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Saving the Forest from the Trees: Expert Views on Funding Restoration of Northern Arizona Ponderosa Pine Forests through Registered Carbon Offsets

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Abstract: Ponderosa pine forests in the southwestern United States of America are overly dense, increasing the risk of high-intensity stand-replacing wildfires that result in the loss of terrestrial carbon and release of carbon dioxide, contributing to global climate change. Restoration is needed to restore forest structure and function so that a more natural regime of higher frequency, lower intensity wildfires returns. However, restoration has been hampered by the significant cost of restoration and other institutional barriers. To create additional revenue streams to pay for restoration, the National Forest Foundation supported the development of a methodology for the estimation and verification of carbon offsets generated by the restoration of ponderosa pine forests in northern Arizona. The methodology was submitted to the American Carbon Registry, a prominent carbon registry, but it was ultimately rejected. This paper presents a post-mortem examination of that methodology and the reasons it was rejected in order to improve the development of similar methodologies in the future. Using a mixed-methods approach, this paper analyzes the potential atmospheric carbon benefits of the proposed carbon offset methodology and the public and peer-reviewed comments from the associated review of the methodology. Results suggest a misalignment between the priorities of carbon registries and the context-specific ecosystem service benefits of this type of restoration; although findings confirm the potential for reductions in released carbon due to restoration, these results illuminate barriers that complicate registering these reductions as voluntary carbon offsets under current guidelines and best practices, especially on public land. These barriers include substantial uncertainty about the magnitude and timing of carbon benefits. Overcoming these barriers will require active reflexivity by the institutions that register voluntary carbon offsets and the institutions that manage public lands in the United States. Such reflexivity, or reconsideration of the concepts and purposes of carbon offsets and/or forest restoration, will allow future approaches to better align objectives for successfully registering restoration-based voluntary carbon offsets. Therefore, the results of this analysis can inform the development of future methodologies, policies, and projects with similar goals in the same or different landscapes.

Keywords: carbon offset; aboveground carbon; ecosystem service; forest restoration; reflexivity; wildland fire risk management

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1. Introduction

Extreme wildfires across the globe throughout 2020 provided a stark reminder of the urgency to mitigate future high-severity wildfires [1], which are exacerbated by climate change and expansion of the wildland-urban interface [2]. This trend has continued into 2021, with record-breaking heatwaves, which are due in part to global climate change, contributing to extreme wildfires across three continents [3]. In many parts of the world, such as the United States of America (US), these wildfires are also increasing in intensity because of changes in forest structure due to a legacy of selective logging and aggressive fire suppression, which have led to the build-up of forest fuels [4]. These high-intensity wildfires are, in turn, a significant source of carbon dioxide, contributing to global climate change [5]. In this context, the utility of thinning and prescribed burning for forest restoration is receiving increased attention (see the review article [6]).

In the U.S., an estimated 65 to 80 million acres of public land managed by the U.S. Forest Service (USFS) needs restoration [7]. One region in the U.S. where this restoration is especially necessary is the southwestern U.S. due to a combination of management, climatic, and biophysical factors that make forests in this region particularly vulnerable to high-intensity, stand-replacing fires [8–10]. Thus, millions of acres in Arizona, New Mexico, southern Colorado, and southern California require restoration to contend with high-severity wildfire [11] and improve ecological function, including carbon sequestration and storage [12,13]. Specifically, ponderosa pine forests in northern Arizona are overdue for restoration aimed at returning these forests to the more frequent, lower-intensity wildfires that they are adapted to experience [8,13–15].

However, forest restoration treatments are difficult to implement due to the prohibitive cost of restoration and other institutional barriers [16,17]. Therefore, increasing forest restoration on public lands in the southwestern U.S. requires additional funding beyond what is currently available from federal budgets and timber sales [17]. This requires finding more ways to align restoration benefits with restoration costs [18,19]. One possibility is monetizing the value of increased aboveground carbon storage and decreased wildfire-based carbon emissions that result from forest restoration as carbon credits and/or offsets [12,20]. Where "carbon credits" refer to tradable reductions in carbon emissions that can be credited against an official limit or "cap" [21], voluntary carbon offsets are not audited against a set cap of emissions [22].

1.1. The Southwestern Forest Restoration Methodology

In 2015, the American Carbon Registry (ACR), a prominent carbon registry in the U.S., began the approval process of a carbon accounting methodology based on this idea to increase the restoration of northern Arizona ponderosa pine forests through the sale of voluntary carbon offsets entitled, "Southwestern Forest Restoration: Decreased Wildfire Severity and Forest Conversion" [23]. This carbon accounting offset methodology, which was developed by Drs. Katharyn Duffy (formally Woods) and Spencer Plumb (2016) with support from the National Forest Foundation, Salt River Project, and Northern Arizona University, provided a carbon accounting framework for the measurement, monitoring, reporting, and verification of carbon emission abatements from the reduced risk of high-intensity fires and the continued and increased carbon sequestration of restored forests after treatment [24]. After three years of public comment and a two-year peer-review by a panel of subject matter experts, this methodology was rejected by the ACR.

Understanding why the Southwestern Forest Restoration (SFR) methodology was rejected provides important and timely insights for anyone interested in increasing forest restoration and/or the number of carbon offsets available for purchase. Among the increasing number of carbon offset projects, the SFR methodology was the first submitted that attempted to register carbon offsets based on forest restoration [24]. In their final decision, the ACR commented on this novelty and concurred with one of the main rationales for this methodology, which is the urgency to conduct this restoration. Other, similar methodologies have since been submitted and also rejected. For these reasons, analyzing the SFR methodology and the reasons it was rejected by the ACR is a timely opportunity for the research presented in this paper. Developing a carbon offset methodology takes considerable effort and resources and the review process is time-consuming. Therefore, this research is helpful to anyone developing a similar methodology in the future and provides details on particularly complex aspects such as the concept of project additionality.

1.2. Additionality and Permanence

The challenge for the SFR methodology authors in developing their methodology, and then responding to reviewers during the two-year peer-review by the ACR panel of cross-disciplinary subject matter experts, was to demonstrate that this methodology would necessarily lead to clear, quantifiable, and clearly additional reductions in atmospheric carbon. When considering carbon offset programs, both biophysical and financial additionality need to be considered [25]: registered carbon offset projects need to establish that, through intervention (in this case, forest restoration), additional carbon storage and/or sequestration will occur above a non-intervention baseline [22]. Relatedly, it needs to be established that without the additional financial capital (generated through the sale of carbon offsets), the interventions that lead to additional carbon will not occur. Thus, carbon offset projects need to establish that through additional revenue, less carbon was emitted into the atmosphere. This additionality is precisely what is verified and monitored by carbon registries [26].

Carbon registry monitoring and verification are also crucial for establishing the permanence of a carbon offset, which is a concept related to the longevity of carbon gains. Carbon permanence is often defined as a guarantee that the additional carbon storage will remain out of the atmosphere for decades or centuries [27]. This concept is controversial and can be a barrier to implementing carbon offset projects [28]. Both additionality and permanence are established on a case-by-case basis according to carbon registry best practices, including but not limited to the Greenhouse Gas Protocol for Project Accounting [29], American Carbon Registry Standards [26], and the Climate Action Reserve Program Manual [30].

Towards this end, during the two-year review process, SFR methodology authors developed an ecological forest model to estimate the net carbon benefit of restoration to demonstrate additionality and permanence in response to reviewer comments and questions. This model was created to provide some indication of when carbon benefits from restoration would occur and to assuage doubts about the conceptual validity of generating carbon offsets through restoration. In this paper, that model is critically evaluated along with a qualitative review of comments from the peer-review process.

1.3. Mixed Methods Post-Mortem of SFR Methodology and Reflexivity

The research presented in this paper is a mixed-methods examination of the SFR methodology that is aimed at understanding: (1) the potential net carbon benefits of the SFR methodology according to a forest model developed by SFR methodology authors, and (2) the rationale for rejecting this methodology as a registered carbon offset program. The methods employed in this paper include an analysis of forest model data (provided by SFR methodology authors) projecting the effects of restoration on total aboveground carbon, and a review of public and internal peer-review comments from the period of 2015 to 2019 about the SFR methodology (which are publicly available), respectively. Thus, this analysis is a post-mortem of the rejected SFR methodology to understand how the issues that caused it to be rejected can be avoided in the development of future methodologies in similar and different contexts.

More specifically, the sequential transformative mixed methods [31] approach employed here allows for a policy-level analysis [32] of the SFR methodology proposal to generate carbon offsets on public lands and the possibility of integrating federal directives, forest plans, and project-level procedures with the standards that guide carbon registry best practices, including but not limited to the Greenhouse Gas Protocol for Project Accounting [29], American Carbon Registry Standards [26], and the Climate Action Reserve Program Manual [30]. This will require considerable reflexivity by federal managers, voluntary carbon registries, and other subject matter experts [33].

The concept of reflexivity refers to individual and/or institutional (re)consideration of how systems are understood and subsequently managed [34]; by reexamining the understandings that led to previous management choices and the consequences of those choices on the system, management practices can be reconsidered. For instance, recognizing that years of fire suppression has actually led to increased wildland fire risk frequency and intensity is an act of reflexivity [35] because it involves reconsidering our understanding of forest systems based on the misalignment of past management goals (i.e., reduced fire risk) and the actual long-term impacts of that management (i.e., increased fire risk). Therefore, this research is ultimately aimed at reconsidering the alignment of restoration and carbon offset goals and the improvement of methodologies aimed at generated carbon offsets and/or credits to achieve restoration of federally managed public land. Results of this analysis suggest a possible misalignment between the priorities of carbon registries and the context-specific ecological benefits of restoration; although findings confirm the potential for reductions in released carbon due to restoration, these results also illuminate barriers that complicate registering these reductions as voluntary carbon offsets under current guidelines and best practices, especially on public land.

2. Materials and Methods

To evaluate the SFR methodology and the proposed generation of carbon offsets through restoration, a sequential transformative mixed-methods process took place in two stages, integrating quantitative and then qualitative methods in a successive process to improve insights from the analysis [31]. First, forest model output data for a case study conducted by SFR methodology authors were analyzed by fitting a linear regression to modeled estimates of total aboveground carbon with a three-way-interaction of time, climate change, and treatment, resulting in estimations of total aboveground carbon at different time periods under different climatic and treatment conditions. Second, these results were paired with a qualitative analysis of comments on the SFR methodology. All code used to analyze the data, and the model simulation outputs themselves, are released in the Supplementary Materials.

2.1. The SFR Ecological Forest Model

In response to peer-review comments and questions, SFR methodology authors constructed an ecological forest model of a case study area based on data from the Cragin Watershed Protection Project provided by the USFS. SFR methodology authors submitted this model, model outputs, and a report on the model and outputs as supplemental documents for reviewers during the peer-review process [24]. Full details of the original SFR methodology and corresponding ecological forest model are given in Supplementary Materials. The original report as released for public review is publicly available (see [24]). However, for clarity, in this section, we give an overview of the ecological forest model created by SFR methodology authors.

The study area for the forest model is 64,433 acres, located approximately 55 miles south of Flagstaff, Arizona on the Mogollon Rim Ranger District of the Coconino National Forest, with 37,667 acres identified for thinning and 63,634 acres identified for prescribed burning [36]. Data on 220 forest plots were provided by the USFS [24]. These plots were originally sampled in 2014 within the study area for the purpose of a National Environmental Policy Act (NEPA) review of proposed forest treatments [36]. The Climate Extension to the Forest Vegetation Simulator modeling program was utilized to model these data at 10-year intervals from 2014 through 2054 with and without treatment under different climate change scenarios. Out of 220 forest plots, data for 189 plots were used in this analysis after data cleaning.

In their case study, SFR methodology authors extracted gridded mean fire return intervals using the LANDFIRE modeling program for each sampled plot, which were inputted to a Weibull distribution of fire probability. Decadal estimates of wildfire occurrence were calculated from the Weibull distribution via the cumulative probability of fire at each time step after subtracting the previous time step's cumulative probability. This process resulted in a total of 7560 data points since each of the 189 forest plots was modeled once at five ten-year intervals under four climate change scenarios for both the forest treatment and baseline (i.e., no treatment) scenarios.

2.2. Analysis of Total Aboveground Carbon Modelling

For the regression analysis conducted as part of this paper's mixed methods, a linear regression was fitted to model output data, with total aboveground carbon (measured in tons per acre) as the dependent variable, using Stata statistical software version 14.2 [37]. The equation for this regression is $Y_i = \beta_0 + \beta_{rtc}X + \varepsilon_i$ where the dependent variable $(Y|i)$ is total forest aboveground carbon (measured in tons per acre) in a given year (i), which was regressed against a three-way-interaction where $\beta_{rtc}X$ is a vector that covers year as an ordinal variable (r), forest treatment as a binary variable (t), and climate change scenario as an ordinal variable (c). In total, there are five ten-year intervals, two treatment possibilities, and four climate change scenarios, resulting in forty total combinations as independent predictor variables (X). The parameter β_0 is the total aboveground carbon intercept, while the unexplained portion of the model is captured by the residuals ε_i, which are assumed to be normally distributed with a mean of zero. For each of the forty combinations of treatment, year, and climate change scenario, coefficients and the lower and upper bounds of 95% confidence intervals (differences from zero) were added to the total aboveground carbon intercept (which is: without treatment or climate change in 2014) to establish forty aboveground carbon estimates.

For this analysis, the full model F-statistic and R^2 of this linear regression were interpreted to examine whether the three-way-interaction has an effect on total aboveground carbon, allowing us to estimate effect sizes while controlling for multiple-testing bias [38]. We used a three-way-interaction between predictor variables as we suspected a relationship between forest treatment and time on total forest aboveground carbon. As this relationship is also affected by climatic variables [39], the climate change scenario was incorporated into this interaction. The climate change scenarios were: no climate change, low climate change, moderate climate change, and high climate change, based on climate projections used in the Climate Extension to the Forest Vegetation Simulator modeling program. To account for potential temporal autocorrelation, we also ran two linear mixed effect models, one with forest plot as a random effect, and one with a combination of forest plot, treatment, and climate change as random effects. The results of these models are provided in the Supplementary Materials, but since those results are qualitatively identical, we present the simpler model in the main text.

2.3. Qualitative Analysis of ACR Comments

A qualitative analysis of the SFR methodology and public and internal peer-review comments on the SFR methodology provides a follow-up analysis to the model data analysis. Qualitative analysis allows for the examination of textual data such as the SFR methodology documents submitted to the ACR and the public comments and internal peer-review of those documents. The SFR methodology was submitted to the ACR for review in 2015. To review this methodology, ACR followed the process defined in the ACR Standard v.4.0 [40] (Chapter 7). ACR completed its internal review of the methodology in early 2016. Public comment was initiated in the summer of 2016 and closed by 17 August 2016. In mid-2017, ACR initiated an interval peer-review to determine if the SFR methodology qualified for verification.

A panel was assembled for this peer-review from experts in the fields of forest fire science, forest management, forest carbon offset project development and verification, forestry carbon modeling, and remote sensing. Panel members were recruited from academia, governmental organizations, non-governmental organizations, and other private entities. These experts assessed the methodology and commented on the validity and/or appropriateness of the methodology as a carbon offset program. During this period AFR methodology authors completed and submitted the forest model, discussed in Section 2.1. Since SFR methodology authors developed the forest model in response to reviewer comments and questions, some of the peer-review comments are in direct response to their case study, forest model, and model output.

Four out of seven reviewers remained engaged throughout the two-year peer-review process and provided a final recommendation to ACR in May 2019. The SFR methodology and revisions as well as comments, responses to comments, and the final recommendation are all available on the ACR website [24]. These documents serve as the raw data for the qualitative portion of this inquiry.

A thematic content analysis was conducted to identify patterns and themes in the publicly available comments by commenters and reviewers [41]. Methodology, comments, revisions, and final recommendation documents were uploaded in NVivo 12 for coding and analysis. Latent content-coding highlighted relevant quotes and identified the underlying theoretical position of commenters, reviewers, and methodology authors in the document text [41]. For instance, examples of comments that openly acknowledged the relationship between what people perceive and structural or biophysical realities at landscape scales or expressed reflection on carbon or forest management practices were coded as "reflexivity." Also, any comments that expressed uncertainty or provided uncertainty by questioning SFR methodology assumptions and assertions were coded as "uncertainty." Several additional emergent themes were also captured through coding as documents were comprehensively read for technical content. These results were then compared to the results of the linear regression. This sequential methodology results in a better interpretation of the SFR methodology than possible with each method in isolation [31].

3. Results and Discussion

Results of the linear regression demonstrate that after the year 2034, treated forests have more stored aboveground carbon than untreated forests. See Figure 1. Also, by 2054, treated forests have more aboveground carbon than untreated forests in 2014. The net difference in aboveground carbon between the first and last timestep and/or between treatment and no treatment in 2054 is, therefore, potentially additional, which means it would not exist if the forest was not treated.

3.1. Undisputed Benefits

Consistent with these results, comments on, and reviews of, the SFR methodology indicate general agreement with the basic proposition that increasing restoration will improve forest aboveground carbon storage. In their final decision, the ACR panel summarized their assessment by first praising the SFR methodology for being the "first of its kind with many technical merits" (ACR website). This decision statement clearly articulates that:

> ACR and the peer review panel do not dispute the author team's assertion of the massive environmental benefit of the project activity, the urgency to conduct these activities nor the scientific literature demonstrating that without treatment, major losses of living trees and carbon sequestration in SW [southwestern] ponderosa pine ecosystems will occur [but] the methodology was not recommended by the peer review panel (ACR Decision).

This restoration is identified as urgent because high-intensity wildfires are converting significant forest acreage in the southwestern U.S. into shrubland or grassland ecosystems with lower carbon storage potential [42]. As natural forests store more carbon than plantation forests due to structures that take centuries to develop [43], this represents a significant threat to stored aboveground carbon stocks that cannot be easily reversed through tree planting. Restoration of these forests has also been identified as a high priority and/or opportunity based on relatively low thinning needed and high resilience to fire after restoration [44]. Moreover, the loss of these forests results in the loss of watershed services and other vital ecosystem service benefits [18,45], but these additional benefits are explicitly not considered in the ACR review of this methodology.

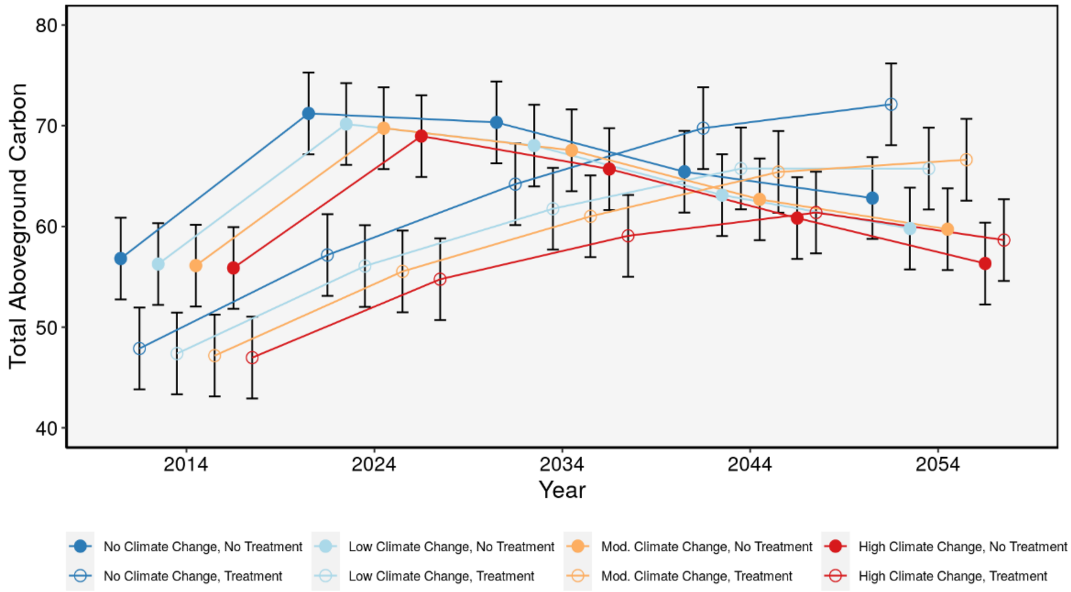

Figure 1. Changes in Total Aboveground Carbon in the Study Area Over Time, where Treated Acres Have More Aboveground Carbon than Untreated Acres by 2044. This figure graphs the results of the linear regression without intercept predicting total aboveground carbon (measured in tons per acre) based on a three-way-interaction interaction among treatment, year, and climate change. The forty total combinations of treatment, year, and climate change are placed in the graph based on aboveground carbon at each ten-year interval. Points with closed circles are without treatment whereas open circles are with treatment. 95% confidence intervals (differences from zero) are represented by interval bars. The colors denote the climate change scenario (see legend). Colored lines connecting points illustrate the change in aboveground carbon over time (recorded along the horizontal axis). Without treatment, aboveground carbon accumulates from 2014 until 2024, at which point it declines. With treatment, aboveground carbon accumulates from 2014 until 2044 when carbon gains level off under low and moderate climate change scenarios and decline under high climate change. Comparing treatment to non-treatment, 2044 is the year when treated forests have more stored aboveground carbon in every climate change scenario. Thus, according to this model, restoration actions begin to show positive carbon benefits in 2044. The model is statistically significant with $F_{39,7520} = 11.02$, $p < 0.0001$, but, critically, the overall uncertainty of this model is high, with an R^2 of 0.0541 (see text for discussion). The residuals of this regression model met parametric assumptions. Results of the two mixed-effects models reveal that variance within plots is more substantial than left-over variation and a Snijders/Bosker pseudo R^2 test results in qualitatively identical explanatory power from the three-way-interaction with virtual no explanatory power in the random effects. See Supplemental Material.

More important than total aboveground carbon in 2054 is the direction of the change in stored aboveground carbon over time. See Figure 1. While stored aboveground carbon is going up or plateauing under three of the four climate change scenarios with treatment (i.e., no climate change, low, and moderate climate change), stored aboveground carbon is declining under every climate change scenario without treatment. However, the variance in total aboveground carbon within the 95% confidence intervals reveals a substantial overlap between the results of treatment and non-treatment scenarios (see Figure 1).

The relatively low R^2 of the model indicates that it only explains a small amount of observed variance in total aboveground carbon, which is either due to a weak relationship, a high degree of uncertainty in model projections, or both. The overlapping confidence intervals suggest that uncertainty is leading to the low R^2 of the model. This uncertainty is due primarily to the probabilistic nature of wildfire in the model since wildfire is the primary factor leading to aboveground carbon losses after treatment.

Thus, results of this linear regression are consistent with other research that indicates that forest restoration leads to reduced carbon losses from high-intensity wildland fires, resulting in increased carbon sequestration and stored aboveground carbon over time [12,13,46–49]. However, the high degree of uncertainty about the timing of those avoided high-intensity fires creates substantial uncertainty about the timing and magnitude of this carbon benefit. The results of the qualitative portion of these sequential transformative mixed methods unambiguously demonstrate that the issue of uncertainty complicates any effort to commodify this additional stored aboveground carbon as offsets [50].

3.2. Uncertainty and Model Limitations

Although there is strong empirical evidence that restoration treatments will result in overall lower carbon emissions and/or greater carbon sequestration [12,46,47], as the responses to the SFR methodology and results of our linear regression reveal, it can be difficult to predict exactly when these carbon benefits will occur. The high degree of uncertainty regarding the precise timing and amount of change in aboveground carbon in the SFR methodology forest model data is one of the more prominent critiques of the SFR methodology. This is reflected in the results of this manuscript's analysis, which is based on these data. In their decision to reject the SFR methodology, ACR cited a "lack of accurate and conservative assessment of uncertainty" as one of the six major reasons for rejection [24]. The results presented in this manuscript demonstrate that uncertainty by calculating 95% confidence intervals, whereas, in the SFR methodology submitted for review by the ACR "the uncertainty is assumed to be zero" [23]. This prompted many commenters to highlight the issue of uncertainty as problematic with comments such as, "for this methodology to be credible it should at least acknowledge uncertainty not just in the magnitude of change, but the directionality" (Reviewer 1).

Critique of the SFR methodology was often focused on modeling techniques: "I disagree that this case study shows clear evidence of carbon benefit. Not without at least estimating uncertainty" (public comment). In the SFR forest carbon model, wildfire risk is determined by a Weibull distribution of the cumulative probability of wildfire based on LANDFIRE modeling, which results in a majority of the study area experiencing fire by 2034 (see Figure 1). Although this is a common method to model fire probability [51], many reviewers felt that this was neither precise enough nor accurate enough to enable reliable prediction of carbon benefits, which are primarily driven by differences in fire frequency and intensity:

> [Wildfire] uncertainty in [the] baseline is the most important part of this whole methodology, and it reads to me like you are just grasping at straws, rather than articulating an integrated approach that, through model iteration, propagates BOTH the stochasticity of fire, weather, and regeneration, AND uncertainly in our ability to estimate it (Reviewer 1).

In an Appendix to the revised SFR methodology, and in response to public and peer-reviewed comments on the ecological model, SFR methodology authors offer a procedure to account for uncertainty, done in part through the use of 95% confidence intervals similar to the methods presented in this paper. However, this approach only provides a more conservative estimation of regression coefficients rather than an actual expression of uncertainty about wildland fire timing and intensity and/or other biophysical uncertainties. To better account for these uncertainties, Reviewer 1 suggested modeling wildfire probability as part of the initial model, rather than manually entering wildfire probability at each timestep post hoc, which would provide a more integrative model of wildfire as a stochastic, ecological process that interacts with other aspects of model logic (see [52] for rationale and examples).

Also, if this revised forest carbon model were run hundreds of times (and not just once as in this case of the SFR forest model) then results would provide a better indication of uncertainty. Moreover, if the SFR model reported aboveground carbon on a yearly basis instead of ten-year intervals, a more detailed picture of carbon gains and losses would be possible. But, ultimately, the exact timing of wildfire starts cannot be predicted with perfect precision [53], and the intensity of those wildfires is based in part on climatic conditions that vary throughout the year [54]. Therefore, while it is possible to predict wildfire across the whole study area in a 40-year period and estimate gains in aboveground carbon, it's not possible to predict when exactly wildfires will occur (or the exact conditions at that time of ignition, which determines wildfire intensity) at a fine-scale, which makes it impossible to predict exactly when atmospheric carbon abatements (and therefore carbon offsets) will occur. In response to this dilemma, one reviewer suggested that manually entering wildfire events in the model at the exact same times for each scenario. This reviewer felt that without comparing the exact same instances of wildfire it is not possible to evaluate treatment benefits. This is notably a very different approach to the solution Reviewer 1 offered for addressing wildfire uncertainty.

More fundamentally, there will always be an unavoidable inability to measure the timing and magnitude of something that didn't happen because of a treatment [55], since carbon benefits are derived from estimating wildfires that explicitly don't happen or which occur at a lower intensity. Some reviewers felt that this unavoidable limitation makes registering these carbon benefits as offsets untenable since "the net carbon storage attributed to treatment comes not from what this landscape retains under treatment, but from what it will not lose to unmitigated wildfire" (public comment). So, "after 40 years, you will never know what did not happen to these forests and are left with nothing but virtual verification" (public comment).

3.3. Additionality

Along with concerns about uncertainty the ACR decision lists one of their six reasons for rejection as simply: "additionality." Additionality can be hard to establish on public lands due to biological and managerial complexity at landscape scales [56]. The issue of additionality is not easily resolved. One reviewer offered the following considerations:

> I understand why proof of additionality is being evoked here (i.e., if the restoration was going to occur anyway for social and ecological reasons, then one could not attribute gains, or losses, of carbon to the crediting procedure). However, this requirement is hypocritical with respect to many other efforts to manage carbon through energy offsets. For instance, to most effectively credit carbon offsets to energy produced from forest biomass, one must first make the case that the biomass is an inevitable byproduct of forest management that would have occurred regardless... In the methodology proposed here, baselines begin before treatment (ensuring additionality can be attributed to treatment); in renewable energy accounting schemes, baselines begin after treatment (ensuring additionality can be attributed to the byproduct of treatment) (Reviewer 1).

What this reviewer is referring to is the fact that in the SFR methodology, and consequently the results of this paper's analysis, treatments occur during the study period, not before (see Figure 1). Striking at a similar conundrum regarding the issue of financial additionality, another reviewer asked:

> What about the case where a federal agency has a forest plan that specifies 'common practice' fuel reduction treatments, but lacks the resources to carry out such treatments? If someone comes along with funding to then support 'common practice' that is applied well beyond what the agency is capable of, then this seems like it should be considered additional even though it is still 'common practice' (Reviewer 7).

Ironically, this question actually summarizes the central thesis of the SFR methodology; this reviewer seems to worry that these "common practice" treatments will be left out of the SFR methodology because they aren't as discretely associated with a separate, clearly additional restoration project, but filling this funding gap is precisely what these carbon offsets would be used to accomplish. To do this "a funding shortfall must be demonstrated in order to demonstrate additionality . . . [but] the source of this shortfall is not specified by the methodology" (SFR methodology author response to comment).

One public commenter asked: "additionality [is] declared in part because the [USFS] has insufficient funds, but how would potential future increases in funding affect the declaration of additionality?" As in, if the USFS receives more funds for restoration in the future, does that reduce the need for carbon offsets since the USFS already prioritizes forest restoration and implements as much as financially possible? This question, and the general difficulty defining additionality for the SFR methodology, reveals that, despite undisputed atmospheric carbon abatements, forest restoration may be incompatible with carbon offsets and/or credits as they are currently conceived and registered by carbon registries.

Moreover, this potential incompatibility is related to a misalignment between the recognized benefits of forest restoration and the incentives of carbon registries to register the most undisputable and efficiently produced atmospheric carbon benefits possible, such as tree planting and/or preventing logging. And yet, those practices can be problematic as well. For instance, a recent investigation, reported by Bloomberg, exposed three forests with registered carbon offset programs where JPMorgan Chase & Co., Walt Disney Co., and Blackrock Inc. had each paid to protect the registered forests from logging. However, this investigation suggested that these forests were not actually at risk to be harvested [57], therefore the offsets were not "additional" at all. This example highlights one way that the SFR methodology, where the payments for carbon offsets are actually needed to conduct the restoration that produces the carbon benefit, may be less problematic than a scenario where payments simply prevent something (i.e., logging) from occurring at all. However, the need to conduct restoration to produce the carbon benefits is one of the things that seem incompatible with the concept of generating carbon "offsets" currently.

One fundamental issue with the SFR methodology is the fact that to generate net carbon benefits, forest restoration actually releases more carbon in the short run; where many carbon offset projects protect forests from deforestation or focus on planting trees, the SFR methodology requires thinning and burning, which releases carbon dioxide. This causes some concern: "I can't see how a carbon project can work if no emission reductions are achieved for 20 years" (public comment). On the other hand, the issue of permanence was not a major topic for reviewers of the SFR methodology, which is interesting because the SFR methodology authors emphasized in their documents and responses to reviewers that one of the benefits of this methodology is the fact that restored forests (if allowed to experience low-intensity fires) would maintain a higher aboveground carbon carrying capacity. Instead, issues of uncertainty about the timing of fires and conceptual issues about quantifying fires that don't occur or the fact that restoration releases more carbon dioxide in the short run were paramount. The issue of the initial release of more carbon in the short run leads to another conceptual concern: is it theoretically justifiable to "short sell" carbon offsets?

3.4. Short Selling Carbon?

The fact that the SFR methodology requires the release of more carbon dioxide in the short-run to produce more net carbon abatements, in the long run, prompted one reviewer to describe the SFR methodology as "a carbon short-sell" since these carbon offsets are essentially sold at a discount before the benefits are in hand, much like a day trader selling shares of a stock they don't own based on market speculation. This is due to the fact that treatment reduces aboveground carbon on the speculation that wildfires will occur and that restored forests will be more resilient to these fires because of aboveground carbon removals and restructuring:

> Betting on restoration is really a carbon short-sell, which depends on the failure of untreated forests to hang on to their carbon, [more] than it does the success of treated forests to hang on to theirs. After all, if the untreated stands continue to escape fire and grow as they have up to now, they will always have more carbon than those subject to thinning (Reviewer 1).

This concern is echoed by another reviewer who pointed out that the actual act of forest restoration "will not increase carbon storage [but rather] will decrease above-ground carbon storage" (Reviewer 7). This reviewer suggested that:

> It would be more accurate to specify that the treatments will result in above-ground carbon storage that is higher than if the project [without treatment] were subject to a high-severity fire, but lower than current storage (Reviewer 7).

This forces one to consider the question of whether it is theoretically acceptable to issue carbon offsets under such speculation, or would it take 40 years for a private funder to be able to claim the carbon abatement benefits as offsets after monitored verification?

With this in mind, examination of current restoration practice and the concept of voluntary carbon offsets presents opportunities: For instance, although it may not be possible to predict exactly at what point in the future these fires will occur, in the long run, these wildfires are all but a certainty. Therefore, carbon offsets could be awarded as a fifty-year bond based on forest model projections [58]. For the duration of this fifty-year period, this bond could be tradeable, offering the value of these expected carbon offsets, but the offsets themselves would be tied up in the bond. After fifty years, a forest inventory analysis could determine if more or less carbon was stored than projected, and the final amount would be awarded to the current bondholder.

This is just one possible approach that will need to be more thoroughly explored. There is a temporal urgency to exploring this and other possible approaches to successfully align the registration of voluntary carbon offsets with forest restoration practices in the southwestern U.S. where high-intensity wildfires are converting significant forest acreage into shrubland or grassland ecosystems with lower carbon storage potential [42]. Reflexivity will help facilitate this exploration and potentially lead to new approaches; in examining the reasons this methodology was rejected, reflexivity allows new insights to emerge that potentially overcomes barriers such that the restoration benefits that are not under dispute can be achieved.

3.5. Reflexivity and Generating Carbon Offsets through Forest Restoration

SFR methodology authors, reviewers, and methodology commenters employed reflexivity in their negotiation of the potential benefits of the SFR methodology and the potential misalignment of recognized benefits of forest restoration with the motivations of voluntary carbon registries. For instance, Reviewer 1 offered the following musing:

> Here is the funny thing about describing the potential carbon benefits of removing trees using the same language more often used to describe the carbon benefits of not removing trees: Concerns regarding permanence (and for that matter additionality and verification) lie not so much [in] events that could later rob carbon from your projects, but the lack of such events you insist will befall the untreated areas (Reviewer 1).

Here, Reviewer 1 is reflexively acknowledging that the “language” of carbon offsets and carbon credits may be hard to apply to this methodology since it is essentially a total reversal of standard carbon offset practice; instead of planting trees or preventing trees from being cut down (which allows applicable projects to count all carbon sequestered by identifiable trees as additional and therefore carbon offsets), the SFR methodology requires tree removal and subjecting forests to fire. Thus, for both SFR methodology authors and reviewers, the proposal requires a reflexive consideration of what a carbon offset actually represents.

In response to questions about the central premise of the SFR methodology, its authors suggest that “this methodology relies on the same counterfactual logic employed in [other accepted] methodologies where credits are generated if emissions in the project scenario are reduced below what would have occurred in the baseline” (SFR methodology author response to reviewers). Therefore, this methodology is just as counterfactual as other payments for ecosystem service schemes aimed at preserving forest function. What is counterfactual in either case is the fact that the additional carbon “produced” is actually an expression of offsets not produced [59]. From this perspective, the SFR methodology is neither less nor more problematic than any other effort to reduce total atmospheric carbon emissions through market-based solutions [60]. Thus, depending on how one thinks about the concept of carbon offsets (which is an act of reflexivity), these different types of projects may seem more or less similar.

Meanwhile, another reviewer was concerned that the SFR methodology may present a "perverse incentive to increase revenues by extracting larger trees (that still meet diameter cap restrictions) while discouraging creative solutions to reduce fire severity" (Reviewer 3). These creative solutions could include "novel and/or more intensive prescribed burning" (Reviewer 3), as well as non-prescribed but managed fires. This reviewer wonders:

> Could offset contracts prevent tribes and public agencies from letting naturally ignited fires burn through or near project areas? If tribes and agencies are required to suppress these fires, low-cost common-practice fire-reduction benefits will be lost and suppression costs will increase (Reviewer 3).

SFR methodology authors replied by indicating that "managed natural fires are explicitly included in both the baseline and project scenarios" (SFR methodology author response to reviewers). Indeed, in the model data, wildfires occur in both baseline and treatment scenarios, but this reviewer is thinking about actually managing forest stands at a per acre scale. If a wildfire starts after restoration, might managers face a perverse incentive to suppress that fire in order to protect carbon gains?

The question remains: can registering carbon benefits from restoration be theoretically aligned with the concept of carbon offsets and/or carbon credits through a reflexive re-examination of the concept of carbon offsets and credits? Theoretically, more and more researchers believe this is possible [17,20,61]. Although carbon offset and carbon credit programs will remain problematic [55,60], in all foreseeable likelihood, the adoption of carbon offsets and/or credits will increase as more nations, states, and corporations start to address their carbon footprints [62,63]. On 9 August 2021, the sixth United Nations Intergovernmental Panel on Climate Change (IPCC) released the first installment of their report, which called for "unprecedented transformational change" to reduce greenhouse gas emissions to zero by 2050 [64]. As the adoption of carbon offsets and carbon credits increases, while climate change realities manifest, the necessity for forest restoration as one climate change adaptation strategy will also increase [65]. For instance, on 24 June 2021 the Plenary of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and IPCC co-sponsored workshop released a report reiterating the need to address climate change in conjunction with preserving biodiversity [66]. This need for reduced carbon emissions and preserved biodiversity will provide new conceptual understandings of both forest restoration and carbon offsets that will accelerate the evolution of forest restoration carbon offset frameworks that align restoration benefits with funding partner interests [67].

In practice, there are other limitations and misalignments. For instance, these carbon benefits may be more speculative than tree planting or avoided deforestation projects [55]. Unfortunately, many carbon markets explicitly forbid carbon speculation such as California's Carbon Market [68], which is the first such market to be implemented in the U.S. On the other hand, SFR methodology carbon offsets are decidedly not presented as tradable carbon credits, but rather voluntary carbon offsets that private firms can purchase to show a good faith effort to address their emissions [61]. This distinction is not substantially parsed by reviewers, who don't reflexively consider the theoretical or practical differences between these different tools.

The speculative nature of these carbon offsets is perhaps not as limiting as to the complexity of aligning restoration on public land with federal agency directives, plans, and procedures, as well as the standards and best practices of carbon registries. One complication is the fact that registries typically require 100-year agreements to ensure the permanence of an offset [26]. While private landowners can enter into long-term agreements for such projects, public land agencies must follow more dynamic planning cycles that make these agreements untenable. Registries also require a transfer of offset title, which holds monetary value and represents the rights and interests associated with the carbon offset [29]. Thus, selling a property right for the carbon stored on public lands could create a conflict with the public ownership of USFS land [69]. Interestingly, these issues do not emerge as concerns during the review process, which is more focused on how to account for the additional carbon from treatment.

Adding carbon offsets into forest restoration may also complicate the already complex management landscape navigated by federal land managers [70]. For instance, assigning offsets a monetary value may interrupt other methods for funding restoration, such as funding as part of timber extraction [71] and selling removed trees from restoration as forest products [72]. However, the low value of this small diameter timber is not in high enough demand to even pay its way out of the woods [17]. Thus, more funding mechanisms are required, even if they are not simple to implement [18]. This issue does emerge in the review, especially in regard to the concept of additionality, see Section 3.3.

These results indicate that for the carbon abatement benefits of forest restoration to be registered as carbon offsets, more careful consideration of these potential incompatibilities and complications is necessary. Perhaps the USFS and/or other agencies that manage wildlands could develop proprietary criteria for registering, monitoring, and verifying carbon offsets from restoration? This novel voluntary carbon registry could work within the statutory limitation of federal agencies [73] while maintaining the key tenets of voluntary carbon registration [26,30]. Alternatively, the USFS and other federal agencies could partner with an existing voluntary carbon registry to collaboratively co-produce standards that would be more appropriate for restoration-based methodologies and/or projects on public land.

4. Conclusions

In this paper, sequential transformative mixed methods were used to examine a proposed methodology for the generation of carbon offsets through forest restoration. Results demonstrated why, despite the undisputed carbon benefits of restoration, the ACR declined to adopt that methodology. Specifically, unresolved issues regarding uncertainty and, relatedly, concerns about when and how much additional carbon benefits are generated by restoration led to the SFR methodology being rejected. Although the SFR methodology was rejected by the ACR, the results of this analysis (including qualitative analysis of ACR internal peer-review comments and decision) demonstrate the potential utility and temporal urgency of this and/or similar methodologies; not only does regression (where the majority of plots burn by 2034) demonstrate the possibility that many of these forest stands, if left untreated, may not return as forests after high-intensity fires [42], but in their decision not to approve the SFR methodology, the ACR even cites the "urgency to conduct these activities" as undisputed. This urgency is compounded by the urgency to address global climate change, reported by the sixth IPCC [64], in conjunction with preserving biodiversity, reported by the IPBES-IPCC [66]. For these reasons, it is clear to us that funding restoration, quickly, is extremely important. Therefore, resolving the barriers that prevent registering carbon benefits as voluntary offsets as one funding mechanism for restoration is imperative.

Qualitative assessment of public and internal peer-review comments on the SFR methodology provides a more detailed examination of the perceived potential benefits of, and barriers to, creating carbon offsets through forest restoration on public land. These comments also reveal important insights into how subject matter experts conceptualize the idea of carbon offsets and/or credits more generally and the reasons this or similar methodologies may or may not be theoretically and/or operationally possible. Carbon offsets/credit methodology approval is currently focused on the most straightforward approach to registering, monitoring, and verifying net atmospheric carbon benefits, rather than finding the flexibility to use these tools to limit or interrupt processes that result in more carbon emissions. Therefore, these qualitative data expose the inherent complexity of what seems initially like a simple proposition. However, to address global climate change, it will prove necessary to implement not only the most straightforward programs but also more complex strategies that protect critical ecosystems and biodiversity.

Rather than abandoning this approach, these data demonstrate the imperative for public land agencies and potential partners to design solutions to address identified complications. For instance, methodology authors need to make a more robust consideration of uncertainty. Decision-making is, arguably, fundamentally about managing uncertainty, whether it be navigating away from a certain sub-optimal future or finding a way to reduce uncertainty by increasing the chances of a better outcome for stakeholders. Uncertainty is a complex topic, but one that almost every human being has some experience working with, and as such, it should be expected that it will be brought up by all sectors of society. This study provides a case study of the importance of communicating openly about the uncertainty, of both action and inaction, and how not addressing it can lead to public pushback.

New or revised methodologies should also make more explicit consideration of the suite of alternative wildland fire risk strategies employed in interagency wildland fire risk management, such as managed natural fire starts [53]. And, as more countries and multinational corporations turn to voluntary offsets as a climate adaptation strategy, the very concept of a carbon "offset" needs to be reflexively reexamined so that proposals are not dismissed for the wrong reasons. For instance, in the case of the SFR methodology, concerns about the uncertainty of wildfires, which leads to uncertainty about the timing of carbon benefits, may be abated by the relative permanence of carbon stored in restored forests due to forest structure relative to a planted forest. Moreover, the difference between offsets and credits, which were not sufficiently parsed in the ACR review of the SFR methodology, needs to be considered as well.

Administrative conundrums also need more explicit consideration. For instance, it will be necessary to delineate restoration facilitated by carbon offsets and/or credits from other efforts to restore forests [74]. There will be plenty of acres left untreated under almost any remotely plausible increase in funding in public land agencies in the U.S., therefore, with careful articulation, there will be plenty of acres available to treat with restoration funded through voluntary carbon offsets and maybe even tradable carbon credits in the future. These issues are not only relevant to the U.S., as many lands in need of restoration across the globe are under more complex management than current carbon accreditation processes favor. To protect other forests at increased risk of stand-replacing fire across the globe, similar methodologies could be implemented where methodology authors will run into similar and different obstacles than those presented here. Unfortunately, the difficulty of implementing payments for ecosystem service programs such as REDD+ [75], which is aimed at the more conceptually straightforward effort to reduce deforestation, suggests that implementing methodologies similar to SFR in other contexts will not be easy, no matter how urgently it's needed. These realities are precisely why wildland managers and those interested in carbon mitigation alike should collaborate quickly to resolve the issues highlighted in this analysis in order to get as much forest restoration completed as possible before it's too late.

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