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Do working forest easements work for conservation?

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Abstract

Conservation easements are voluntary legal agreements designed to constrain land-use activities on private land to achieve conservation goals. Extensive public and private funding has been used to establish 'working forest' conservation easements (WFCE) that aim to protect conservation values while maintaining commercial timber production. We use variation in the timing and location of easements to estimate the impacts of WFCEs in Maine from a 33-year time-series of forest loss and harvesting. We find that WFCEs had negligible impacts on an already low rate of forest loss. Compared to matched control areas, easements decreased forest loss by 0.0004% yr^{-1} (95% CI: −0.0008, to −0.00003%) the equivalent of 3.17 ha yr^{-1} (95% C.I.: 1.6, to 6.7 ha yr^{-1}) when scaled to the 839 142 ha of total conserved area. In contrast, WFCEs increased the rate of harvesting by 0.37% yr^{-1} (95% CI: 0.11%–0.63%), or 3,105 ha yr^{-1} (95% C.I.: 923–5,287 ha yr^{-1}) when scaled to the conserved area. However, more recently established easements contained stricter restrictions on harvest practices and stricter easements reduced harvest by 0.66% yr^{-1} (95% CI: −1.03, −0.29). Our results suggest that future easements could be more effective if they were targeted to higher risk of loss areas and included additional provisions for harvest restrictions and monitoring.

1. Introduction

Protection of private land is needed to achieve societal goals for climate regulation and maintenance of biodiversity, ecosystem functions, and natural resources. Conservation easements are a primary mechanism for advancing public conservation goals on private land (Parker and Thurman 2019). Easements transfer a subset of property rights from the landowner to the easement holder (usually a land trust or government agency) and restrict specified land uses, often in perpetuity (Rissman *et al* 2013). Easements are frequently preferred for conservation because they are voluntary, generally less expensive than fee acquisition, and because the landowner retains most property rights while receiving substantial income and/or favorable tax treatment (Parker and Thurman 2018, 2019). Although easements are primarily used in the U.S., voluntary and private-sector approaches to land protection are an increasingly important strategy for nature-based solutions to climate change and biodiversity conservation worldwide (Kamal *et al* 2015, Selinske *et al* 2017).

The proliferation of conservation easements in the U.S. began in the early 1980s, when Congress incentivized their use through changes to the tax code, allowing easements donations to be treated as tax-deductible charitable contributions (McLaughlin 2010, Kay 2016, Parker and Thurman 2018), and by funding easement purchases. The U.S. federal government now spends more than $450-million annually to conserveagricultural and forest lands using conservation easements (CRS 2017, 2018) and grants more than $1-billion in tax breaks for new easements (CRS 2019). Cumulatively, more than 16-million hectares are now protected by conservation easements—more than the combined area of all U.S. National Parks. Easements also receive public support through lower ongoing tax obligations to state or local governments as a result of reduced assessed property values (Kalinin *et al* 2023). Despite their vast extent, few studies have examined the impact of easements on

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land-cover change (but see Nolte *et al* 2019, Hagen *et al* 2024) and we are not aware of any prior studies assessing the impact of easements on rates of timber harvesting.

Conservation easements are voluntarily negotiated between the landowner (grantor) and the easement holder (grantee) and their terms vary substantially. However, they typically include several consistent elements, including: a statement of purpose, the rights of each party and restrictions on land-use to meet conservation goals (Merelender *et al* 2004, Rissman *et al* 2013). Specific land-use restrictions within conservation easements are individually negotiated between the landowner, the easement holder (a land trust or government agency) and any additional funders of the easement but must achieve at least one of the broadly defined conservation purposes articulated by the Internal Revenue Service and the Uniform Conservation Easement Act (McLaughlin 2010, Rissman *et al* 2013). Eligible purposes include outdoor recreation, fish and wildlife habitat, open space scenery, and historic preservation.

So-called 'working forest' conservation easements (WFCEs) are an informally defined class of easements intended to protect managed forests from conversion to non-forest uses and/or to promote sustainable forestry and other conservation values (Tesini 2009). In 1990, the Forest Legacy Program was added to the U.S. Farm Bill to help fund the protection of privately-owned working forests through conservation easements and land purchases (Murray *et al* 2018). A core objective of the Program, and of working forest easements generally, is to protect timber-based economies and the rural culture and landscapes they support, while also enhancing ecological conditions and recreation opportunities by protecting long-term public access and large contiguous land parcels (Noone *et al* 2012, Legaard *et al* 2015, L'Roe and Rissman 2017, Reeves *et al* 2020). Since the establishment of the Forest Legacy Program, the largest share of forestland protected in the U.S. has been through WFCEs.

WFCEs vary substantially in terms of the protections they provide. Most focus on limiting development, parcelization and ensuring continued forest cover. Forest Legacy funded easements, for example, require multi-resource management plans, definitions of incompatible uses, and clarity on whether land may be subdivided in the future (USFS 2017). Some WFCEs include restrictions meant to curb unsustainable harvesting, including temporary harvest moratoriums, limits on timber volume removed relative to growth, or protections in sensitive areas (Daigle *et al* 2012, Owley and Rissman 2016).

In the U.S., the proliferation of large WFCEs beginning in the late 1990s coincided with the broad scale financialization of timberlands. Land financialization is the process of incorporating land into global networks of investment capital as financial assets (Gunnoe *et al* 2018). Today, nearly all vertically structured commercial timberland for timber and wood products in the U.S. have been acquired by investment interests, including timber and real estate investment trusts (Bliss *et al* 2010, L'Roe and Rissman 2017, Gunnoe *et al* 2018). Concerns that the shorter time horizons of investment owners might incentivize them to break-up, convert, and/or mismanage the forests led many conservationists to support establishment of large WFCEs (e.g. Stein 2011). WFCEs were also attractive to the new fiduciary owners, who could enhance short-term returns from the land investment from selling the restrictions on development (Saul 2021). WFCEs have been financially supported by a combination of federal, state, local, and private conservation funding (Tesini 2009).

Overall, proponents argue that WFCEs can contribute both to conservation objectives and to local and regional economic prosperity (Murray *et al* 2018). Opponents argue that the protections offered by these easements offer little public benefit because easement terms do not sufficiently restrict unsustainable harvest practices (Duveneck and Thompson 2019, Gunn *et al* 2019). In addition, many of the easements have been applied where threats of conversion are low, potentially limiting their impact on forest loss (Pidot 2005). The harshest opponents brand them as public subsidies to industry that primarily benefit distant investors (Sayen 2023).

To assess the impacts of WFCEs on land-use change and harvest rates, we use a 33 year time series of forest loss and harvesting data in the state of Maine (figure 1). Maine serves as an ideal case study, having experienced rapid growth in land conserved through WFCEs during this period (Meyer *et al* 2014). Indeed, in 1990, just six percent of the Maine landscape had any type of protection and 80-percent of that was public land. By 2020, 22-percent of Maine had a protected status, with large WFCEs accounting for 70-percent or 839 142 ha, approximately the size of Yellowstone National Park.

We compare rates of forest loss and harvest within the easement areas to matched control sites in unprotected private lands that are similar in terms of relevant observable covariates. We also characterize and assess land-use restrictions articulated within the easements and how changes in easement strictness relate to observed patterns of land use.

Overall, we find that the easements had little effect on rates of forest loss or harvesting. Our results indicate that WFCEs decreased forest loss by 0.0004% yr^{-1} (95% CI: −0.00082, −0.00003), or the equivalent of 3 ha yr^{-1} (95% C.I.: 1.6–6.7 ha yr^{-1}) when scaled to total conserved area. These magnitudes are small both in an absolute sense and in comparison to the accuracy of the remote sensing products used. Compared to matched controls, WFCEs did not reduce harvest rates. Our results

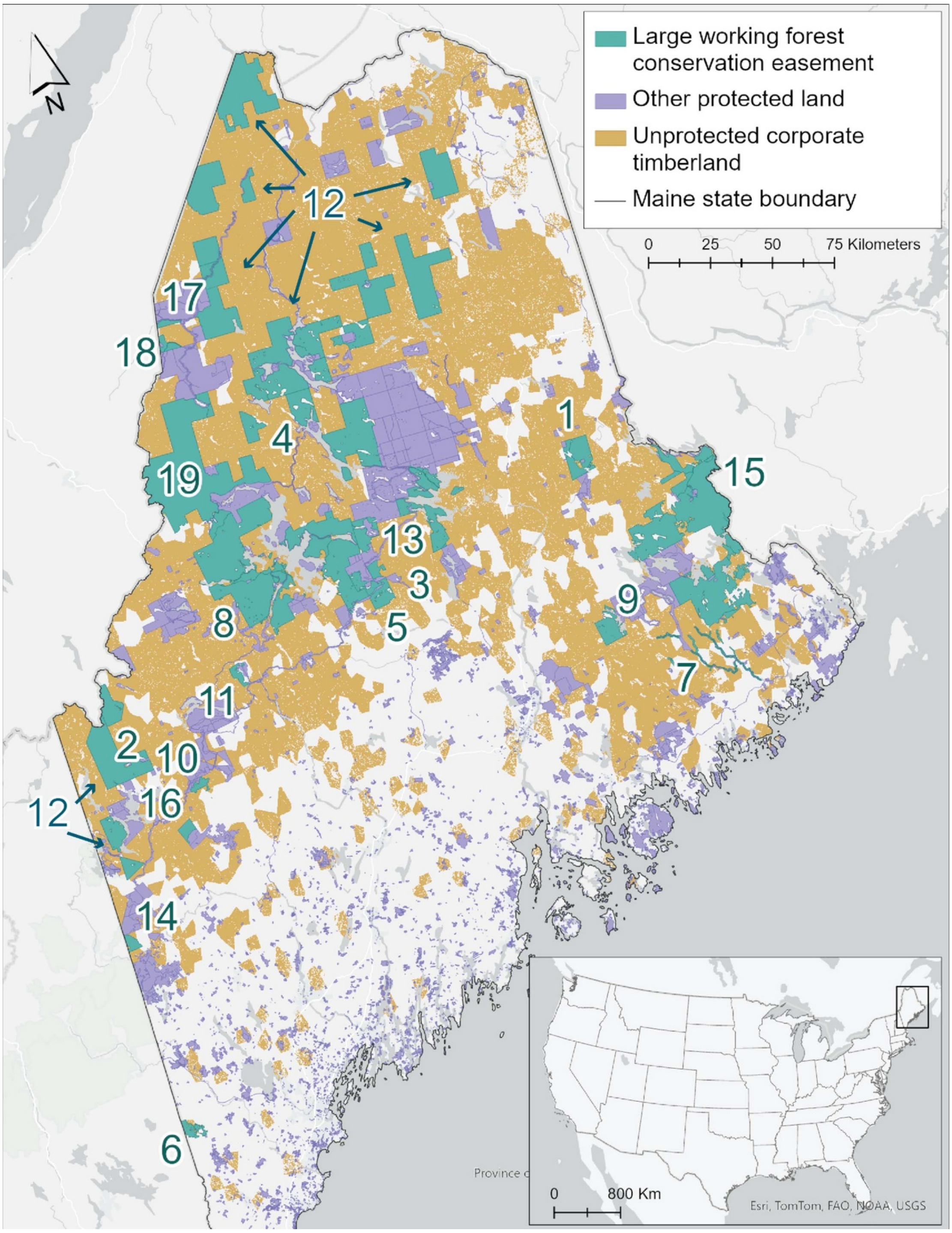

Figure 1. We analyzed rates of forest loss and harvest within 19 large working forest conservation easements (green) that span 839 000 hectares and are embedded in a matrix of other protected (lavender) and unprotected corporate owned timberlands (brown) throughout northern Maine. Note the numbers on the map correspond to the WFCEs described in table 1.

indicate that WFCEs actually increased the rate of harvesting by 0.37% yr^{-1} overall (95% CI: 0.11, 0.63), or 3105 ha yr^{-1} (95% C.I.: 923–5,287 ha yr^{-1}) when scaled to the 839 142 ha of conserved area. These findings indicate that while WFCEs may have supported continued recreational access or changed some management practices, they have not produced substantial additional ecological benefits by reducing forest loss or harvest rates overall compared to status quo commercial timber operations. However, our analysis of easement terms indicates that more restrictions have been imposed over time, and that stricter easements reduced the rate of harvesting by -0.66% yr^{-1} (95% CI: -1.03, -0.29). Together our results indicate that WFCE effectiveness could be increased by changes in easement design and enforcement that prioritize areas under active threat from conversion and strengthen restrictions on harvest rates.

2. Methods

2.1. Study area and easements

We analyzed WFCEs throughout Maine (figure 1) where >7 million hectares of forests cover >90% of the land area. The southern half of Maine is dominated by northern hardwood forests, which transition to boreal spruce-fir forests in the north (Thompson *et al* 2013). Two centuries of sawlog harvesting and one century of intensive pulp production have created a forested landscape that is highly fragmented, traversed by roads, and dominated by young, even-aged trees (Gunn *et al* 2019). Maine's forests are primarily owned by private entities, including corporations (59%) and families (32%; Sass *et al* 2021).

We define large WFCE as those protecting >1500 hectares of forestland and where maintaining forest management is one of the stated purposes of the easement. We focus on large easements because they are a distinctive feature of corporate timberlands (i.e. smaller easements are common throughout the U.S.) with an outsized influence on regional socio-ecological dynamics, particularly in Maine where they constitute 85% of the total area under easement, but just 0.6% of the total number of easements. Additionally, forest management conducted at large scales tends to be different from small-scale forestry in many ways including motivations, species selection, and harvest intensity (Harrison *et al* 2002). Using a geodatabase of all protected land in New England (Harvard Forest 2023), and easement contracts we obtained from the Maine Registry of Deeds, we identified 19 easements that met our definition of WFCEs (table 1). These range in size from 1700 to > 308 000 ha. They represent 49% of the total protected area in the state, and 72% of the private protected area. Nine of the easements are held by conservation NGOs and ten by government agencies. At least twelve of the nineteen projects received public funding totaling > $50 million (table 1), most of which (55%) came through the Forest Legacy Program (table S1). Other projects received substantial support from private conservation organizations and/or individual donors and in the form of future reduced tax obligations, but these funding sources are not reported in a consistent or complete way.

To analyze WFCE impacts, we divided land areas in Maine inside and outside of the WFCEs into 10 hectare hexagonal grid cells. For each cell, we measured outcomes over time as well as multiple environmental and social characteristics used to ensure comparability between sites. Outcomes on each grid cell in each year are influenced by locally-specific determinants of conversion pressure or harvest rates, including forest type and productivity, accessibility, and market conditions, in addition to easement terms.

2.2. Quantifying land-use and land-cover change

Our panel data of environmental outcomes spans the years from 1985 to 2018 and measures rates of forest loss and harvesting within the WFCEs and similar unprotected control sites. We calculated the proportion of forest loss and forest harvest within each unit and year.

Our estimates of forest loss are based on the U.S. Geological Survey's Land Change Monitoring, Assessment, and Projection (LCMAP; Brown *et al* 2020). LCMAP is a Landsat-based (30 m resolution) annual time series of land cover produced using the Continuous Change Detection and Classification approach (Zhu and Woodcock 2014). LCMAP products are specifically designed for characterizing land-cover change on decadal time scales (Sohl *et al* 2019), provide a series of annual maps (Brown *et al* 2020), and have been found to clearly outperform other national and global datasets in terms of class accuracies and consistency with relatively low error rates in Northern New England (Wang and Mountrakis 2023). We used LCMAP CONUS v1.2 and measured pixels that transitioned from the tree cover class to a developed class as forest loss.

Our forest harvest estimates are based on recently constructed annual maps of harvest events in Maine from 1985 to 2018 (Pasquarella *et al* 2023)[3]. Harvests were detected using the LandTrendr temporal segmentation algorithm (Kennedy *et al* 2018) applied to Landsat time-series of three spectral indices: Normalized Burn Ratio, Normalized Difference Moisture Index and Tasseled Cap Wetness time series. The three sets of segmentation results were ensembled using a simple decision tree approach, which resulted in a characterization of harvest events with a high degree of accuracy (see Supplemental Methods for details).

2.3. Environmental variables and covariate pre-matching

To evaluate the impacts of working forest conservation easements, we identified social and environmental variables known to be correlated with rates of forest loss and harvesting (based on Thompson *et al* 2017a, 2020). We then used covariate pre-matching to ensure that the joint distributions of these variables were similar between treatment (WFCEs) and control groups. Matching variables for harvest rates included correlates with forest productivity (i.e. light, climate, forest type, forest structure, nitrogen deposition), and with harvest access (i.e. topography, road density, wetlands, streams). Matching variables for forest loss included similar variables, plus distance to

[3] Please see interactive harvest viewer associated with Pasquarella et al (2023) on Google Earth Engine here: https://valeriepasquarella.users.earthengine.app/view/harvest-map-explorer.

Table 1. Attributes of the 19 working forest conservation easements analyzed in this study. Note the row numbers correspond to the numbers on the map in figure 1.

#	Easement name	Year	Area (ha)	Fee owner/grantor	Easement holder	Holder type
1	Apple Conservation	2016	12 985	Shelterwood Holdings, I, LLC	Forest Society of Maine	NGO
2	Boundary Headwaters	2004	9105	SP Forests, LLC; International Paper	Forest Society of Maine	NGO
3	Gulf Hagas—White Cap	2016	2855	Pine State Timberlands, LLC	Maine Bureau of Parks & Lands	State
4	Katahdin Forest Project	2002	75 808	Maine Timberlands Company	The Nature Conservancy	NGO
5	Katahdin Ironworks	2009	10 828	AMC Maine Woods, Inc.	Maine Bureau of Parks & Lands	State
6	Leavitt Plantation Forest	2003	3405	GMO Forestry Fund 1, LP	Maine Bureau of Parks and Lands	State
7	Machias River Watershed	2003	5348	SP Forests, LLC; International Paper	Maine Atlantic Salmon Commission	State
8	Moosehead Lake	2012	143 402	Plum Creek Maine Timberlands, LLC	Forest Society of Maine	NGO
9	Nicatous Lake	2000	8725	Robbins Lumber, Inc.	Maine Bureau of Parks & Lands	State
10	Orbeton Stream	2014	2318	Linkletter Timberlands LLC	Maine Bureau of Parks & Lands	State
11	Pierce Pond	1996	2722	SD Warren Company	United States of America	Federal
12	Pingree	2001	305 681	Six Rivers Limited Partnership; Pingree Associates, Inc.	New England Forestry Foundation, Inc.	NGO
13	Roaches Pond	2009	7143	AMC Maine Woods, Inc.	Maine Bureau of Parks & Lands	State
14	Robinson Peak Forest	2008	2720	LBA Forest Stewardship Initiative,	Maine Bureau of Parks & Lands	State
15	Sunrise Easement	2005	124 331	Typhoon LLC	New England Forestry Foundation, Inc.	NGO
16	Tumbledown Mount Blue	2002	3148	Hancock Land Company, Inc.	Maine Bureau of Parks & Lands	State
17	Upper St. John River North	2012	1694	The Tall Timber Trust	The Nature Conservancy	NGO
18	Upper St. John River South	2009	2878	Stetson Timberlands, Inc.	The Nature Conservancy	NGO
19	West Branch Penobscot Headwaters	2003	114 046	Merriweather, LLC	Forest Society of Maine	NGO

population centers and distance to energy transmission infrastructure in order to capture land conversion pressure (table S2). To ensure the best possible matches, we matched hexagonal grid cells separately for each easement; however, we do not double-count any of the control grid cells when reporting summary statistics (Ho *et al* 2011).

For the forest loss analysis, matched hexagons were selected from the population of all unprotected private land within the counties that contain WFCEs. This was done to include lands that may have originally been commercial timberlands but were sold to other owners as well as to ensure that matches came from within areas with similar development pressure. For the harvest rates analysis, matched hexagons were selected from the population of unprotected commercially owned timberlands in Maine. Landowner data came from Sass *et al* (2020). Data limitations prevent us from matching on more highly resolved owner classes (e.g. Real Estate Investment Trusts versus Timber Investment Management Organizations). For each easement, matching was done without replacement, with similarity defined by nearest neighbor measured in Mahalanobis distance, with exact matching used for categorical variables (i.e. forest type) and with calipers set to one standard deviation for continuous variables. Matching resulted in a forest loss dataset with 180 924 hexagonal grid cells and a harvest dataset with 168 106 hexagonal gird cells, both of which cover 33 years. Matching succeeded in balancing covariate distributions (figures S4 and S5). Trends in loss and harvest are similar prior to easement adoption dates as expected for well-matched sets (figures 2, 3, S2 and S3).

2.4. Estimates of easement impacts

After matching, we estimate the impact of the easements using a difference-in-differences approach, wherein we estimate the difference in forest loss and harvesting between the control and easement sites before easements were established and subtract that from the difference after the easements were established (also figures 2 and 3). This approach accounts for general trends in conversion or harvest, so the estimated effects can be attributed to the easement policy.

We evaluated WFCE impacts with two sets of weights. First, we calculated the percent of WFCE area affected by each land use across all the areas within WFCEs, which weights the easements by their size and shows their aggregate effect within the region. Second, we evaluated the percent of forest loss at the individual WFCE scale, which gives each easement equal weighting as a single treatment unit. For analysis at the easement level, grid cells were aggregated to an easement level dataset with 38 units of analysis and 33 years of observations for each unit. We also compare rates of loss in WFCEs to overall rates in the state as a whole in order to provide context for the magnitudes of the results (figure S1).

2.5. Easement coding

Following Owley and Rissman (2016), who examined trends in easement complexity by coding easement terms according to the degree of control, we coded terms in the 19 WFCE contracts related to easement purposes, their allowed land uses (e.g. forestry practices & construction), and management, enforcement, or conservation outcomes (e.g. subdivision & subdivision cost, ecological monitoring). To construct an index of strictness, we used the 14 terms that captured potential restrictions on land use or harvesting. Each term has possible values ranging from 0 to 1, with language that corresponds to more control over landowner activity receiving higher scores; these are summed to create an 'easement strictness index' (also see SI).

3. Results

3.1. Forest loss

Compared to Maine's forests as a whole, corporate-owned timberlands, whether protected by a WFCE or not, have a low rate of conversion to non-forest land cover (figures 2 and S1). Using the difference-in-difference approach to compare rates of forest loss between easement and matched control units, we estimate a very small reduction—i.e. 0.0004% less forest loss per year (figure 2) attributable to the WFCEs (95% CI: −.00082, −.00003). When aggregating to the easement level and equally weighting the easements, the impact is similarly small—i.e. 0.0008% less forest loss per year (95% CI: −.00147, −.00014). We also see that no individual WFCE clearly altered the trajectory of forest conversion relative to their control plots (figure S2). Taken at face value, when we scale the differences in rates by the areas of the easements, we estimate that the WFCEs prevented 3.17 ha yr^{-1} (95% C.I.: 1.6–6.7 ha yr^{-1}) from being converted. However, given inherent limitations in the accuracy of remote sensing, these estimates should be interpreted as suggesting either a very small or no detectable effect on forest loss.

3.2. Forest harvesting

In contrast to forest loss, rates of forest harvesting within WFCEs and in unprotected corporate forestlands are higher than for Maine's privately-owned forests overall (figure S1). Comparing rates of forest harvesting between easement and control areas, we estimate WFCEs actually increased harvest rates by 0.37% per year (95% CI: 0.11, 0.63). Scaling by the areas of the easements, we estimate the WFCEs resulted in 3105 ha yr^{-1} (95% CI: 923–5286 ha yr^{-1}) more harvesting (figure 2). With equal weighting of easements, we estimate that easements resulted in no change in harvest rates—i.e. the differences in harvest rates before and after are estimated to be close to zero (0.0045, with 95% CI −0.4468, 0.4558) (figure 2).

There is substantial variation in harvest rates across the individual WFCEs (figure S3). Few show distinct changes in harvest rates after the time of easement (figure S3). The Roach Pond Track is one exception; this property was bought and enrolled in an easement by a conservation organization (AMC) with the explicit intention of letting it recover from over-harvesting before resuming harvesting in the future. This is reflected in the lower rates of harvest after the easement date (figure S3).

3.3. Easement strictness and heterogeneity

Because easements are individually negotiated, there is substantial variation in easement language

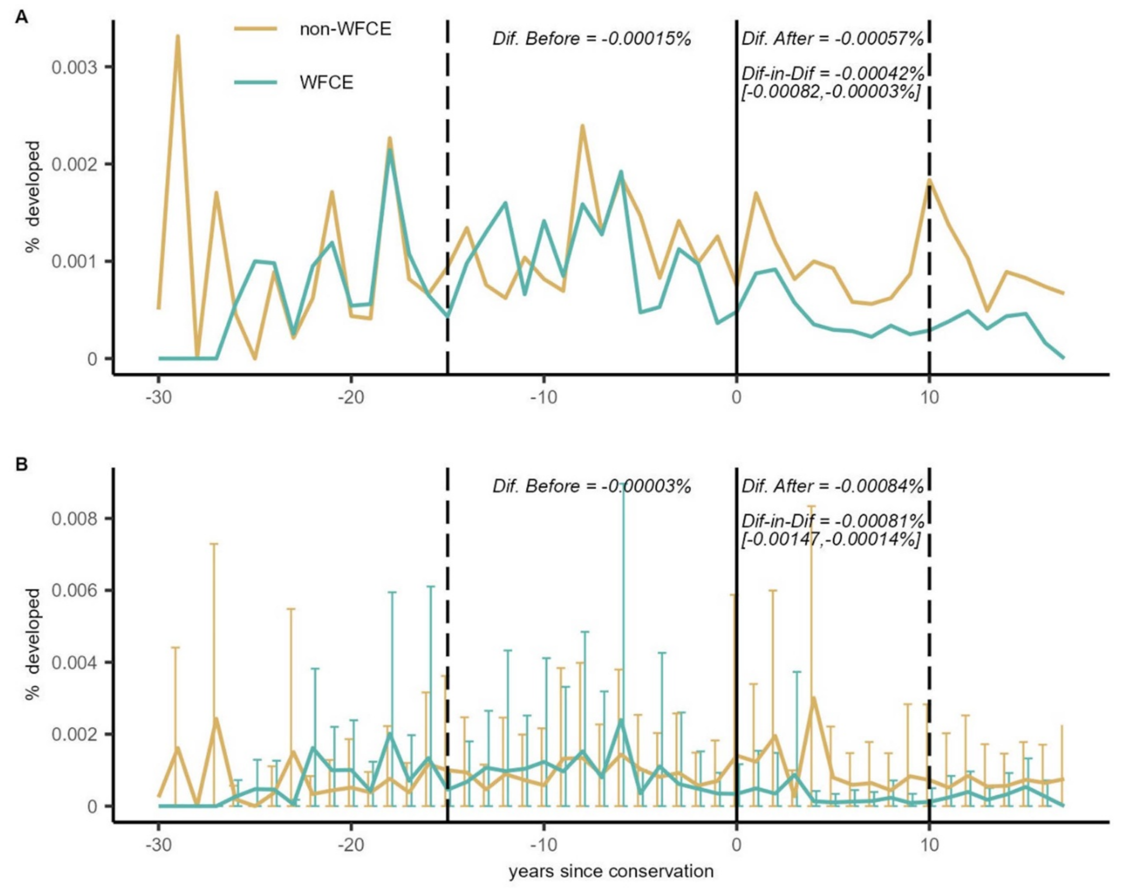

Figure 2. Annual rate forest loss within 19 working forest conservation easements (WFCE; blue) and their 19 matched control areas (brown). Solid vertical line indicates the year of conservation, which has been scaled to zero for all easements. Dotted vertical lines at −15 and +10 indicate the years used to calculate the difference in difference estimates. Numbers in brackets are 95% Confidence Intervals for the estimated difference in differences. The longer window of time for the pre-period reflects greater data availability for that time so we can reasonably extend the averaging window. (Top) Average annual percent of forest loss calculated across all WFCE land, which effectively weights the easements by their size. $N = 180\,924$ treated and control grid cells across 33 years for each cell. (Bottom) Average annual percent forest loss within each easement, such that each easement is one sample regardless of size. Hexagonal grid cell data aggregated to each of $N = 38$ treated and control easement units across 33 years. Error bars are standard deviations.

concerning restrictions on land-use, monitoring, and harvesting practices (figure 4, SI methods). We find a general trend towards stricter easements over time (figure 4) with additional provisions in easement language for reporting, monitoring, and controls on harvest practices. We also find that harvest rates declined relative to their matched controls for those WFCEs that adopted more restrictive easements (highest 50th-percentile of strictness index) with magnitudes of −0.66% yr^{-1} (95% CI −1.03, −0.29) when we consider all areas and −0.62% yr^{-1} (95% CI −1.11, −0.14) when we weight by the easement units (figure 4). Harvest rates within WFCEs with low strictness (lowest 50th-percentile) increased by 0.56% yr^{-1} (95% CI 0.28, 0.85) and 0.61% yr^{-1} (95% CI: −0.27, 1.49). We note that there is substantial uncertainty in these estimates, however, because of the small number of easements involved and because several of the more strict easements have limited post-easement data (figures S2 and 4).

4. Discussion and conclusion

A primary goal of WFCEs has been to prohibit permanent development and ensure future forest cover. While we find that WFCEs have experienced low rates of conversion from forest to developed uses, these low rates are similar to the rates on counterfactual sites within unprotected private land generally. This is consistent with the fact that the lands protected by WFCEs are overwhelmingly located in the rural unincorporated territories of Maine, where there are few people and there has been a low threat of conversion to date.

Hagen *et al* (2024) examined a range of conservation easements held by the Nature Conservancy in the Northeast, Mid-Atlantic and California. While fee acquisitions reduced rates of conversion to developed uses, easements did not except when the land was also acquired by conservation organizations in high-threat regions. Nolte *et al* (2019) found that easements

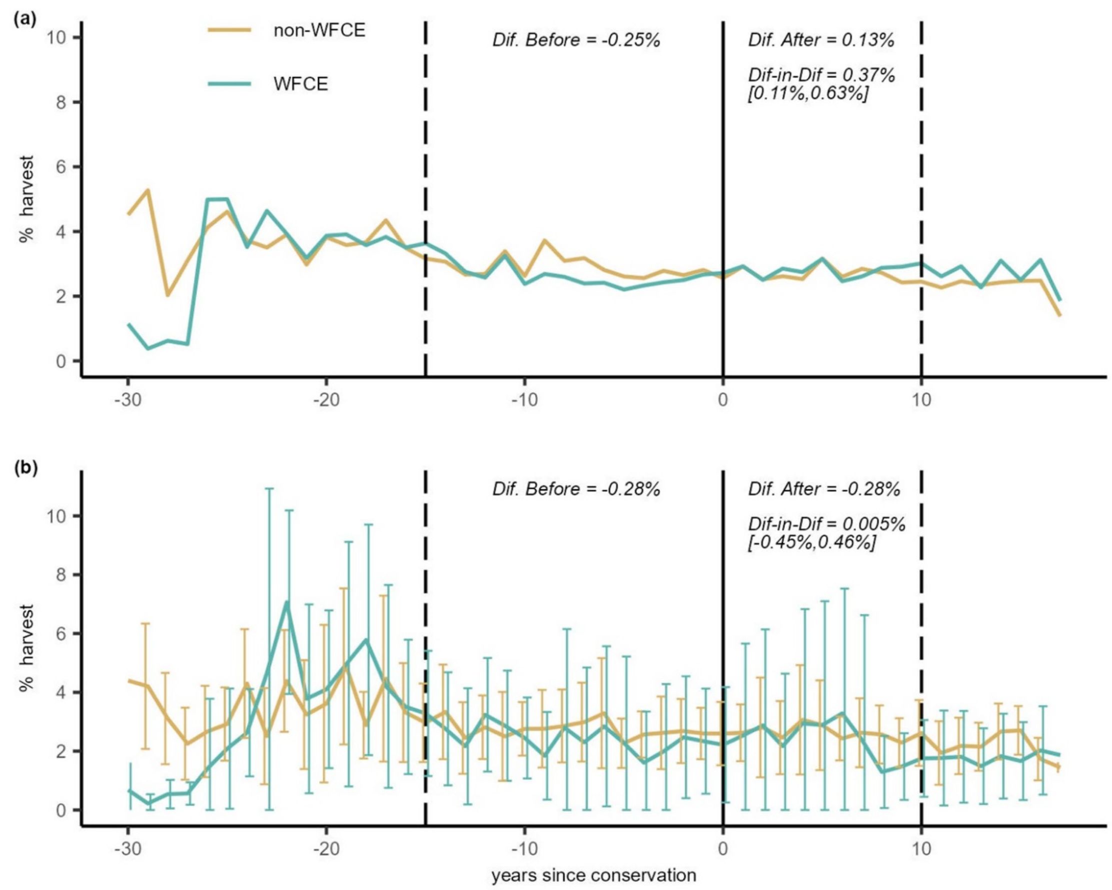

Figure 3. Annual rate of forest harvesting within 19 working forest conservation easements (WFCE; blue) and their 19 matched control areas (brown). Solid vertical line indicates the year of conservation, which has been scaled to zero for all easements. Dotted vertical lines at −15 and +10 indicate the years used to calculate the difference in difference estimates Numbers in brackets are 95% Confidence Intervals for the estimated difference in differences. (Top) Average annual percent of forest harvested calculated across all WFCE land, which effectively weights the easements by their size. $N = 168\,106$ treated and control grid cells across 33 years for each cell. (Bottom) Average annual percent forest harvest within each easement, such that each easement is one sample regardless of size. Hexagonal grid cell data aggregated to each of $N = 38$ treated and control easement units across 33 years. Error bars are standard deviations.

in Massachusetts reduced the rate of conversion to developed land, notably in a setting where development pressures were quite high. Our results and these both indicate that the near-term benefits of WFCEs and easements more generally could be improved by prioritizing new easements on lands that are at the highest threat of conversion. This accords with similar findings in the global literature highlighting the importance of targeting both voluntary conservation approaches and protected areas to high risk of loss locations (e.g. Alix-Garcia *et al* 2015, Pressey *et al* 2015).

However, economic and ecological pressures are shifting with time and the threat of forest loss in our study region may certainly increase in the future. The terms of the WFCEs are attached to the land in perpetuity, including through ownership transitions. Over the past thirty years, the major driver of forest loss in the other parts of Maine, particularly Southern Maine, has been dispersed residential construction associated with exurban development (Thompson *et al* 2017b, Schlawin *et al* 2021). In the future, these pressures for residential conversion may expand to more areas of the State. However, until now, the limited forest loss we did observe in unprotected lands close to WFCEs mainly arose from the development of energy infrastructure, e.g. powerlines, pipelines, wind, and solar. Widespread energy development was not a common concern for conservationists at the time when these easements were written. However, given that current plans to decarbonize and electrify energy sectors are expected to dramatically alter landscapes worldwide (Lovering *et al* 2022) and in Maine specifically (Merrow 2018), WFCEs may also play a previously unanticipated role in limiting forest loss as future energy development pressures grow. In addition, WFCEs may have contributed other conservation-related economic benefits through recreational and heritage use of the easement lands (Daigle *et al* 2012, Murray *et al* 2018, Sims *et al* 2019). Further understanding of these impacts are important avenues for future research.

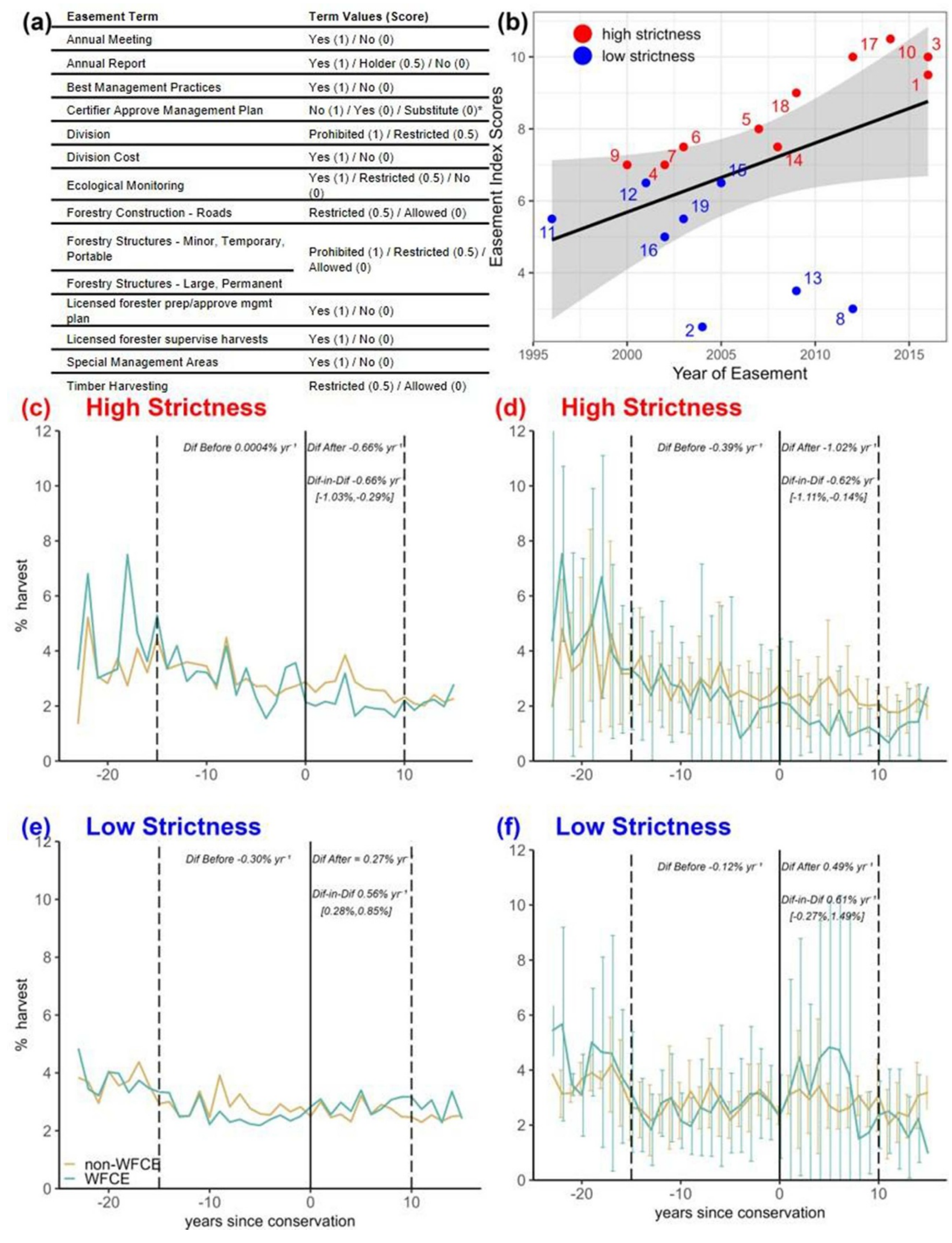

Figure 4. (A) Coding rubric for harvesting restrictions used to make the strictness index. *Substitute means that certification substitutes for a management plan, and the WFCE is not required to have a management plan if it maintains its certification status. (B) Harvest strictness index over time. Shaded area represents standard error. Match the numbers to table 1 to identify WFCEs by name. (C) Harvest rates within all easement land within the upper 50th percentile of easement strictness and matched controls. (D) Harvest rates measured per easement for the easements in the upper 50th percentile of easement strictness and matched controls (error bars = standard deviations). (E) Harvest rates within all easement land within the lower 50th percentile of easement strictness and matched controls. (F) Harvest rates measured per easement for the easements in the lower 50th percentile of easement strictness (error bars = standard deviations) and matched controls. Numbers in brackets are 95% Confidence Intervals for the estimated difference in differences.

Our central finding is that the establishment of the WFCEs overall had little impact on the rate of timber harvesting. This is consistent with the stated goals of many easements to maintain harvesting, but disappointing given that rates of harvest on industrial owned land in the region are understood to be ecologically degrading the forests (e.g. Barton *et al* 2012, Duveneck and Thompson 2019, Gunn et al 2019). WFCEs do, in concept, have the potential to improve forest management practices to benefit wildlife habitat and ecosystem services, including biodiversity (L'Roe and Rissman 2017). It may be possible that the WFCEs in our study meaningfully changed forestry practices to benefit biodiversity or other ecological outcomes, e.g. by not harvesting in sensitive areas or increasing erosion controls, even if they did not alter the overall rate of harvesting. There is some prior evidence to support this—e.g. Zhao et al (2020) report larger average harvested tree size within private protected land in Maine (but not explicitly WFCEs), suggesting landowners may have longer harvest rotation periods in protected forests. Unfortunately, nuanced changes in practices cannot be measured comprehensively over time to match our study period and design. Past work that reviewed the provisions to conserve biodiversity within six large WFCEs in Maine and New York concluded that they lacked the biological surveys, management plans, and explicit performance standards that would be needed to conserve existing biodiversity (Jenkins 2008).

Our analysis of specific easement restrictions indicates that the restrictions of harvest practices within the WFCEs have increased over time and that stricter easements reduced the rate of harvesting. These new WFCEs demonstrate potential approaches to better respond to threats from unsustainable and/or damaging harvesting. For example, the 2016 Apple Easement in Reed Plantation, Maine, includes explicit restrictions to maintain sustainable harvest volumes and practices and includes protections on water quality and fish and wildlife habitat as well as endowed funds for easement monitoring. Perschel (2006) provides case studies on two of the largest WFCEs in this analysis focused on how easement terms can support sustainable forestry.

How should conservationists interpret these findings? As scarce conservation dollars and tax incentives are used to place WFCEs on industrial forestlands and as conservation organizations tout the land as 'protected', many might reasonably assume that the forests are protected from the land uses that threaten them most. Yet, our results suggest that in our study area of Maine, there have been misalignments between the application of funding and restrictions in the easements and the current nature of the threats to these forests to date. The threat of forest conversion in the region has been extremely low but was the primary focus of the WFCEs. Forest harvesting practices are well-documented threats and yet many of the easements included few restrictions on harvesting. We also do not find evidence that easements were needed to sustain forestry in the region given continued ongoing rates of harvest in the unprotected forests during this period. However, threats to forests are constantly changing over time and conversion pressures may be higher in the future or in other settings throughout the U.S. where WFCEs are growing. Encouragingly, we do find suggestive evidence that newer WFCEs are more likely to restrict unsustainable and damaging harvest practices. Overall, our research indicates that private philanthropy and public funding like the Forest Legacy Program—whether in Maine or elsewhere–could increase conservation benefits by requiring WFCEs to better align easement protections with the land-use practices that most threaten those lands.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://harvardforest1.fas.harvard.edu/exist/apps/datasets/showData.html?id=HF437; https://zenodo.org/records/7764284.

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