

Forest offsets partner climate change mitigation with conservation¹

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Abstract

Are forest offsets good for the climate? Are they good for other reasons? In climate change mitigation portfolios, offsets allow industries and individuals to compensate for their own greenhouse gas emissions by purchasing emissions reductions elsewhere. But offsets may detract from needed mitigation if offset programs give credits for emissions reductions that would have happened anyway. We evaluate California's forest offset program, the first-ever legally enforceable 'compliance' offset program for existing forests, to determine (1) if projects provide *additional* emissions reductions that would not have occurred without the program and (2) if projects yield other benefits. We find that California's forest offset program, as a small portion of the state's mitigation portfolio, does not inhibit overall emissions reductions. Further, the program advances stringent 'additionality' of emissions reductions through multiple mechanisms. Finally, mitigation through forest offsets can yield a suite of important conservation co-benefits. Lessons from California's experience with forest offsets can inform offset programs increasingly under development around the world.

Introduction

Forest offsets have been used since the 1980s for voluntary climate change mitigation (Trexler *et al.* 1989; Brown and Adger 1994). They work by selling forest carbon sequestration to offset the greenhouse gas (GHG) emissions of individuals and industries. Because forest offsets function by sequestering carbon in trees, they may provide a unique opportunity for climate change mitigation alongside co-benefits like conservation and sustainable forest management. Mitigation through forest offsets has been controversial for multiple reasons (Trexler and Kosloff 2006; Mason and Plantinga 2013). First, they allow offset purchasers to avoid reducing their own emissions (Kintisch 2008). Second, the 'additionality' of their credited emissions reductions is difficult to assess — that is, whether forest offset programs stimulate additional emissions reductions or instead credit emissions reductions that would have happened anyway (Gillenwater *et al.* 2007; Wara and Victor 2008). Forest offsets are commonly described as providing 'emissions reductions,' and we follow that convention here. More accurately, a forest offset achieves a net reduction by increasing a sink.

To support design, deployment, and refinement of forest offset programs within mitigation portfolios, we evaluate the first-ever legally enforceable offset program for existing forests. (The Clean Development Mechanism under the Kyoto Protocol provided a compliance offset market that included reforestation and afforestation projects but specifically excluded projects related to existing forests (Paulsson 2009).) Our analysis explores two fundamental questions: (1)

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Additionality—Can forest offsets effectively contribute to climate change mitigation? And (2) Co-benefits—Do they provide further co-benefits for other objectives? Our particular focus is California's compliance-based forest offset program for climate change mitigation. Through multifaceted climate policy, including offsets, California aims to reduce its GHG emissions to 1990 levels by 2020, and 40% below 1990 levels by 2030 (State of California 2006, 2016) (Figure 1; WebPanel 1).

We analyze the mitigation benefits and the co-benefits of California's forest offset program based on the structure of the program, the features of the areas protected, and the characteristics of project participants.

Methods

We reviewed all public project documents in California's forest offset program, including project registry filings for project design, verification, submittal, and attestation (Climate Action Reserve 2016; Winrock International 2016). From each, collected data included required reporting of project area, year initiated, carbon stock, etc. Additionally, collected data reflected non-required, voluntarily reported information provided in thorough documentation for most projects (WebPanel 2; WebTables 1-2). A search for projects that applied for program participation but failed to meet its acceptance requirements yielded insufficient data for analysis.

We organized a database of the collected and classified data, creating a comprehensive, and where possible quantitative, characterization of California's forest offset projects. For quantitative data, ranges and averages were calculated and reported in terms of project area or metric tons of CO₂ equivalent (tCO₂e) (WebTables 1-3). Determination of project additionality considered ownership, risk rating, forest inventory, and logging data. For project co-benefits, the basis for analysis was voluntarily reported information in design documents, verification reports, submittal forms, and data reports. References to any type of project co-benefit were grouped into several categories: water, recreation, flora and fauna, and sustainable forest management, with subcategories of endangered species, hunting, and conservation easements.

The forest offset protocol for California recognizes 17 different potential carbon reservoirs in forests. Only some of these reservoirs are included in carbon measurement and crediting. Reservoirs included for crediting are standing live carbon (above and below ground), standing dead carbon, soil carbon (only as a source), carbon in in-use forest products, and forest product carbon in landfills. In addition, several emissions sources are accounted for: leakage (discussed in greater detail below), biological emissions from decomposition of forest products, and biological emissions from site preparation activities (indirectly measured) (WebTable 4). These reservoirs are not disaggregated in our database, but the primary pool in the aggregated data is standing live carbon.

Results

The current forest offset credits are distributed among 39 forest offset projects that have been operating for an average of 7 years. Projects, located over much of the contiguous US, have an average size of 9,000 hectares. On average, each project has been credited 650,000 tCO₂e over its life to date (WebTables 2-3). Not weighting for project area, per-project average credits

are 96 tCO₂e/ha for the first year of project operations, and 27 tCO₂e/ha for the second. For projects that report credits for years seven through ten, the value drops to 21 tCO₂e/ha. Credits in the first year are earned based on existing forest carbon stock above the calculated project baseline stock, and credits in the second and subsequent years are earned based on forest growth and changed management practices (WebFigure 1). Weighted for project area, the average first-year credit is 49 tCO₂e/ha, reflecting the fact that the projects with the highest initial stocks are relatively small.

Offset projects are credited in the California market, but forests may be located anywhere in the contiguous US (Figure 2), and more recently in a portion of Alaska as well. 16 of the 39 credited projects are located in California. California projects account for 20% of the land area under project management, but 40% of total offset credits. The national distribution of projects generally matches the distribution of private forest land in the US, with notable exceptions of Oregon (no projects) and Washington (1 project). Sustainable forest management rules mandated by the offset protocol are stringent and may reduce the fraction of projects in regions with less stringent sustainable forest management rules.

1) Are forest offsets good for the climate?

There are two prominent concerns about using offsets for mitigation: First, they can operate like the purchase of indulgences, decreasing the incentive for internal emissions reductions from industries, individuals, and sectors in outsourcing responsibility to offset providers. Second, they may credit emissions reductions that would have occurred even without the offset program. We examine these concerns to determine if forest offsets can be beneficial for intensive climate change mitigation.

For the first concern, California's forest offsets are unlikely to detract from overall emissions reductions because the forest offsets occupy a small fraction of California's cap-and-trade market by design. Currently, forest offset credits account for 2% of credits in the California cap-and-trade system, and the total use of offsets is limited to 8% (California Air Resources Board 2012, 2016). As a result, regulated entities must substantially reduce their own emissions even if they purchase and use offsets (EDF 2012). Although their total use is constrained, offsets could still act as indulgences if overused in the early stages of the program. In particular, forest offsets' small fraction of the overall cap-and-trade market could represent, at its upper limit, a large share of the emissions reductions required by 2020. If the program approaches the 8% maximum, reassessment of the magnitude of impacts would be appropriate to assess whether offset credits have too great an impact on other emissions reductions.

For the second concern, multiple evidence lines suggest that California's forest offset projects result in additional emissions reductions, beyond reductions that would have occurred in the absence of the program. To achieve 'additionality' of forest-offset emissions reductions, the program must change existing practices, such as decreasing logging. To evaluate the additionality of California's forest offset emissions reductions, we test two additionality hypotheses and analyze five metrics California uses to ensure project robustness. Our concern here is additionality of the overall program, rather than strict additionality of each ton in the program. At the program level, some projects may be under-credited because of strict project discounting, and others may be over-credited by having non-additional credits. But with all projects evaluated by the same protocol, and the overall program should achieve program level additionality (Bento *et al.* 2016).

Forest owner hypothesis. We hypothesize that forest ownership may be indicative of an offset project's additionality. For example, conservation non-profits are likely to be uninterested in logging their forest for profit, and their management practices may already sequester forest carbon. Initiating forest offset projects may therefore be easier for conservation non-profits, but have a lower likelihood of emissions-reductions additionality. We found that projects have been initiated by diverse actors: individuals, companies, investment firms, and tribes (Figure 3A; WebFigure 2). Relatively few projects (25%, representing 12% of credited forest offset emissions reductions) are held by conservation non-profits, so the forest owner hypothesis points to overall program additionality.

Active logging hypothesis. We also hypothesize that active logging can be used to assess additionality in improved forest management (IFM) projects. That is, if a forest offset project were actively logging at or prior to project inception, the program would be more likely to induce altered practices leading to additional forest carbon sequestration. By contrast, projects not actively logging would be easier for forest owners to implement. Areas without active logging would not require major adjustments to their forest management to join the offset program, but associated emissions reductions would also be less likely to be additional. We found that most IFM projects are actively logging at or prior to project inception (n=21; 64%), so the active logging hypothesis points to overall program additionality.

Risk metrics. We further assess the suite of metrics California developed to ensure that forest offset credits are robust. The California program includes three types of formal risk discounting that reduce the forest owner's credited carbon. First, reversal risk is based on an estimated calculation of the likelihood of, for example, major fire or disease releasing the carbon. California mandates that a percentage of credits equal to the reversal risk estimation be surrendered by the forest owner and placed in a state-held 'buffer pool'. The buffer pool is held in reserve and designated to replace any credits that are lost to natural disturbance such as wildfire or beetle outbreak. Cooley *et al.* (2012) recommend the buffer pool approach for dealing with reversal risk in forest offset projects. Second, a confidence deduction is based on sampling error from field measurements. Third, leakage is estimated at 20% of the difference between estimated baseline harvest and actual harvest. Together, these measures reduce credited offset carbon by about 20% on average and help provide assurance that the remaining credited carbon is robustly accounted (Figure 3B).

Feasibility tests. In addition to formal risk accounting, the California forest offset program requires financial and legal feasibility tests to demonstrate project additionality. The financial test requires that the calculated logging baseline against which IFM projects are credited would have been financially feasible. IFM projects must demonstrate financial feasibility of the baseline either by modeling net present value (NPV) of logging or by showing that similar logging has occurred on properties in the general project vicinity. For IFM projects that modeled NPV of logging to establish financial feasibility (n=6), values range from \$1,042 – \$4,273/ha over 100 years. Additional projects used modeling to establish financial feasibility but excluded these data from public reports. The legal feasibility test requires that projects discount carbon that is already legally protected. Legal exclusions primarily cover pre-existing conservation easements, endangered species activity centers, and stream management zones (WebPanel 3).

2) Are forest offsets good for other reasons?

Our analysis points to significant non-climate co-benefits from forest offset projects. Co-benefits matter because the offset program provides new opportunities for conservation and sustainable forest management. All current offset projects are privately rather than publicly owned, and most participating forest owners (n=26; 66%) are timber companies or investment landowners, who do not traditionally seek strong conservation co-benefits. In this way, forest offset projects may change the traditional conservation paradigm. Usually, conservation-oriented land owners have managed land primarily for conservation, and they have achieved sustainable forest management and carbon sequestration as co-benefits. In the California program, by contrast, forest-offset land owners adjust land management for carbon and, in turn, achieve sustainable forest management and conservation as co-benefits. This inversion and recognition of multiple motivations provides an alternative pathway for conservation and sustainable forest management enabled by climate mitigation.

More than carbon. Based on voluntarily reported data, forest offset projects can efficiently provide carbon, sustainable forest management, and conservation benefits together in one program. Through the forest offset program, more than 349,000 hectares of forest land are under sustainable forest management and guaranteed to remain so for at least 100 years of monitoring. As a conservation example, there are 17 projects and 57,000 hectares containing activity centers for endangered species, and improved forest management on forest surrounding these activity centers creates opportunities for additional endangered species protection (Figure 4A). Compared to other emissions reductions and non-forest offset projects (e.g., for livestock and ozone-depleting substances) under the cap-and-trade program, forest offsets provide not only emissions reductions, but also sustainable forest management and conservation co-benefits. Of course, in comparing across alternative mitigation approaches, the co-benefits of each should be part of any evaluation (Cushing *et al.* 2016).

Measured conservation co-benefits. Most forest owners voluntarily reported on some kind of co-benefit (n=36; 92%). This included 31 (79%) reporting on water quality, 26 (66%) reporting on recreation, and 34 (87%) reporting on flora and fauna generally (Figure 4B). 15 (38%) projects voluntarily reported on hunting opportunities. In addition, 26 (66%) projects have conservation easements intended to protect the forest land in perpetuity. Several projects voluntarily provide evidence of avoiding forest parcelization and conversion. Since these data are based on voluntary project reporting, and project owners have no incentive to report in this area, it is likely, though not certain, that actual figures are higher.

Discussion

From our analysis, multiple themes emerge toward enhancing forest offset programs in the future. First, explicit, not just voluntary accounting of project co-benefits would enable more rigorous and holistic understanding of the gains from mitigation investments. For example, all forest offset projects in California's program may yield water co-benefits; however, we can conclude only that at least 80% of projects reported water co-benefits because other projects did not voluntarily report on this metric. These self-reporting gaps are found across all co-benefit types. Explicit accounting for co-benefits could take a basic approach to start, such as consistently listing existing qualitative information about co-benefits or reporting on project areas with particular co-benefits.

Second, specifically including climate change risks in the forest offset protocol may increase the robustness of forest offset programs. California's forest offset protocol does not offer guidance on accounting for climate change impacts such as changing forest fire regimes, precipitation, or disease outbreaks. (The protocol does include a provision for planting non-native tree species where appropriate for climate change adaptation.) Climate change will impact US forests (Dale *et al.* 2001; Asner *et al.* 2015; Abatzoglou and Williams 2016), potentially compromising both mitigation and co-benefits, especially given the minimum 100-year project duration. Yet no projects voluntarily report on climate change impacts in their project documentation. Internalizing climate change in the protocol could ensure more secure project benefits that appropriately account for climate change risks.

Four particularly effective components of California's forest offset program can provide useful examples for programs elsewhere, such as those under development in Quebec, Ontario, and China (Yin 2013; Quebec 2015). First, California's program requires a minimum 100-year project commitment, which enhances the climate benefits and co-benefits of its projects. Projects must participate in 100 years of monitoring and maintaining forest carbon stocks after the last year in which they receive credits (up to 25 years of crediting without project renewal) (California Air Resources Board 2015). The 100-year time horizon provides confidence that the offsets credited are real emissions reductions that will be held for 100 years. Further, 22 projects initiated a forest offset project simultaneously with a conservation easement intended to last in perpetuity. Simultaneously initiating a forest offset project and a conservation easement may make both outcomes more feasible, as revealed by the frequency of such pairing. California's program may be thereby tapping and enabling long-lived synergies between climate change mitigation and conservation co-benefits.

Second, IFM projects may have a structural comparative advantage in producing climate benefits, especially as implemented in the California protocol, compared to Avoided Conversion (AC) and reforestation. In California's program, IFM projects are by far the most common project type in use (84% of projects). Compared to AC ($n=6$) and reforestation ($n=0$), IFM projects often provide substantial carbon credits in the first year of enrollment, given avoided forest loss (WebFigure 1). This first-year effect is followed by a small stream of credits from tree growth in subsequent years. That is, IFM projects receive, in the first year, credit for existing forest biomass above a modeled baseline based on average regional carbon storage and project-specific modeling. This front-loaded credit approach for the dominant IFM projects may enable projects that would not otherwise be financially feasible.

Third, the California program establishes a method for rigorous yet inclusive additionality. One component of this method is 'temporal additionality,' in that all projects are required to participate for at least 100 years. Several IFM projects noted high pressure to convert their forest land, with the forest offset project therefore contributing to long-term forest cover (California Air Resources Board 2015). Another facet of California's approach is its treatment of additionality criteria in light of other project benefits. California's program demonstrates strong evidence of forest-offset emissions-reductions additionality. Nonetheless, strict additionality accounting may not be the most efficient program management strategy. That is, myopic focus on strict additionality may forgo projects motivated by multiple desirable features. Projects that are the most securely additional are those that can demonstrate that there is no beneficial reason to sequester carbon apart from the offset project. In fact, forest carbon sequestration often has multiple motivations in project deployment. The California program embraces projects

with multiple motivations while using appropriate risk discounting and feasibility testing. The program thereby achieves more in total – for both climate mitigation and the range of co-benefits projects can provide. Unnecessarily strict additionality criteria may too severely discount the suite of reasons for participating in forest offsets and the co-benefits that projects can provide. In the California program, the primary outcome measure is carbon, as it should be, but California does not exclude projects that also carry strong co-benefits. Rather than focusing on strict additionality at the level of the ton of carbon or at the level of the project, California effectively focuses on overall *program* level additionality.

Fourth, calculating minimum carbon baselines in California's program relies on credible Forest Inventory and Analysis (FIA) data, a long term forest census kept by the US Forest Service (Bechtold and Patterson 2005). While the FIA program could benefit from finer-scale regional differentiation in particular, the FIA data are an understood and widely used data source for the contiguous US based on a standardized method. These data increase confidence in the program's climate benefits and additionality of emissions reductions. Forest offset projects in other jurisdictions have struggled to establish similarly reliable and standardized baselines (Bento *et al.* 2016), and the California program has benefited greatly from having long-established regional baseline data. To address this challenge in programs outside of the US, we recommend consideration of different levels of discounting for uncertainty. The California program has several mechanisms detailed above for discounting credits based on uncertainty. Similar frameworks could be developed for projects in jurisdictions without FIA-like forest census data.

Conclusion

Offsets can contribute to climate change mitigation, but they can also hinder it if they distract from necessary emissions reductions overall or decrease the feasibility of deep decarbonization. Our analysis shows that California's forest offsets account for a small percentage of emissions reductions, by design. Yet at the same time, they provide an important opportunity to supply meaningful carbon sequestration and multiple co-benefits. California's pioneering program demonstrates that forest-based offsets are feasible in a compliance market. It also offers several lessons for the future of forest-offset programs in the state and beyond. As California and eventually others set land-based mitigation goals, the lessons of forest offsets can inform mitigation on non-forest lands: project additionality can be ensured through careful risk and uncertainty accounting in measuring and monitoring land-based carbon; and potentially substantial co-benefits can be directly incorporated into project design and evaluation. While we evaluate the performance of existing forest offset projects, future research must also consider essential questions around when and how to deploy offsets within overall mitigation portfolios towards a deeply decarbonized future.

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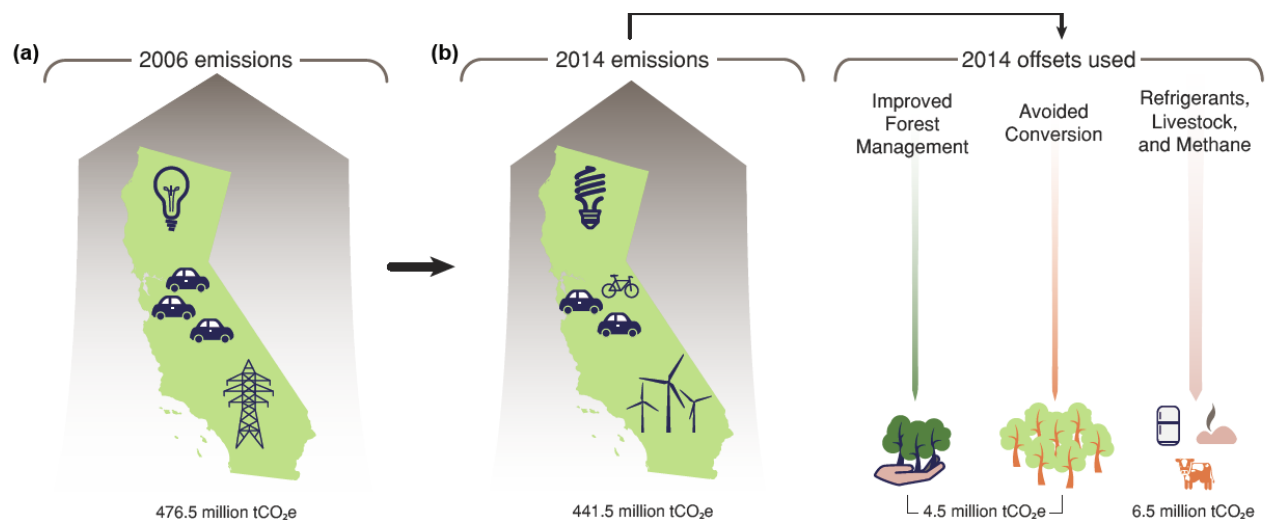
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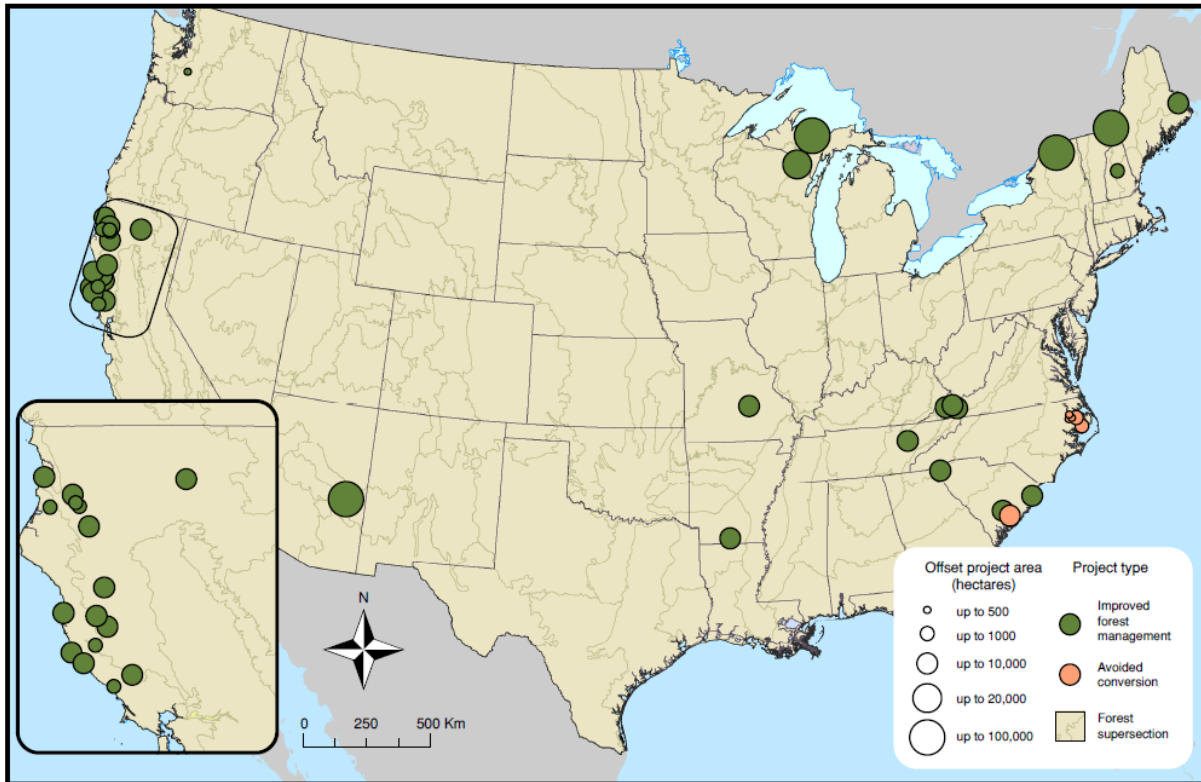
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Figures

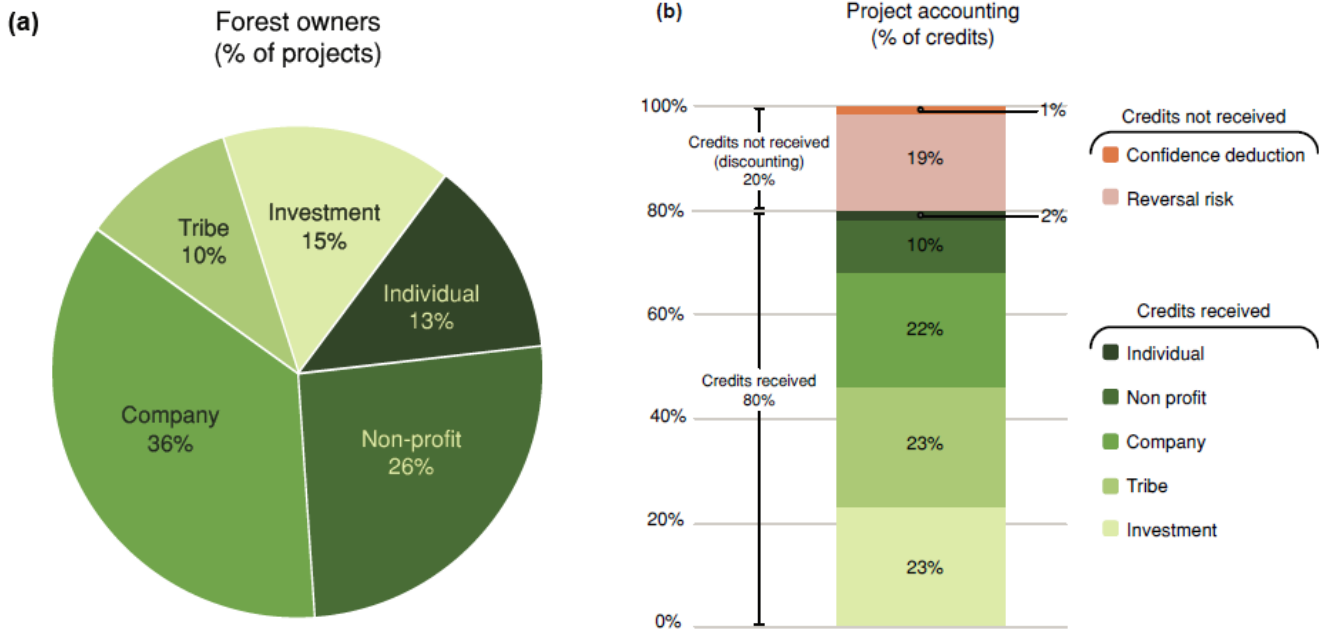
1. Forest offsets are a small but robust part of California's climate change policies. (a) California's landmark Climate Solutions Act was signed in 2006. Total GHG emissions that year were 476 million tCO₂e. (b) Total GHG emissions in 2014 were 441 million tCO₂e (most recent reporting year available). Emissions reductions occurred through the cap-and-trade market, complementary policies, and offsets. Forest offsets used in 2014 were equivalent to 1% of California's total emissions. They are not deducted from the emissions totals presented.



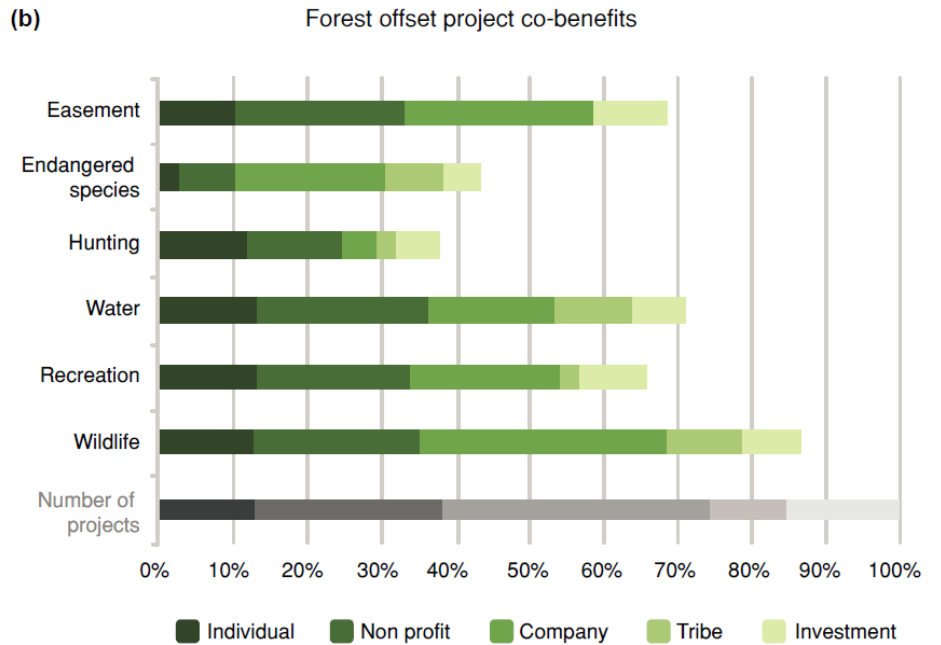
2. Forest offsets are sold in the California cap-and-trade market. But the forest projects themselves can be located anywhere in the contiguous US. There are currently 39 credited offset projects, accounting for more than 349,000 hectares of forest land in both improved forest management (green) and avoided conversion (blue) projects. Background map depicts forest SuperSection, used in calculating baseline forest carbon. Circle size corresponds to project size.



3. Evidence suggests additionality of forest offset credits. Based on several metrics, California's offset projects reduce emissions more than would have happened in absence of the program. (a) The diversity of forest owners emphasizes project additionality. (b) On average, 20% of project credits are deducted or held in reserve to ensure robustness. (Leakage data from any estimated displacement of logging is estimated to be a small and is not shown within this illustration.) In total more than 25.5 million credits have been issued over 349,000 ha of forest as of July 2016.



4. Forest offset projects can have substantial co-benefits. (a) The California program protects endangered species like the red-cockaded woodpecker. © Greg Lavaty. (b) Most projects (92%) voluntarily report that their projects include co-benefits associated with, for example, easements, endangered species, hunting, water, recreation or wildlife. All categories of co-benefits below are stand-alone—recreation is exclusive of hunting, and wildlife is exclusive of endangered species.



Web-only Materials

Supporting Information for

Forest offsets join climate change mitigation with conservation

Web Panel 1. California climate change context

The Global Warming Solutions Act, AB 32, was signed into law in California in 2006; 2016 marks the 10 year anniversary of this act (Cullenward 2014). AB32 requires the state to reach 1990 GHG levels by 2020. Subsequent legislation requires the state to reach 40% below 1990 levels by 2030 (State of California 2016). California's 1990 GHG levels, and thus the limit for 2020, are estimated at 431 million metric tons CO₂ equivalent (tCO₂eq; Rogers *et al.* 2007; California Air Resources Board 2015a). As a comparison, credited emissions reductions through forest offsets since California's program inception are approximately 23 million tCO₂eq.

The cap-and-trade market, one of the signature elements of AB32, went into effect in 2013. The cap initially covered the power and industrial sectors, and it now includes transport and natural gas as well. In total, their emissions account for 85% of California's emissions (Cullenward 2014). These capped sectors can buy offset credits to offset their emissions.

One 'credit' in the cap-and-trade system is equivalent to 1 tCO₂eq. There are various types of credits in the California system: offsets, auction, allowances, and issuances. When a credit is 'used' to meet state compliance regulations, it is referred to as 'retired'.

Although the cap-and-trade system is often framed as the main mechanism of AB 32, and the main mechanism for reducing California's GHG emissions to 1990 levels by 2020, cap-and-trade accounts for only about 20% of emissions reductions. The other 80% of emissions reductions are achieved by 'complementary policies' that require greenhouse gas emissions reductions. These 'complementary policies' include the renewable portfolio standard (1/3 renewable energy by utilities by 2020), energy efficiency standards, and transport fuels standards (Cullenward 2014).

California offset crediting process

There is multi step process for forest offset projects to be credited by California for their stored forest carbon. First, offset credits are issued by one of the three approved offset registries: Climate Action Reserve, American Carbon Registry, or Verified Carbon Standard (none are listed with VCS to date). Then, the 'registry offset credits' must be converted to 'ARB offset credits' through an application process that takes around two months. The California Air Resources Board (ARB) lists the 'ARB offset credits' in the 'Compliance Instrument Tracking System Service' (CITSS) ("Compliance Instrument Tracking System Service" 2016).

Web Panel 2. Additional information on methods

Here we define in greater detail some of the terms and concepts relevant to our methods.

Active Logging. We defined projects as actively logging if logging occurred within the project area at any time 5-7 years prior to project establishment. (In some cases years reported by forest owners were estimates.) We further reported that projects were actively logging if they were maintaining some kind of sustainable forestry certification, such as Sustainable Forestry Initiative (SFI) or Forest Stewardship Council (FSC) certification. We reported projects as not actively logging if they did not maintain any kind forestry certification. We also reported projects as not actively logging if they had no timber harvest plan (THP) or had a THP but reported that they were not using it. With this combination of criteria, we were able to classify each project as actively logging or not actively logging.

Carbon Credits. For carbon credit numbers, we relied on the link provided by ARB in their listing report of offset projects. We verified these numbers with the project documents uploaded on the registries. In case of discrepancy between the project documents and ARB, we maintained ARB crediting numbers, which were generally lower, indicating that transfer of credits from voluntary to compliance was either incomplete or had not yet occurred. For cases in which ARB was missing crediting numbers for the most recent crediting year (usually 2015), we included credit data for that year based on Project Verification Statements, again from the registry project documents.

Common Practice. Carbon stock in the initial forest offset project period is credited with respect to 'common practice', or "the average carbon stocks [tCO₂eq/acre] of the above-ground portion of standing live trees from within the forest project's assessment area, derived from FIA plots on all private lands within the defined assessment area"(California Air Resources Board 2015b). The offset protocol is updated every five years with new FIA data from the latest forest inventory (California Air Resources Board 2016). Annual reporting of on-site carbon must occur, and can rely on previous year inventory and modelling for up to 12 years, or until there is a land sale, harvest, or 'natural event' that changes on-site carbon. Every 12 years, an onsite field inventory must be re-conducted.

Early Action projects. The California offset program officially commenced crediting in 2013. However, while the state worked on the crediting methods, it provisioned for 'early action' forest offset projects dating back to January 2001 in the voluntary forest offset market to join the California program. We considered both pre-2013 and post-2013 forest offset projects in this analysis, both of which are credited under the California cap-and-trade program.

First Compliance offset program for existing forests. California has established the first compliance offset program for existing forests. 'Compliance' is used in the offset literature to refer to programs that are legally enforceable or part of a legal structure, as contrasted with 'voluntary' programs, which are conducted on a purely voluntary basis by actors who wish to voluntarily reduce GHG emissions. The Clean Development Mechanism (CDM) also included compliance forest offsets, but only for growing new forests (reforestation and afforestation offsets), not for maintaining standing forests and avoiding deforestation (improved forest management or avoided conversion offsets) (Zomer *et al.* 2008).

Forest offset project type. There are three forest offset project types: improved forest management (IFM), avoided conversion (AC), and reforestation. Reforestation projects involve reforesting deforested land. No reforestation projects have been credited in the California program to date. AC projects account for forest carbon on land that is under imminent pressure for conversion to non-forest use. All six of the credited AC projects are avoiding conversion to agriculture, primarily for corn and soy production. IFM projects, the majority of credited projects, receive credits for changing forest practices. Five categories of change in practice are eligible: 1) thinning to release growth, 2) increasing rotation age, 3) maintaining high carbon stocks, 4) improving stock on understocked areas, and 5) removing brush and short-lived species to encourage growth. Increasing rotation age and maintaining high carbon stock are the most frequently used of these five options, though projects may undertake a combination of the above approaches for forest and carbon management. Because IFM projects are the most common in use, they are the primary focus of this research.

Missing Data. Four early action projects did not have project design documents because they were not required to according to the provisions of Early Action projects. For these projects, no data were included in this analysis for several metrics including baseline and initial carbon stock. For all projects, data were collected and analyzed in July and August 2016. Any data available after that period are not included in this analysis.

Reported Data and Protocol Changes. In cases in which data changed between initial project listing and the Project Design Document or Offset Project Data Reports, the most recent data were used (for project area, for example). Most often these changes occurred when the forest inventory had not been completed at the time of project listing, or changes were needed after listing because of errors in methods. For discussion of protocol details, we use the most recent version of the Forest Offset Protocol (2015). Each offset project is bound to the version of the protocol in effect at the time of project inception.

Sustainable Forest Management. Sustainable Forest Management is a broad concept that refers to management of forests that is sustainable and that balances economic, ecological, and social needs. The forest offset protocol does not explicitly define sustainable forest management, so the definition from the Food and Agriculture Organization (FAO) is used here: "Sustainable forest management addresses forest degradation and deforestation while increasing direct benefits to people and the environment. At the social level, sustainable forest management contributes to livelihoods, income generation and employment. At the environmental level, it contributes to important services such as carbon sequestration and water, soil and biodiversity conservation." (FAO 2016)

Web Table 1. Description of data sources

The following is a list of the project documents reviewed for this analysis.

Document name	Description
Project design document	Quantitative and descriptive review of project plan
Verification reports	Annual third party verification report of crediting
Submittal form	Initial project planning submission for registry listing
Annual offset project data reports	Annual crediting and risk reporting
Addenda	Further design documents, modeling data, etc.
Project boundaries	Spatial data on project extent
Attestations of title	Verification of land title
Attestations of voluntary implementation	Verification of voluntary implementation, together with project documents
Attestations of Regulatory Compliance	Verification of regulatory compliance

Web Table 2. Data collected

Data	Description of possible entries (Range)	Number of projects reporting
ARB project ID	#	39
Project name	Name	39
Type of protocol	Early Action; Compliance	39
Offset Project Operator (OPO)	Individual/Company name	39
Registry used	American Carbon Registry; Climate Action Reserve; Verified Carbon Standard	39
City	Name	39
County	Name	39
State	Name (excluding Hawaii, Alaska)	39
Area	Acres (282 – 234 001)	39
Commencement date	Date (5/31/2001 – 1/17/2014)	39
Listing date	Date (7/1/2005 – 10/1/2014)	39
Registered date	Date (12/23/2008 – 10/22/2015)	32
Crediting period expiration date	Date (5/31/2101 – 12/22/2103)	39
Number of years to date	# (2.5 – 15)	39
Authorized project designee (APD)	Individual/Company authorized to manage/None	39
Project type	IFM; avoided conversion; reforestation	39
Easement	Y/N	39
Protocol version	Early Action; 3.1; 3.2	39
Project design document authorship	Individual/Company	39
Carbon pools included	IFM 1-17; AC 1-17	35
Total offsets credited	# (46 875 – 4 451 645)	39
Offsets credited annually through 2015	# (0 – 4 451 645)	39
Initial carbon stock	# tCO ₂ eq/acre (15.6 – 232)	36
Estimated baseline stock	# tCO ₂ eq/acre/100 years (50.34 – 165.7) (NA for AC projects)	30
Common practice stock	# tCO ₂ eq/acre (50.23 – 176.16) (NA for AC projects)	30
Minimum baseline	# tCO ₂ eq/acre (50.36 – 165)	23
Final baseline (above ground and below ground biomass and standing dead)	# tCO ₂ eq/acre/100 yrs (61.65 – 153.99)	12
Actual onsite carbon stocks (above ground and below ground biomass and standing dead)	# tCO ₂ eq/acre (70.53 – 567) (including soil carbon for AC projects)	20
Estimated 25 year stock (as available)	# tCO ₂ eq/acre (137 – 617)	9

Estimated 100 year stock (as available)	# tCO ₂ eq/acre (173 – 836)	9
Logging NPV (as available)	\$/acre/100 yrs (\$422 – \$1,730)	6
Project reversal risk rating / Buffer pool contribution	% (12.37 – 20.94)	35
Confidence deduction	% (0 – 6.2)	36
Owner of multiple offset projects	Y/N	39
Forest ownership	Company, investor, individual, tribe, non-profit	
Type of land ownership	Public; private	39
Verifier	Company (Rainforest Alliance; Det Norske Veritas; Environmental Services; SCS Global Services; Ruby Canyon Engineering & Foresters)	39
Active logging	Y/N	39
Certification	Sustainable Forestry Initiative; Forest Stewardship Council; Tree Farm; None	39
SuperSection	Name (see Web Table 2)	39
Assessment area	Name	39
Measurement and modeling inventory method	Forest Vegetation Simulator; FORESEE / CRYPTOS; Forest Projection and Planning System Software	39
IFM method	thinning to release growth; increasing rotation age; maintaining high carbon stocks; improving stock on understocked areas; removing brush and short-lived species to encourage growth (NA for AC projects)	39
Flora & fauna	Reported/No Report	39
Recreation	Reported/No Report	39
Water	Reported/No Report	39
Hunting	Reported/No Report	39
Endangered species	Reported/No Report; species name	39
Legal exclusions	name	39

Web Table 3. US forest SuperSections with number of forest offset projects

SuperSections are FIA forest types that are used in establishing the ‘common practice’ baseline for forest offset projects (US Forest Service). SuperSection boundaries are shown in the map in Figure 2.

SuperSection	Number of Projects	Forest offset project (ha)	SuperSection area (ha)
Adirondacks & Green Mountains	2	42,508	1,718,823
Allegheny & North Cumberland Mountains	4	9,860	6,884,453
Aroostook Hills and Lowlands			1,007,620
Atlantic Coastal Plain & Flatwoods	7	9,251	8,236,788
Bitterroot Mountains			2,492,673
Blue Mountains			3,987,443
Blue Ridge Mountains			4,462,538
Booneville Basin			7,268,269
California Central Valley Basin			749,425
Catskill Mountains			938,446
Central California Coast			1,330,618
Central Great Plains			9,347,207
Central Interior Broadleaf Forest Central Till			4,360,372
Central Interior Broadleaf Forest Eastern Low			3,182,337
Central Interior Broadleaf Forest Ozark Highlands	1	1,611	12,300,517
Central Interior Broadleaf Forest Western Low			1,414,912
Central Maine & Fundy Coast & Ebyment			619,802
Central New Mexico			1,001,137
Chihuahuan Semi-Desert			16,987,326
Colorado Plateau			7,914,125
Colorado River Canyon Lands			5,147,608
Columbia Basin			6,976,892
Cross Timbers and Prairie			8,414,562
Eastern Broadleaf Forest Cumberland Plateau			1,804,817
Eastern Cascades			2,534,455
Eastern Great Plains			5,503,420
Erie & Ontario Lake Plain			2,676,005
Florida Coastal Plains Central Highlands			2,514,017
Florida Everglades			2,140,643
Great Divide Basin			3,951,408
Great Plains			4,386,831
Gulf Coastal Plain			11,086,115

Idaho Batholith			4,658,560
Laurentian Mixed Forest Arrowhead			2,473,989
Laurentian Mixed Forest Green Bay Lobe			2,026,452
Laurentian Mixed Forest MN & Ontario Lake Plain			2,147,645
Laurentian Mixed Forest NLP/EUP	1	94,697	1,829,856
Laurentian Mixed Forest Northern Highlands	1	11,528	2,956,533
Laurentian Mixed Forest Southern Superior			549,306
Laurentian Mixed Forest Western Superior & Lake			2,072,738
Lower New England - Northern Appalachia			1,276,652
Maine - New Brunswick Foothills and Lowlands	1	7,737	1,314,815
Modoc Plateau			2,329,585
Montana Rocky Mountains			2,181,069
MS River Delta			5,818,994
MS River Mixed Forest			6,765,593
MW Broadleaf Forest Central Till Plains			7,472,529
MW Broadleaf Forest Driftless & Morainal			1,175,415
MW Broadleaf Forest Great Lakes Morainal & Sands			878,110
MW Broadleaf Forest SC Great Lakes & Lake Whittles			6,031,732
Nevada Mountains			5,524,993
North Central Great Plains			6,514,880
Northern Allegheny Plateau			1,866,457
Northern Atlantic Coastal Plain	1	934	1,979,516
Northern California Coast	6	25,437	1,637,663
Northern Great Plains			4,167,303
Northern Rocky Mountains			2,188,298
Northwest Cascades	1	210	2,879,334
Northwestern Basin and Range			7,073,888
Okanogan Highland			3,074,050
Oregon and Washington Coast			4,211,732
Ozark Broadleaf Forest-Meadow Boston Mountains			1,692,745
Prairie Parkland Central Till Plains & Grand			16,851,792
Prairie Parkland North Central Plains			12,845,924
Prairie Parkland Red River Valley			3,476,094
Puget Trough			1,714,683
SE Middle Mixed Forest Arkansas Valley			2,506,937
SE Middle Mixed Forest Cumberland Plateau & Valley			2,347,945

SE Middle Mixed Forest Piedmont	1	1,465	8,496,727
SE Middle Mixed Forest Western Mid Coastal Plains	1	6,398	9,142,471
Sierra Nevada			5,253,054
Sierra Nevada Foothills			1,819,132
Snake River Basin			5,578,097
Southern Allegheny Plateau			8,349,542
Southern California Coast			1,417,103
Southern California Mountains			2,754,831
Southern Cascades	10	44,254	1,848,397
Southern Rockies Front Range			5,490,948
Southern Rocky Mountains			1,382,942
Southwest High Plains			10,652,360
Southwest Plateau			5,778,900
Southwestern Desert			13,457,163
Southwestern Rocky Mountains			2,411,056
St Lawrence & Mohawk Valley			1,454,818
Subtropical Prairie Parkland Gulf & Oak Prairie			3,516,802
Tonto Transition			3,059,199
Utah Mountains			2,112,019
Wasatch Range			598,287
Western Allegheny Plateau			3,063,108
Western Basin and Range			2,091,842
Western Great Plains			1,842,929
White Mountains	1	57,086	4,220,741
White Mountains - San Francisco Peaks - Mongollon	1	36,342	5,451,848
Willamette Valley			1,488,422
Yellowstone / Bighorn			3,566,631

*For projects in more than one SuperSection, the entire project was classified with the SuperSection in which its largest percentage of forest resides.

Web Table 4. US forest offset protocol carbon pools and sources*

Protocol Name	Carbon Pool/Source	Notes
Included Pools/Sources		
IFM-1; AC-1	Standing live tree carbon (above and below ground)	
IFM-3; AC-3	Standing dead tree carbon	
IFM-6; AC-6	Soil carbon	Only included as a source where there is major disturbance for site preparation in IFM projects. No crediting of increased soil carbon.
IFM-7; AC-7	Carbon in in-use forest products	
IFM-8; AC-8	Forest product carbon in landfills	Only included when project harvesting is below baseline
IFM-9; AC-9	Biological emissions from site preparation activities	Only included indirectly as measured by changes in the above pools
IFM-14; AC-14	Biological emissions/removals from changes in harvesting on forestland outside the project area	Estimated with leakage factor
IFM-17; AC-17	Biological emissions from decomposition of forest products	Calculated as a function of IFM-7 & IFM-8. Only CO ₂ included, not CH ₄ or N ₂ O; Secondary effect source
Excluded Pools/Sources		
IFM-2; AC-2	Shrubs and herbaceous understory carbon	
IFM-4; AC-4	Lying dead wood carbon	
IFM-5; AC-5	Litter and duff carbon	
IFM-10; AC-10	Mobile combustions from site preparation activities	Secondary effect source

IFM-11; AC-11	Mobile combustion from ongoing project operation & maintenance	Secondary effect source
IFM-12; AC-12	Stationary combustion from ongoing project operation & maintenance	Secondary effect source
IFM-13; AC-13	Biological emissions from clearing of forestland outside the project area	Secondary effect source
IFM-15; AC-15	Combustion emissions from production, transport, and disposal of forest products	Secondary effect source
IFM-16; AC-16	Combustion emissions from production, transport and disposal of alternative materials to forest products	Secondary effect source

*Adapted from California Air Resources Board. 2015a. Compliance Offset Protocol U.S. Forest Projects. Sacramento, CA, pp. 40-42 & 43-46.

Web Panel 3: Additionality and risk metric definitions

As relevant to our methods of analysis, here we provide definitions in greater detail for terms and concepts related to additionality and risk in the forest offset program.

According to the additionality definition used by the California Forest Offset Protocol, offset projects must pass a performance standard evaluation, legal requirement test, and financial test (a subsection of the performance standard evaluation) to be considered additional and eligible for participation.

Performance standard evaluation. The performance standard evaluation requires that, “Emissions reductions or removals enhancements achieved by a forest project must exceed those likely to occur in a conservative business-as-usual scenario” (California Air Resources Board 2015b). IFM projects automatically meet the performance test by modeling their baseline forest carbon. AC projects meet the performance test by obtaining an appraisal of their forest land showing that the land would be more valuable under agricultural use than under forest use.

Financial test. As a component of the performance standard evaluation, projects must demonstrate the financial feasibility of the business-as-usual scenario. As mentioned above, AC projects demonstrate financial feasibility with an appraisal showing their land to be of higher value as agricultural rather than forest land. For the avoided conversion projects (n=4) that publicly reported this information, appraisals found that the forest land was valued on average at \$400 per acre versus \$1,400 per acre for using the same land for agriculture.

For IFM projects, the baseline harvest model against which projects are credited must be economically feasible. As of the most recent protocol, to demonstrate that the modeled baseline is economically feasible, each project either must provide evidence that similar harvest programs have taken place on three similar nearby properties in the past 15 years, or must construct a financial model to calculate the net present value of logging (California Air Resources Board 2015b). Both methods have been used by project operators in the California program. For the IFM projects that modeled and publicly reported on NPV of logging for the baseline scenario (n=6), values range from \$422/acre to \$1,730/acre.

Legal requirement test. The legal test requires that all forest that is already legally protected be excluded from offset project crediting. The primary legal restrictions for California-based properties include the Z’Berg-Nejedly Forest Practice Act of 1973, which is a law that covers use of timberland in CA; the California Forest Practice Rules, which are the regulatory features of the above mentioned Act; the California Timberland Productivity Act of 1982, which protects timberland to remain as timberland rather than be used for development; the California Environmental Quality Act (CEQA), which is the state-level equivalent of the National Environmental Policy Act (NEPA); the Porter-Cologne Water Quality Control Act, which is the state-level equivalent of the Clean Water Act; the US Clean Water Act, which regulates clean water; the California Endangered Species Act, which is the state-level equivalent of the Endangered Species Act; and the US Endangered Species Act (1973) itself (Clark 2010).

One of the most common legal constraints for projects registered in Northern California is Northern Spotted Owl Activity Centers. The Northern Spotted Owl (NSO) is protected by the Endangered Species Act, and identified NSO activity centers require no harvest in a 100 acre protected area around the activity center. In addition, NSO activity centers are protected by a secondary buffer of 0.7 mile radius. In this secondary area 2/3 of basal area must be retained, along with 100 acres of nesting habitat and 100-200 acres of foraging habitat (Gaman 2013). Another endangered bird, the Marbled Murrelet has habitat in many of the registered California projects; its protection plan is limited to preserving its single nesting tree. The most common endangered species found on project lands outside of California is the red-cockaded woodpecker, whose management plan also requires protection of the single nesting tree, along with restrictions on road building and herbicides in the surrounding area.

As noted in our paper, there are three primary metrics used to discount project credits: reversal risk, confidence deduction, and leakage. We define them in further detail here.

Reversal risk. The reversal risk is estimated based on a calculation of the likelihood of occurrence of various reversals for each project. The potential reversals included in calculation are financial failure, illegal forest biomass removal, conversion, over harvesting, social risk, wildfire, disease/insect outbreak, and other catastrophic events. The credits discounted by reversal risk average about 19% of project credits, and these credits are reserved in a 'forest buffer pool' which is held by the state as a form of insurance in case of project reversal. If project reversal occurs *unintentionally*, by a lightning-strike forest fire, for example, then credits are removed/retired from the forest buffer pool to account for the loss of carbon. Using a buffer pool to deal with reversal risk is the most common approach taken and is recommended in the academic literature (Cooley *et al.* 2012)

In cases of *intentional* project reversal (loss of forest carbon greater than planned in harvest planning), project owners must pay back the credits lost and in addition must pay a 'compensation rate' graduated according to the length of time the credits were held (California Air Resources Board 2015b).

One major concern with offset projects in the US and in California in particular is that maximizing carbon stock may also maximize the risk of unintentionally caused forest fire. The reversal risk metric takes a first step in addressing this concern. For forest offsets in other locations, this may not be a large issue. In the Amazon, for example, forest fires are predominantly only human-caused fires from clearing (Tollefson 2016).

Confidence deduction. The confidence deduction is calculated based on the sampling error from the forest offset project's forest inventory. If the error is greater than 5%, the project must deduct credits on a graduating percentage scale. If the error is great than 10%, then all of the credits are invalidated (California Air Resources Board 2015b). The average confidence deduction amounts to 1% of total project credits.

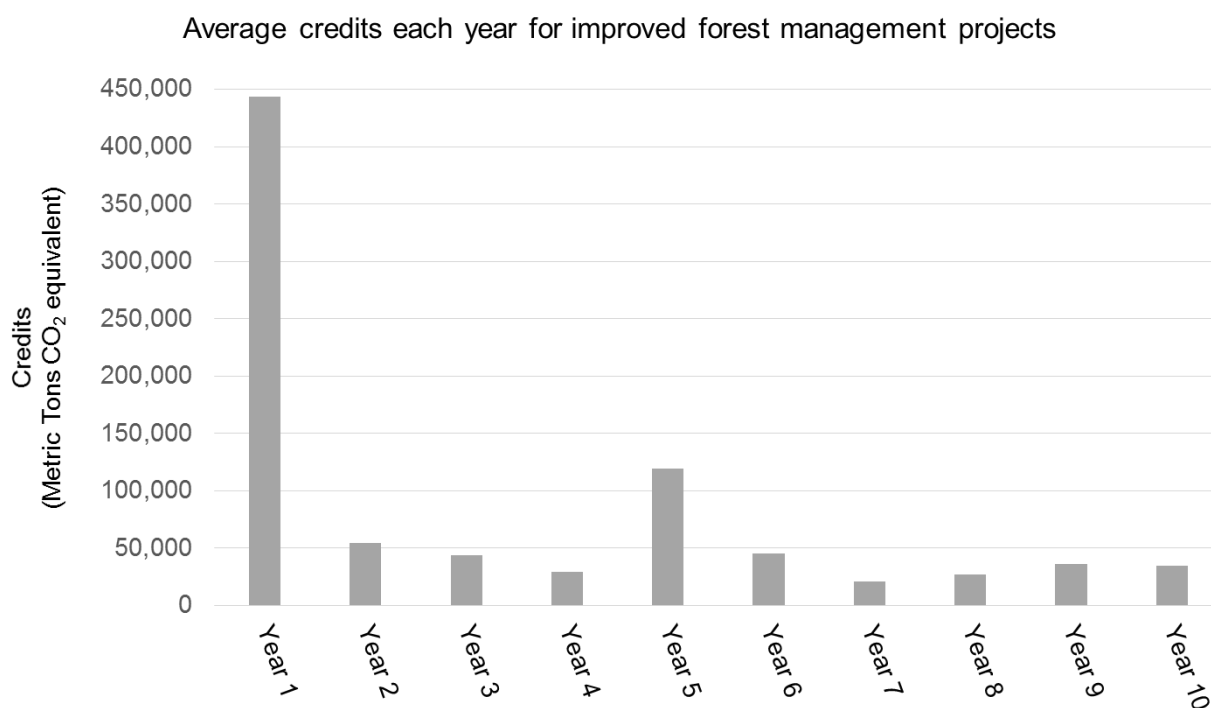
Leakage. Projects must account for leakage under IFM-14 'Biological Emission from change in harvesting on forestland outside the project area.' The protocol default estimate for

leakage is 20% of the difference between the modeled baseline harvest and the actual harvest in each year of harvest (California Air Resources Board 2015b). Disaggregated data for project level leakage is not publicly available for the California program at this time, so we do not included it in this research. We estimate that leakage, as defined by the California protocol, is minimal because the annual harvest volume is small. In addition, if a forest owners holds additional forest land outside of the project but in the same assessment area as the project, then that forest must be held to agreed on standards of sustainable forest management. This provision limits leakage within lands held by a single owner.

Web Figure 1. Average credits each year for improved forest management projects.

IFM projects often receive a large number of credits in the first year of program participation and a small, steady stream of credits in subsequent years. This is because IFM projects in the first year receive credit for avoided forest loss, measured by standing forest carbon that exceeds a modeled baseline.

Forest offset project carbon stocks are 24% higher than the average carbon stock in year one. Some researchers have noted that projects with high initial carbon stocks suggest a problematic selection bias in program participation. Given the evidence offered above on additionality, we view high initial carbon stocks as an indication of efficient use of land and program incentives. That is, forest offset projects have high carbon stocks so may be protecting 'carbon gems' efficiently. There is some research evidence that high carbon stocks may also be associated with biodiversity and other co-benefits, which the program may want to preferentially protect (Strassburg *et al.* 2010).

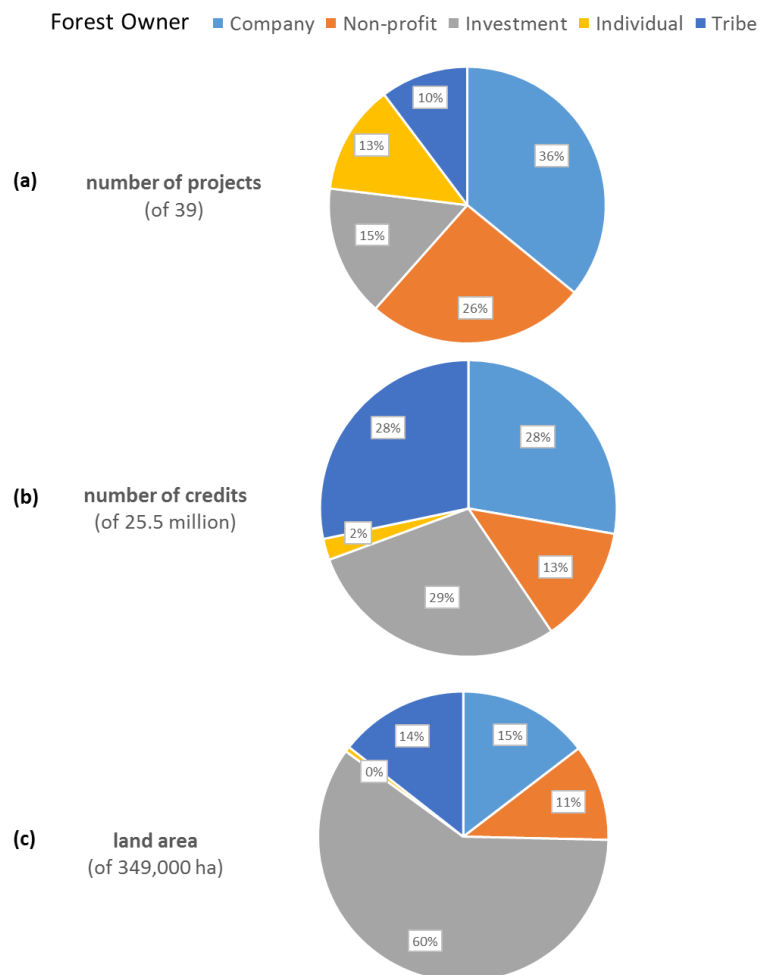


*For Year 5, there are three projects that had unusually high crediting, likely due to correction of errors in earlier years or back-crediting of earlier credits.

Web Figure 2. Project ownership by number of projects, number of credits, and land area.

(a) Projects are held by diverse owners: companies, individuals, non-profits, investment firms, and tribes. (b) Of forest offsets received, companies and investment firms received a larger share of forest offset credits than the fraction of their project ownership would imply, while individuals, non-profits, and tribes have received fewer. (c) Measured by project area, investment firms hold a much larger share of the land area in forest offset projects than do other types of project owners.

Per the forest owner hypothesis, because few projects are owned by non-profits, project ownership points toward additionality of the program overall. This paper focuses on program level additionality rather than project or credit level additionality, but future research analyzing each forest offset project in depth would be of value. Further project-level assessment may be desirable for non-profit project owners, who account for 25% of projects and 12% of credits. The published literature on the forest offset program to date asserts that strict program requirements may prevent qualified forests from participating, not that unqualified forests may be participating in the forest offset program. (Schmitz and Kelly 2014; Kelly and Schmitz 2016)



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