015). Forest managers are contending with pressure to expand management activities to reduce risks to forests and improve their resilience to future climates (Nong and Siriwardana, 2018; Stephens et al., 2024), while at the same time funding and capacity for management have declined for several decades (Korhonen and Frey, 2023). Forest management activities often face tradeoffs with respect to the cost of performing them compared to the expected benefits. Benefits derived from ecosystems through investments in conservation can either be consumptive (e.g., timber extraction and recreation), or non-consumptive public goods (e.g., carbon sequestration). There is a growing awareness that the conservation deficit and the associated funding gap have potentially grave and extensive consequences, and that strategic approaches are necessary to help government and private sectors more effectively partner to bridge the gap (Dobrowski et al., 2024).

Private sector investments in forestry substantially outpace those of the public sector (Korhonen and Frey, 2023). Although the majority of private investment is associated with industrial forestry, a growing portion of private sector investment involves investing in forest management toward greater resilience, in particular on public lands (Kovacs et al., 2013). The private sector may benefit in multiple ways through investing in forest resilience as a public good, including improved or additional sources of goods and services, tax-saving incentives, investment earnings through bonds, meeting corporate sustainability objectives, or meeting institutional conservation priorities, among others (e.g., Emerton, 2000; Seipp et al., 2023). Some benefits, such as water security and avoided costs to infrastructure, directly benefit private groups making the investment. This is especially true for non-industrial private forests that can generate multiple income streams such as carbon sequestration (Kelly et al., 2017). Other benefits, such as water and biodiversity conservation, provide a means for private groups to meet corporate sustainability goals through conservation investments on forest lands managed for multiple public benefits (Humphreys et al., 2020).

Regardless of the target outcomes (i.e., desired benefits), managers and investors alike are faced with the need to effectively quantify the costs and benefits of management options to inform and justify the investment. In a growing number of cases, investors in forest management are becoming interested in some measure of return on investment. Return on Investment (ROI) is an economic measure of benefits and costs that reflect the expected return from a given investment, traditionally communicated in monetary units. ROI is expanding into environmental sectors (Phillips et al., 2014), including forest management on public lands, where it is being used to evaluate and prioritize management activities, and to garner funding for implementation through public (e.g., government grants) and private (e.g., conservation finance) sources.

Underlying the calculation of ROI is a myriad of foundational economic concepts. For example, ecosystem service accounting and natural capital accounting (Comte et al., 2022) are often included in ROI calculations, which use capital theory to value natural assets such as groundwater reserves (Fenichel et al., 2016), forests (Hashida and Fenichel, 2022), and other natural amenities in order to integrate environmental quality with economic performance. Many of these and other benefits and costs accrue through time, and so must be discounted. Discounting adjusts future values to present-day terms (Polasky and Dampha, 2021), accounting for what economists call the time value of money (Baur and Lagoarde-Segot, 2016). There is a large body of literature on selecting a discount rate (e.g., Price, 1989; Price and Willis, 2024) and how different discount rates reflect different social norms and values. In addition, the economics literature has several areas that are relevant to ROI calculations, including real options (flexibility in management decisions over time; Chaudhari et al., 2016), multicriteria decision making models (mechanism for reconciling multiple, potentially conflicting benefits; Aruldoss et al., 2013), and blended finance models (strategic combination of funding sources to bridge finance gaps; Flammer et al., 2024).

ROI is also related to other metrics that compare costs and benefits, notably Net Present Value (NPV), cost-benefit analysis, and cost-effectiveness analysis. NPV is calculated by subtracting discounted costs from discounted benefits and is utilized frequently in cost benefit analysis (Shou, 2022). In contrast, ROI is typically calculated as the ratio of benefits over costs, and is used oftentimes for ranking or prioritizing projects with a narrow set of benefit objectives (Reinhardt et al., 2024). While cost-benefit analysis monetizes all benefits in order to compare them directly with costs, cost-effectiveness analysis instead evaluates the cost required to achieve a specific environmental outcome. In an ROI application, the representation of the return can be expressed either as a ratio of monetary units (cost-benefit approach) or in physical units per dollar invested (cost-effectiveness approach). This added flexibility makes ROI a particularly useful construct in evaluating and guiding investments in restoration and conservation activities.

The two principal components of ROI—benefits and costs—can be characterized, estimated, summarized, and interpreted in a variety of ways in forestry applications, leveraging the rapidly expanding economic theories and tools, each with concomitant strengths and weaknesses (e.g., Boyd et al., 2015; Collins and Schultz, 2021). ROI units in forest management are commonly expressed as a ratio of monetized benefits and costs or as environmental benefits (e.g., tons of carbon) gained per monetary unit invested. Though the use of ROI is explored in depth across several studies (e.g., Boyd et al., 2015), there is little discussion of the tradeoffs involved when calculating ROI, and the implications for their application to different land ownerships and associated operating principles. This is particularly true for forested lands managed for multiple benefits (e.g., public forest lands), where priority outcomes are a mix of monetary and non-monetary benefits. Non-monetary benefits range from quality recreation experiences to carbon sequestration to biodiversity conservation.

ROI application to public forested lands offers a particular challenge in accounting for near-term and long-term multiple public benefits. In calculating ROI for forest management on public lands, costs are typically limited to implementation costs. These can include labor, contracting, materials, machinery, etc. In addition, these can include continued economic costs for maintenance. Benefits associated with forest management on public lands, on the other hand, can include any number of additional economic or ecological values associated with the implementation of a forest management project. Central to implementing ROI on landscapes are benefits in the form of ecosystem services, including water deliveries, water quality, carbon sequestration, and the provision of habitat for wildlife (Seipp et al., 2023). Though investments can provide value through improving or sustaining services, they can also provide value by reducing the potential for losses associated with catastrophic wildfire. For instance, investments in forest resilience can reduce the risk of wildfire damaging or destroying housing and other infrastructure, as well as the risk of killing trees, which provide multiple services such as wood products, carbon sequestration, and habitat (Dillon et al., 2015; Evans et al., 2022; Thompson et al., 2022).

The use of ROI in forest and landscape management can be used to look forward or backward in time. ROI can be used to assess the benefits of completed projects, for which the accomplishments of one or more investments (e.g., portfolio performance) are quantified and potentially tracked over time (retrospective analysis). It can also be used to evaluate the benefits of alternative potential future management investments and activities to identify the most favorable investment option (prospective analysis). As a prospective planning tool, ROI can be used to prioritize interventions that provide the highest ROIs or to identify projects that meet investment criteria, specifically whether a project achieves a required goal or desired threshold level of ROI per increment of funding and time. ROI can be particularly useful in conservation finance, which engages with, obtains, then deploys financial resources in ways that align incentives for conservation (Meyers et al., 2020). As a prospective evaluation tool, ROI is increasingly used to leverage conservation finance to expedite and expand forest management. Thus, ROI is important for bringing investors together with on-the-ground forest management opportunities and needs for mutual benefit. It's important to note that traditional ROI concepts used for conservation finance have been criticized for biasing decisions away from maximizing the public good (Pascual et al., 2014); thus, ROI concepts that more carefully consider a wider range of benefits can help mitigate this issue.

ROIs use in landscape management and conservation finance has the potential to streamline and expedite management activities. However, its limitations with respect to management have been noted by several authors, and its widespread incorporation into management of forest landscapes proceeds largely without explicit recognition of the novel context posed by non-industrial forest management. Though the use of ROI is explored in depth across several studies (e.g., Boyd et al., 2015), there is little discussion of the tradeoffs involved when calculating ROI and sustainability goals, and the implications for decision making, sustainability, and landscape resilience that follow.

In this paper, we provide a conceptual framework of six primary focal areas that shape ROI applications to multi-benefit forest management investments: (1) the overarching challenge of bias in benefit selection based on ease of calculation or motivation for investment, (2) navigating uncertainty related to ROI components, (3) accounting for risk, (4) reconciling economic discounting and environmental improvement, (5) common pitfalls in summing up of multiple benefits, and (6) the relationship between ROI and socio-ecological sustainability (Figure 1). Underdeveloped approaches to addressing these six focal areas limit the current utility and effectiveness of most ROI applications used to inform forest management investments with multiple benefit outcomes. We provide an in-depth discussion of each of the six focal areas, including common practices, current strengths and liabilities, and future options for improving the utility and impact of ROI in multi-benefit forest management and conservation applications.

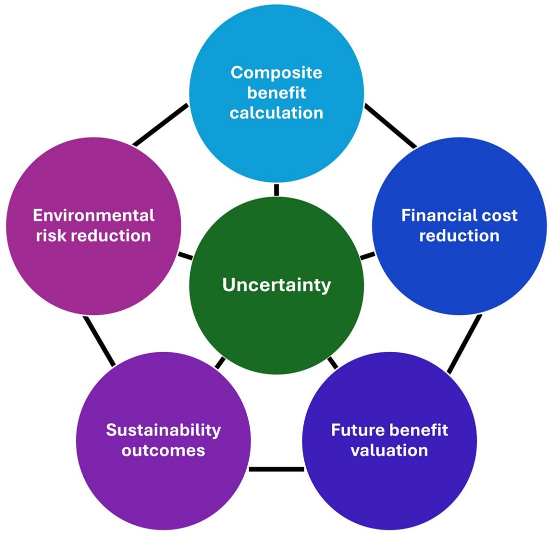

FIGURE 1
Six major issues that currently limit the utility of ROI applications used to inform non-industrial forest management investments.

2 Misaligned incentives for selecting benefits

The use of ROI in a prospective application to incentivize investments in management and conservation actions is particularly vulnerable to biased calculations based on what benefit categories are selected by the practitioner. First, the use of ROI requires that benefits are quantified in a realistic manner so relative or absolute benefit comparisons can be made across investment options. Some benefits are easier to quantify than others, for instance changes in carbon sequestration before and after a management investment might be easier to calculate than changes in levels of biodiversity. Further, ROI calculations can face limitations in terms of resources, and so there is often a tradeoff faced with which benefit categories to include, exclude or ignore. As a result, ROI can potentially include only those benefits that are readily quantified, as opposed to the full suite of outcomes that are likely to result from specified management actions, resulting in a dramatic underestimation of benefits. In addition, a narrowly focused ROI could incentivize activities in areas that would otherwise reflect lower, neutral or even negative returns.

Furthermore, the use of ROI in conservation finance can emphasize projects related to the wealthiest payors that care or benefit from specific fungible outcomes (e.g., increased water availability), at the expense of other potential costs and benefits that may have broader social benefit or may be more challenging to ascribe dollar values (e.g., biodiversity). Methods for selecting benefits for conservation finance often emphasize identifying benefits for payors (Seipp et al., 2023). However, in the case where there are wealthy payors, it might result in prioritization of certain projects over others due to the benefit categories selected.

In addition to bias from ease of calculation and potentially limited groups of benefitors and payors, the scale of projects can also introduce benefit selection bias. Classic production-based forestry focused on forest stands and their desired outcomes (primarily timber volume; Popkin, 2021), and the collection of stands selected within a landscape to be included in a given management project were commonly driven by benefits or constraints external to the landscapes, such as targets for volume or acreage treatment, fiscal limitations, profit objectives, equipment capabilities, and workforce capacity. In contrast, managers and policy makers are increasingly being challenged with large-scale dynamics in the form of extensive and destructive wildfires, large-scale beetle infestations (e.g., Chen et al., 2025), sweeping drought-induced tree mortality, and chronic impacts to biodiversity that threaten large suites of species and entire communities. Today's land stewards, and the science that supports them, are now in the business of large-scale ecological forestry (Franklin et al., 2007) and the need to address multiple resource outcomes affected by complex landscape dynamics, accompanied by high costs and substantial uncertainty—territory replete with the potential for unaccounted for costs (including resource impacts) and benefits.

Increasing the spatial scale of analysis and planning across landscapes is accompanied by a corresponding increase in the diversity and complexity of social and ecological conditions and associated costs and benefits. Forested landscapes, particularly in mountainous terrain (e.g., Jiuzhaigou National Park of China, Blue Mountains of Australia, northern boreal forests across multiple countries), extend across diverse biophysical conditions and gradients, and encompass a diversity of meso- and micro-scale environments. Furthermore, forested landscapes are increasingly populated with a combination of dispersed endholdings, small rural communities, embedded moderately sized communities, and in many cases larger urban areas that are adjacent to large extents of forested public lands. For example, at the stand scale (e.g., 50-ha), ROI could consist of a single objective (e.g., timber volume or improved wildlife habitat) and a single cost (e.g., contract costs to accomplish the work, potentially offset by marketable yields from the work). At a multiple stand scale (e.g., 5,000-ha planning area), ROI can be complicated by a greater diversity of yields (e.g., tree species and sizes) and costs (e.g., equipment needs, access costs, potential constraints from or impacts to non-target resource conditions, such as riparian areas or archeological sites) that can vary widely across the landscape (Barker et al., 2025). At a small landscape scale (e.g., 50,000-ha subwatershed), additional potential costs and benefits come into the equation, such as water quality, air quality, and local community infrastructure and values. At a large landscape scale (e.g., 500,000-ha), a large suite of ecological and social factors are likely to be affected and their fate of concern and interest to local, regional, and even national interest groups.

Thus, as spatial scale increases, ROI calculations face either ignoring a growing suite of unaccounted for costs and benefits, or attempting to reasonably quantify a much larger suite of costs and benefits and the complexities of their interactions with larger margins or error. Either path has its pitfalls, but in this era of large scale events and global change, it is incumbent upon scientists, managers, and economists to portray, evaluate, and inform management investments as inclusively as possible in order to enhance their ability to improve and secure social-ecological resilience.

3 The tyranny of uncertainty

Benefits and costs associated with ROI calculations face uncertainties from a variety of sources, particularly when they are calculated prior to implementation to forecast management benefits (Boyd et al., 2015). There can be uncertainty regarding the implementation of the management action itself, which means that costs are not known with certainty, nor the scale of the treatment (Neuendorf et al., 2018). Further, once the management action is implemented, the actual level of benefits acquired can vary depending on natural processes, resulting in uncertainty in benefits over time (de Lima et al., 2017). In many financial models, interest rates on investments often account for the risk of non-delivery (Dal Maso et al., 2024), and in some environmental markets (e.g., carbon), there are mechanisms to hedge against uncertainty as well (e.g., Rau et al., 2024). However, in simple ROI calculations, uncertainty is oftentimes unvalued, with the expected value used directly without adjustment for uncertain outcomes.

The goal of ROI in conservation planning is to assess not only the benefits and costs, but also the uncertainty related to investments in conservation actions over time (Boyd et al., 2012). ROI constructs are appealing in conservation finance because they promise a rigorous, finance-like way to allocate limited resources for maximum benefit. Yet ROI analysis often relies on assumptions of predictability and precision that do not hold in ecological systems. Conservation outcomes in forest ecosystems, such as carbon sequestration, species habitat preservation, or wildfire risk reduction, are highly uncertain, driven by nonlinear ecosystem dynamics, threshold effects, and feedbacks that are not commonly captured in standard ROI models. Though estimating expected values can provide a measure of the most likely outcome, they may not provide an accurate depiction of the range of economic impacts (positive and negative) that could occur.

In addition to the uncertainties associated with ecosystem outcomes, economic and policy uncertainties introduce further volatility. Many conservation finance mechanisms rely on environmental markets (e.g., carbon, water, biodiversity credits), where prices depend heavily on policy design and regulatory stability. Policy shifts, unpredictable market changes, or changes in eligibility rules can reduce expected returns, particularly over more extended investment horizons.

Risks are often correlated across projects and services, and ROI models often do not account for these correlated risks of ecosystem service loss. For example, a forest conservation project might experience drought, wildfire, or pest outbreaks, which can simultaneously depress outcomes across multiple projects in a portfolio, undermining diversification assumptions from a traditional finance perspective. The ROI construct also relies on ecosystem service supply models with uncertain vulnerability parameters, such as forest growth models and the impact of unfavorable future climate conditions. As a result, a conservation investment's modelled optimum may be highly contingent on unknowable futures, and it can be especially difficult to reasonably represent these uncertainties in ROI modeling.

ROI frameworks also tend to focus on quantifiable and monetizable benefits, which often leads decision-makers to favor projects with more certain, easier-to-measure outcomes. High-uncertainty but high-value interventions, such as maintaining forest ecosystem connectivity, restoring complex forest structure, or supporting species with uncertain recovery trajectories, may be undervalued (or not valued at all) despite their ecological importance. In these cases, uncertainty is not just a technical challenge but a governance issue. The treatment of risk and uncertainty can shape which kinds of conservation actions are pursued, who benefits, and which ecosystems are prioritized. To be useful for conservation finance, ROI approaches should explicitly incorporate uncertainty through scenario analysis, probabilistic outcomes, adaptive management, and attention to irreversibility.

Prospect theory and optimal control methods could be introduced into forest management and conservation applications to better account for uncertainty from various sectors and thereby to reduce the bias and impact of uncertainty on ROI calculations. Recent economic work in prospect theory indicates that alternative outcomes may matter in estimating economic values, since losses may be valued differently than additional benefits (Zeeshan et al., 2024). Optimal control methods and methods from prospect theory could be integrated into a composite ROI construct to better handle some of the nonlinearity in dynamic ecosystems; however, data demands and system complexity often constrain the practicality of these models. Both approaches represent an opportunity to expand ROI in that they provide guidance on how benefits can be adjusted to account for uncertainty. In the case of prospect theory (e.g., Rosenman et al., 1988; Wang et al., 2021), it can provide values of uncertainty directly, allowing for ROI calculations. Optimal control models that include uncertainty about the state of the ecosystem (e.g., Sloggy et al., 2020) can be used to improve management prescriptions conditional on the level of information available about the ecosystem.

4 The role of risk reduction and counterfactuals in ROI

Risk can manifest in multiple ways in forest management, and it can show up in multiple parts of the ROI evaluation process. Although risk can arise from uncertainty (e.g., uncertain product yields creating a risk of low or negative returns), here we focus on existing risks to environmental, social or economic values, and how investments with expected measurable reductions in those risks, as a primary objective or a co-benefit, can be valued in ROI calculations for forest management and conservation. First, there is the existing risk of degradation and loss of a resource value in its current state (baseline conditions), such as the risk of loss of large trees to high intensity fire (ecological risk). Depending on the value being assigned to large trees, existing risks may come from multiple sources (e.g., drought and fire), to different degrees, and may be represented in monetary or non-monetary units. Second, management actions could result in reduced or increased risk of degradation or loss (benefit determination), reflecting a management outcome (management impact risk). Third, there may be a risk that the management action will fail to improve conditions (benefit determination) or reduce the risk of impact to large trees from fire (management effectiveness risk). Finally, there is a risk of retrogression, where reduced risks or improvements in condition resulting from management are lost over some period of time (benefit determination), potentially over a short period of time (instability risk). ROIs in forest management and conservation are most realistically portrayed in light of a robust risk assessment, where possible.

The first two risks are typically considered in standard economic practices of calculating expected benefits (Morgenstern and Landy, 2014), and extended by concepts such as prospect theory (Barberis, 2013). In these set-ups, all possible outcomes of the benefits are considered and weighted by their probability to arrive at an expected benefit such that as the risk of loss increases, so too does the expected benefit, even if the most probable outcome remains the same (Morgenstern and Landy, 2014). In prospect theory, the risk is essentially valued explicitly such that losses are valued differently than gains (Barberis, 2013). Risk regarding the effectiveness of implementation has also been examined in the economics literature through optimal control models, such as Eiswerth and Van Kooten (2007) who included treatment effectiveness in models of invasive pest management.

Closely related is the problem of counterfactuals and baselines, which define what "return" actually means in conservation. ROI estimates depend on comparing an intervention to a hypothetical future with no intervention (e.g., de Castro Dias et al., 2016). Under climate change and accelerating land-use pressures, baselines (i.e., existing conditions) are not static over time: the counterfactual trajectory may itself be deteriorating rapidly. In other words, in a growing number of circumstances there is an expectation of unavoidable decline in conditions and values, and the intent of management is to minimize, forestall, or mitigate future declines. As a result, counterfactual baselines can be challenging to estimate, often require additional modeling to estimate with confidence, and are commonly poorly specified. Failure to account for shifting baselines can distort perceived returns, either understating gains by assuming baseline stability where declines are likely without intervention, or undervaluing investments that result in declines, but without them even greater declines would have resulted.

Integrating explicit treatment of risk, uncertainty, and dynamic baselines into ROI approaches would move conservation finance closer to a true measure of the value of investment, one that reflects not only absolute gains, but gains relative to other options for action or inaction, and the stability (duration) of those gains over time. Frameworks for ROIs in forest management could be developed that explicitly recognize standardized categories of risk and uncertainty that managers and scientists could evaluate for any given application, thereby providing a road-map for explicitly accounting for sources of risk and uncertainty regarding present and future conditions.

5 Discounting while valuing future benefits

Forest management investments typically pursue one of four broad objectives: reducing risk to existing assets (e.g., fuels treatments to reduce wildfire damage), generating immediate resource extraction (e.g., timber harvest), improving future resource extraction potential, or enhancing long-term conservation outcomes (e.g., forest thinning to reduce future drought vulnerability of large trees). Because these objectives differ in timing and persistence of their benefits, discounting plays a central role in determining how they are evaluated within an ROI framework.

Discounting allows future costs and benefits to be expressed in present-value terms so that they can be compared with near-term investments (Heinzerling, 1999; Groom et al., 2005,; Lipman and Attema, 2024). In forest management, the application of discounting has important implications for how restoration and conservation benefits accrue over many decades. Discounting shapes which projects appear most economically attractive. Two projects with similar undiscounted benefits streams can reflect very different ROIs depending on the discount rate applied, thereby altering their value proposition for investment despite comparable long-term ecological outcomes. Similarly, a project with lesser long-term ecological outcomes may rank higher as a result of future discount rates alone.

The selection of a discount rate is therefore consequential. In private-sector settings, rates often reflect the opportunity cost of capital (i.e., passive income; Heinzerling, 1999). In public-sector forest management, debate centers on the appropriate social discount rate and how to account for intergenerational welfare. Fixed positive discount rates reduce the present value of long-term benefits, which can disadvantage restoration investments with returns that materialize over 40–100 years. This dynamic creates a potential investment barrier to realizing ecological and social benefits such as carbon storage, habitat development, and risk reduction unfold gradually (Atkinson et al., 1997; Groom et al., 2005).

A central limitation of conventional discounting in forest management ROI analysis is the implicit assumption that benefits are substitutable across time and categories. This assumption is questionable for irretrievable or irreplaceable ecological outcomes, such as species extinction, loss of old-growth forest structure, or degradation of culturally significant landscapes. Treating such outcomes as fully discountable implies that sufficiently large near-term gains can compensate (i.e., mitigate) for irreversible long-term losses. This assumption often conflicts with conservation objectives. In such cases, thresholds for ecological outcomes could function as constraints within ROI analyses rather than tradeable outcomes subject to discounting, providing a safeguard against the impact of irretrievable losses.

Intergenerational outcomes further complicate this picture. Forest management often produces benefits that persist or even increase over time, including ecosystem service flows and cultural values passed to future generations (Lindhjem et al., 2014). The economics literature has addressed this issue through concepts such as bequest value and declining discount rates (e.g., Groom et al., 2005; Arrow et al., 2014; Qasim, 2019). This long-view perspective is prevalent and highly valued in Indigenous Native American cultures (e.g., seven generations philosophy; Clarkson et al., 1992). Within an ROI framework, declining discount rates can materially alter outcomes by allowing long-horizon benefits accrued to non-specific beneficiaries to retain decision relevance. Without such adjustments, conventional discounting tends to disincentivize investments whose primary ecological returns are the altruistic availability of benefits to others into the future.

Uncertainty about ecological and economic outcomes in the future also challenges conventional net present value approaches. Real Options Theory provides a complementary framework that values flexibility, learning, and adaptive management in the face of uncertainty, such as changing climate, market dynamics, and policy conditions (Chaudhari et al., 2016). Rather than treating forest investments as irreversible commitments evaluated through a single discounted expectation, real options approaches recognize the value of staged, adaptive decisions that can shift with changing circumstances.

Concerns regarding the selection of discount rates has been an important topic in the economics literature for decades (e.g., Nordhaus, 2007). Selecting lower discount rates transfers more importance to future investments and benefits, including future generations (Nordhaus, 2007), but potentially forgoes near-term benefits that could be reinvested with higher return (Hepburn and Koundouri, 2007). Thus, the solution to valuing long-term outcomes is not whether to discount, but rather how to do so in a manner consistent with long-term ecological outcomes. In forest management and landscape restoration, this may require blending discounting with ecological constraints, declining rates, and explicit recognition of intergenerational and non-substitutable values. Although this ensemble of conditions is not new or necessarily unique to forest management or conservation (e.g., Booth, 1994; Heinzerling, 1999), few applied ROI analyses currently incorporate these features systematically, leaving substantial room for methodological development.

6 Summing up benefits

Efforts to evaluate management and conservation investments through an ROI lens often involve assigning monetary values to multiple ecosystem services and summing them to estimate total benefit. While this approach aims to make management and conservation comparable to other forms of capital investment, it introduces considerable conceptual and methodological challenges for restoration and conservation targets. Ecosystem services are deeply interdependent: improvements in one domain, such as forest cover, may simultaneously influence carbon sequestration, water quality, recreation, and habitat provision. Treating these services as separate, additive benefits risks double counting the same underlying ecological processes (Fu et al., 2011). For instance, wildlife habitat and metrics of biodiversity may both be quantified but have considerable overlap. Wildfire risk reduction and avoided structure loss are another example of overlapping benefits.

Even when double counting is avoided, trade-offs among ecosystem services complicate the process of aggregation to represent composite desired outcomes (e.g., multiple goods and services, environmental restoration, ecosystem resilience). Management interventions that increase one service can diminish another. Thinning a forest, for example, may improve fire resilience and water yield but reduce carbon storage and canopy-dependent wildlife habitat. Analyses can explicitly acknowledge and evaluate these tradeoffs, as shown in Yackulic et al. (2025) and Maes et al. (2012). However, ROI frameworks typically assume that benefits can be expressed as independent, positive contributions to a metric of total value (e.g., de Castro Dias et al., 2016; Hjerpe et al., 2024). In practice, ecosystems exhibit multidimensional tradeoffs, where gains in one service may come at costs to others. Reducing such relationships to a single scalar measure of "return" can obscure these trade-offs and potentially lead to overly optimistic assessments of project performance, especially when individual, environmental metrics are important.

Relying solely on ROI as the representation of investment value is made more difficult when target outcomes are associated with nonlinear ecological thresholds. Many ecological functions exhibit threshold behavior, where small changes have little effect until a tipping point is reached, beyond which outcomes shift dramatically. For example, in western U.S. mixed-conifer forests, fuels-reduction through forest thinning has almost no effect on crown fire probability until treatment intensity crosses a critical threshold of tree basal area removal (Agee and Skinner, 2005). Once that point is reached, fire behavior can shift abruptly from stand-replacing crown fire to low-severity surface fire. Managing forested areas below this treatment intensity threshold yields little marginal change in fire risk, while treating forested areas above it produces disproportionately large benefits. A linear aggregation of 'risk reduction per unit area' would treat all forested areas as equivalent. Aggregating ecosystem services linearly assumes proportionality and independence that may not exist in complex ecological systems. Moreover, spatial and contextual variation means that the marginal value of a given service depends on local conditions and the presence or absence of substitutes elsewhere. Summing values across sites or services can therefore produce misleading results, particularly if underlying valuation methods differ in scale, baseline, or beneficiary scope.

There are several methodological alternatives that can be utilized to facilitate the evaluation of multiple outcomes within a single ROI valuation. For example, multi-criteria decision analysis (MCDA) and optimization frameworks explicitly evaluate tradeoffs across multiple objectives (e.g., Abelson et al., 2021; Ferdous et al., 2024; Manley et al., 2025). Using these frameworks, decision-makers can compare management alternatives across a vector of outcomes (e.g., carbon storage, wildfire risk reduction, water supply, etc.). Estimating Pareto frontiers is another alternative that allows for the consideration of multiple management outcomes that are equally efficient (Abate et al., 2024). Further, metrics can be assigned weights to help balance or exaggerate their relative influence, such as equal ("naive") weighting, analytic hierarchical process (AHP) weighting, statistical weighting, and optimized weighting. Optimized weighting balances the influence of metrics on the composite measure (ROI in this case), and can be particularly useful in forest management applications where a diverse subset of multiple outcomes of interest (e.g., timber value, carbon storage, biodiversity value) are likely to be correlated, effectively reinforcing each other leading to an implicit increase in their combined weight (Becker et al., 2017; Fuentes et al., 2026).These approaches can address some of the aggregation shortcomings of a scalar-ROI approach. In order to evaluate thresholds, instead of linearly applying benefits via an area-based benefit transfer (e.g., Tsay and Paulson, 2025), the probability of crossing the threshold for a given event (e.g., high-severity fire regime) is valued. This can be accomplished by first valuing the event itself, (e.g., the cost of transitioning to a new fire regime) and then accounting for the change in probability of occurrence (e.g., reduced probability of high severity fire) resulting from the investment.

Aggregation within ROI frameworks can also obscure the distributional consequences of conservation investments. Benefits that are easily assigned a dollar value are often included in ROI aggregation calculations, while benefits that are harder to quantify and monetize, cultural values in particular, commonly receive less representation (e.g., Anderson et al., 2015). For example, fuels reduction treatments in an upstream forested watershed may generate high ROI values when calculated based on avoided sedimentation and improved municipal water reliability. The majority of monetized benefits accrue to downstream urban water users and utilities, while local rural or Indigenous communities experience smoke exposure, altered landscape conditions, or changes to culturally significant forest attributes that are weakly represented in the aggregated metric. Similar concerns have been raised in the literature regarding payments for ecosystem services and conservation finance, where efficiency-oriented allocations of conservation investments can generate uneven distribution of benefits across stakeholders and landscapes (e.g., Kovacs et al., 2013; Muradian et al., 2013). When these distributional effects are embedded within a single aggregated return metric, the resulting investment signals may reinforce existing inequities rather than making trade-offs explicit. Recognizing these distributional allocations is important because conservation investments that appear economically efficient under aggregated ROI metrics may fail to deliver socially equitable or politically durable outcomes (Pascual et al., 2014).

The practical consequences of these aggregation challenges is that ROI-driven investment decisions may favor projects that appear to maximize total quantified benefits, even when they erode system resilience or shift costs onto unrepresented services or stakeholders. When ecological interactions are compressed into a single metric, important information about distributional impacts and long-term system behavior is lost. A more robust application of ROI in forest management would make explicit how various ecosystem services interact and where thresholds exist, rather than assuming that all benefits can meaningfully be summed into a single number. Social Return on Investment (SROI) is gaining traction in some sectors as a means of balancing the scales between short- and longer-term benefits that are challenging to monetize, and it has promise for improving forest management and conservation ROI applications (Yates and Marra, 2017).

7 Sustainability and sustainable ROIs

Here we explore the interdependency of investments intended to improve or support sustainability and how adopting that outcome is likely to drive ROI itself toward more stable, sustainable returns over time. The discussion in this section is intentionally conceptual, given the limited formal literature on "sustainable ROI" in forest management. We outline a set of design principles that is intended to motivate future empirical and methodological development.

We define the ability of the landscape to support consistent and substantial stable ecosystem services over time as sustainability. Commonly ROI is transactional, associated with a discrete opportunity for investment—an annual program of work, an increment of grant funding—and the question is how best to invest it to get 'the biggest bang for the buck', with the focus on the return being captured by a specific investor. This can lead to less expensive, less risky, high-yield investments that will have a higher ROI and be more attractive to investors than challenging, more expensive, lower yield investments.

When investments are constrained to a given landbase or sector (e.g., sequential annual programs of work, annual grant cycles), it is reasonable to expect that serial investments will have declining ROIs over time. This is consistent with supply theory from economics, in that the highest ROI projects are selected first (e.g., Jack et al., 2009) leaving lower ranking ROI projects for future investments. Declining ROIs may become a barrier to future investment, potentially making it challenging to achieve sustainability in any given landscape. For example, forest fuels reduction projects are commonly evaluated based on reduced risk to infrastructure from wildfire. In a five year planning process, high ranking investments based on ROI would be those that are less expensive to implement and have the highest cumulative risk reduction (e.g., amount of risk reduction, cost of infrastructure, number of units with reduced risk). In the next 5 year planning process, if progress were being made in overall risk reduction, then absolute ROIs would be lower than those in the first 5-year plan, resulting from some combination of more expensive treatments and more challenging circumstances in which to reduce risk.

Does a declining ROI present a problem for sustainability? In many applications, this may be the case. First, a declining ROI won't occur if the need for investment far outpaces the availability of natural capital investments with commensurate, competing yields. The "perennial austerity problem" (e.g., Dempsey et al., 2020) currently applies to forest restoration across the west, as well as global conservation demands (e.g., $20 billion Global Conservation Framework funding gap; Deutz et al., 2020). In this circumstance, sustainability is not accomplished because investments are inadequate. If adequate and consistent funding were available for a given geographic area (e.g., National Forest System lands) and objective (e.g., sustainable forest products and water), a classic ROI based on maximizing near-term gains per unit of investment would decline over time, and investments (public or private) would be likely to reach ROI thresholds (e.g., yields per dollar requirements; Walsh and Dowding, 2012) and stop. The outcome may be similar, in that sustainability is not accomplished because investments are discontinued until ROI values increase again (i.e., conditions deteriorate).

We propose that an ROI construct constrained by sustainability does not necessarily result in lower returns, but may instead be driven by a novel configuration of values and valuations (e.g., Bardy and Massaro, 2013; van den Belt and Blake, 2015), resulting in a more temporally consistent (sustainable) ROI. First, the object of the investment would be the condition of the geographic area—a specified target level or range of integrity, functionality, and ecosystem services to be maintained over time. Second, the time period over which the ROI is calculated, or over which multiple sequential ROIs are generated, would be ecologically informed to reflect the pace of growth, change, and response to disturbance that affect ecosystem services of interest. Extended time frames are similarly amenable to accounting for prospect theory and associated bequest values (Qasim, 2019) and values reflected in Social Return on Investment (SROI) frameworks (Nikolaki and da Viega, 2023), which also reflect ecosystem services that feed into overall sustainability. Third, the temporal rank order of investments would be engineered to balance costs and benefits over time. Fourth, this serial investment strategy and extended net benefit evaluation may not only be the most effective approach to realizing sustainability, but may also be a favorable business model for investors (public and private) by offering a stable financial investment strategy that is designed to provide consistent benefits over time. Finally, a potential combined benefit to ecosystems and investors is the realization of stable benefits fueled by tangible progress in restoring and supporting sustainability. This last benefit is beginning to gain in its value in ROI evaluations as a bet-hedging strategy that mitigates growing uncertainty regarding the future availability of more traditional, renewable and non-newable sources of natural resources (Raihan, 2023).

Intentionally orchestrating a sustainable ROI differs from an adaptive decision process (e.g., real options approach; Chaudhari et al., 2016) in that it is anticipatory as opposed to reactionary, thereby setting expectations based on the prenegotiated constraint of sustainability. In other words, it entails constraining the ROI objective with an final ecological outcome requirement that reflects the sustainability goals for the landscape. A sustainable ROI can respond to dynamic conditions as they change over time (e.g., Underwood et al., 2008), leveraging positive interactions, cumulative effects, and unexpected outcomes, while minimizing risks to losses. It can also mitigate ecological inefficiencies associated with the location of investments based on the interests of private investors (Larson et al., 2016).

Private investment in public lands is seen as an important component of supporting public land stewardship and sustaining essential goods and services (e.g., Van Haveren et al., 2025). The more that ROI calculations consider longer-term yields and integrate them into near-term incentives for investment, the more likely that ROI calculation will result in investments that will support forest and landscape restoration and sustainability. Such enhancements would have major implications for the ways in which federal and state agencies perform prioritization of management treatments on public lands. Furthermore, it would greatly enhance the next generation of conservation finance, likely promoting more blended finance models that can bridge limitations associated with any one institution, for supporting and maintaining ecosystem services on public lands into the future.

8 Conclusion and recommendations

The use of ROI for incentivizing and monitoring progress resulting from public and private investments in forest management and conservation is becoming more prevalent and influential in what and where investments are made. As a decision support tool, ROI has the potential to greatly enhance the effectiveness of investments and incentivize more investment, thereby propelling the rate at which progress is made toward greater forest and landscape resilience. However, traditional ROI approaches are inadequate for this task, and in some cases may be antithetical to achieving desired environmental improvement and conservation outcomes in forest ecosystems and forest-dominated landscapes.

Forest management and landscape restoration pose a unique case for ROI application in that they entail accounting for a broad array of sources of and timespans for benefits, costs, risks, and uncertainty. The diversity and complexity of factors affecting ROI in the forest sector are a function of the diverse array of potential desired outcomes, ranging from conservation objectives (e.g., improving old forest conditions for long-term retention), to extraction objectives (e.g., timber volume), to restoration objectives for future conservation or extraction (e.g., improved forest health), to reducing risk to human populations and infrastructure, to reducing risk to current and/or future conservation or extraction objectives (e.g., reduced risk of loss to wildfire), and more. Each category of forest and landscape outcomes has a unique set of considerations in how to represent benefits, particularly in capturing future resource and market dynamics. Here, we identify a set of four focal areas for investment and suggest best practices and future research and development that would improve the value and effectiveness of ROI applications in forest management and conservation.

8.1 Extend temporal and spatial scales

1 As a hedge against bias from unaccounted for costs and benefits, ROIs applied to forest and landscape management projects would benefit from explicitly buffering the spatial and temporal scales to expand the extent of costs and benefits to account for non-target consequences, with some benefit categories justifiably extending far beyond the spatial and temporal footprint of the project. Appropriate scaling will depend on the ecological processes and ecosystem services of interest. In many current applications, ROI boundaries are defined by administrative or funding constraints, rather than ecological considerations, creating a risk of omitted costs and benefits.

2 Landscape or place-based investment strategies and associated ROIs temporally span at least one full natural disturbance cycle (e.g., >20 years in most fire cycles) in order to reflect the value of diversification, sustainable continuous investment, balancing risk and reward, and success in terms of resilience and sustainability.

Research needs: Determine empirically appropriate spatial and temporal scaling rules that align ROI analyses with the underlying ecological processes and beneficiary groups relevant to forest management outcomes.

8.2 Broaden the scope for outcomes and benefits

3. It is important to include a representative breadth of benefits in ROIs, including those that are challenging to calculate or represent (as opposed to limiting benefits to those that are easy to calculate and/or commonly included in business applications), which will precipitate innovations in rigorous processes for identifying and quantifying a richer and more representative suite of benefits.
4. When benefits or costs are difficult to monetize for inclusion in an ROI framework, instead of them being excluded from the analysis, a blended framework of ROI (monetized) and cost-effectiveness (non-monetized) metrics would better reflect the suite of values and benefits associated with forest management and conservation.
5. Analyses could benefit from taking into account the tradeoff between completeness of the analysis, and the time, funds, and data required to calculate benefits. As ROI calculations become more complete, by increasing the spatial scale or number of benefits considered, they may also become more costly. This is particularly important for institutions facing budget constraints, where decisions like these can impact project feasibility.

Research needs: Develop standardized approaches to credibly representing monetary and non-monetary values for challenging costs and benefits to enhance the breadth of future ROIs applied to public goods. Also develop methodologies for combining monetary and non-monetary values into a single ROI that conform with standard economic valuation practices but also meet the needs of land managers. At the same time, acknowledging that the development and deployment of standardized sets of metrics is a long and involved process in many cases.

8.3 Take the long view in the valuation of future outcomes

6. ROI calculations for public forested land applications would benefit from accounting for future resource scarcity and concomitant increases in resource value, given private-sector trends in the conversion of wildland forest ecosystems and landscapes to housing or industry to support human population growth.
7. The bequest value of conserving and restoring forest ecosystem integrity and landscape resilience for future generations goes far beyond banking resources for future extraction to include the health and wellbeing of people, communities, society and the global ecosystem, and merits a well-accepted mechanism for representing its value in ROI calculations in nearly every application.

Research needs: Develop an inventory/library of future bequest values pertinent to forest management and conservation, and classify them based on relevant economically and socially relevant criteria (e.g., replaceability; economic/social/cultural impact) into categories that are then assigned appropriate discounting procedures or options (e.g., no discount, declining discount rate, variable discount rate based on other factors, etc). Also identify options for mitigating any potential biases that may accompany these alternative discount rates.

8.4 Adopt sustainability as a core value

8. Ecosystem services that flow from forests are a function of landscape conditions and dynamics over time, and sustainability can be fostered by treating landscapes as closed economies, where investments are not at risk of ending because a higher ROI can be garnered elsewhere. As a result, criteria for investments are likely to shift to include longer term outcomes and consistent benefits.
9. The diverse array of benefits and variable maturation rates suggest that ROIs for large-scale forested ecosystem investments could apply different discount rates across both benefit types and stakeholder groups. For instance, public benefits may warrant lower social discount rates, while private or investor-oriented benefits may justify higher discount rates.
10. Methods and example applications of sustainable ROIs would help demonstrate how economically advantageous landscape management investments can be designed to pay modest but reliable dividends over time, and more are likely to result in a greater accumulation and more reliable yield of benefits than one-off or periodic, opportunistic investments based on short-term benefit yields.

Research needs: Expand on the concept of sustainable ROI as a contribution to the economic literature, forming a new and novel foundation for ROI that is complementary to maximizing short-term gains, in that it is tailored to maximizing a stable, sustainable, and ideally yielding net gains over a specified area and time period. In addition, develop industry standards for the use of multiple discount rates associated with tangible, but longer term, benefits to expedite their broad application.

In conclusion, ROI is a powerful and highly useful construct for guiding and supporting forest management and conservation. It is intuitively appealing, and it is flexible enough to be adapted to the unique and compelling needs and benefits associated with forest ecosystems and sustainably managing the myriad of goods and services that they provide and upon which communities and societies depend.

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