Aligning ecology and markets in the forest carbon cycle

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A forest carbon (C) offset is a quantifiable unit of C that is commonly developed at the local or regional project scale and is designed to counterbalance anthropogenic C emissions by sequestering C in trees. In cap-and-trade programs, forest offsets have market value if the sequestered C is additional (more than would have occurred in the absence of the project) and permanent (sequestered within the project boundary for a specified period of time). Local management and ecological context determine the rate of C sequestration, risk of loss, and hence the market value. An understanding of global C dynamics can inform policy but may not be able to effectively price an ecosystem service, such as C sequestration. Appropriate pricing requires the assistance of ecologists to assess C stock abundance and stability over spatial and temporal scales appropriate for the regional market. We use the risk that sequestered C will be emitted as a result of wildfire (reversal risk) to show how ecological context can influence market valuation in offset programs.

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The atmosphere is, by its very nature, a global commons (Hardin 1968) and addressing rising atmospheric greenhouse-gas (GHG) concentrations requires international cooperation among the major carbon (C)-emitting countries. One mechanism that has been widely considered for mitigating climate change is the "offset", whereby removal of carbon dioxide (CO_2) from the atmosphere compensates for – or offsets – an equivalent amount of CO_2 emissions elsewhere. The ability of forests to sequester CO_2 from the atmosphere has captured the attention of policy makers, non-governmental organizations, and a burgeoning number of offset project developers. The underlying concept is simple: sequester C from the atmosphere by reforesting degraded lands, thereby increasing the amount of C stored in current forests, or reducing forest loss (Canadell and Raupach 2008). However, implementing a system to quantify and monetize (ie place a dollar value on) this mitigation benefit requires attention to details that will help ensure that the forest offset is actually equivalent to the emission it is meant to compensate for.

In a nutshell:

- The idea behind cap-and-trade programs for mitigating climate change is that greenhouse gases stored in one place can offset emissions from somewhere else, thereby reducing total emissions
- Forest growth removes carbon dioxide from the atmosphere and represents one type of emission offset
- Although climate change is a global issue, forest carbon (C) storage is driven by local ecological context because local factors determine management and growth of forests, as well as C emissions

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In the absence of international action to curb GHG emissions, many regional and voluntary initiatives have emerged. These efforts have resulted in a project-based approach to offsets that adds complexity to accounting that will only be alleviated by national or international agreements (Andersson and Richards 2001; Richards and Andersson 2001). Generally, in voluntary markets, forest offset projects are developed following a C accounting protocol specific to a C registry. The registry serves as the platform for tracking offsets, making sure that they meet certain requirements and that they are only sold once. Common requirements for offset projects include ensuring that the project sequesters more C than would have been the case in the absence of the project (additionality); that certain activities, such as timber harvest, are not just displaced to a different location (leakage); and that the C remains sequestered in the forest for some required time period (permanence). Because of these requirements, C registries must deal with a range of confounding factors that cross the social–natural science divide (ie that require both social and natural science expertise). For example, registries must assess uncertainty in quantifying C stocks (natural science domain), maintain reasonable costs for project development to allow for broad market participation, and attempt to predict the reaction of global markets to changes in wood supply, to assess leakage (social science domain). In short, an offset is not simply a piece of the C cycle, but rather a fungible (ie interchangeable) mitigation asset that results from more C being sequestered in a

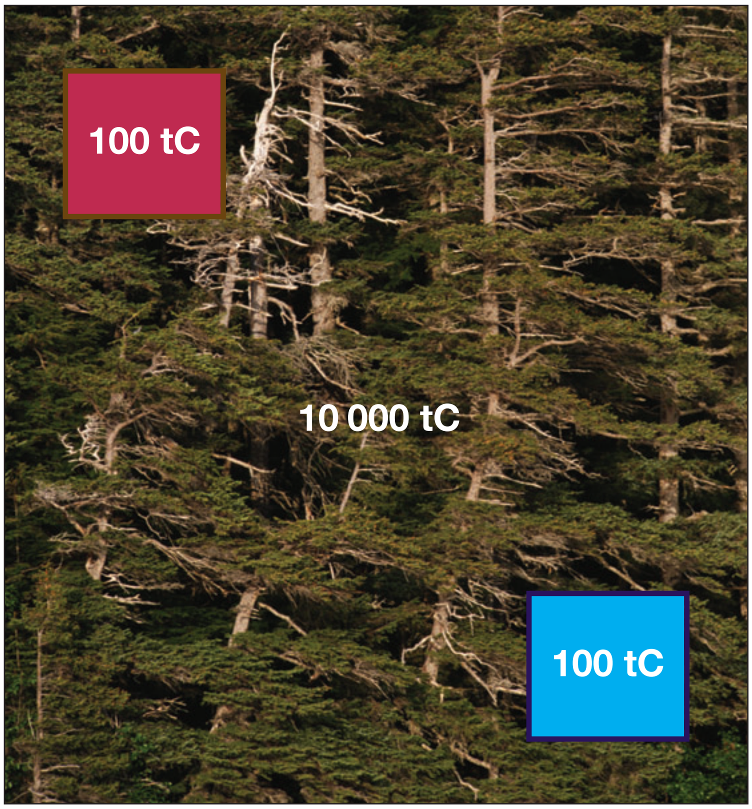

Figure 1. *A hypothetical forest landscape (background image) sequesters 10 000 tons of forest C per year. Embodied within the landscape are two forest C offset projects, each sequestering 100 tons of forest C per year. If a disturbance occurs within one project (red box), C sequestration across the landscape will be sufficient to compensate for the loss. However, in a market context, the tons registered in the two projects represent the entire stock of forest C, and the undisturbed project (blue box) would need to sequester the equivalent number of tons of C lost to disturbance in the red box to compensate.*

geographic location than would have occurred under a business-as-usual scenario.

In the absence of a global market, the current patchwork approach of voluntary markets to climate-change mitigation and forest offsets brings considerable challenges (Richards and Andersson 2001). Regional markets such as the European Union Emission Trading Scheme and the Regional Greenhouse Gas Initiative have evolved but often struggle to regulate and effectively price a commodity when much of it originates outside the market's boundaries. Complex systems that successfully govern the commons do evolve at a range of scales (Ostrom 2009b) but require trustworthy information about the stocks, flows, and processes within the resource system being governed (Dietz *et al.* 2003). It is difficult to evaluate an ecosystem service such as C sequestration, unless ecologists are engaged in providing accurate information on stock abundance and stability or risk over appropriate temporal and spatial scales for regional markets. Here, we focus our attention on how the scientific community can contribute to improving these efforts in the systems that currently exist.

Scientists assist in protocol development by improving allometric equations, quantifying tree growth relationships, understanding the ecology of disturbance, and working to further elucidate the nuances of sequestering C in forests. Yet, the scale of forest C-cycle science often fundamentally differs from that required in the market-based system within which these projects are developed and sold. In the context of the C cycle, local processes and events in forests are often buffered by a broader spatial and temporal background (Kashian *et al.* 2006). If natural disturbance events occur, vegetation regrowth during succession re-sequesters the C lost during the disturbance, given sufficient time (Kashian *et al.* 2006). Similarly, while a local C stock may decrease because of a disturbance event, when considered over a larger area, the C stock may be maintained or may even increase because of a lack of disturbance and continued forest growth in the larger area (Ryan *et al.* 2010). When examining forests as part of the global C budget, it is important to identify the appropriate spatial and temporal scales in which to contextualize the C stocks and fluxes. The proper scale is also necessary in a market-based context, and the offset market scale differs substantially from the global C-cycle scale. Because a given registry's offset portfolio consists of registered projects at specific geographic locations, each with a contracted life span, the spatial and temporal scale appropriate for a given registry is dictated by its offset portfolio.

Registries seek to ensure that their C offsets (eg forest offsets) are equivalent to reductions from fossil-fuel combustion. Once a unit of forest C is quantified, registered, and sold, it is tied to C stored in trees or wood products within a specific project boundary. If the unit of C is lost through a disturbance event, it is counted as an emission and must be reimbursed (Figure 1). Risk is the probability of an event occurring multiplied by the consequences. For example, in the case of wildfire, risk is the product of the probability of a wildfire occurring and the magnitude of the resulting C loss. Exclusive of extremely large events (Randerson *et al.* 2006), wildfires contribute relatively little to the global C cycle and national C budgets (Stinson *et al.* 2011). However, at the smaller scale of a registered forest C project, losses to fire or other disturbances can be important.

Fire-prone forests as an example

Previously, Hurteau *et al.* (2008) proposed that reducing C stocks in certain dry forests could yield a long-term C benefit by reducing the risk of high-severity wildfire. Although the C balance depends on forest type, these

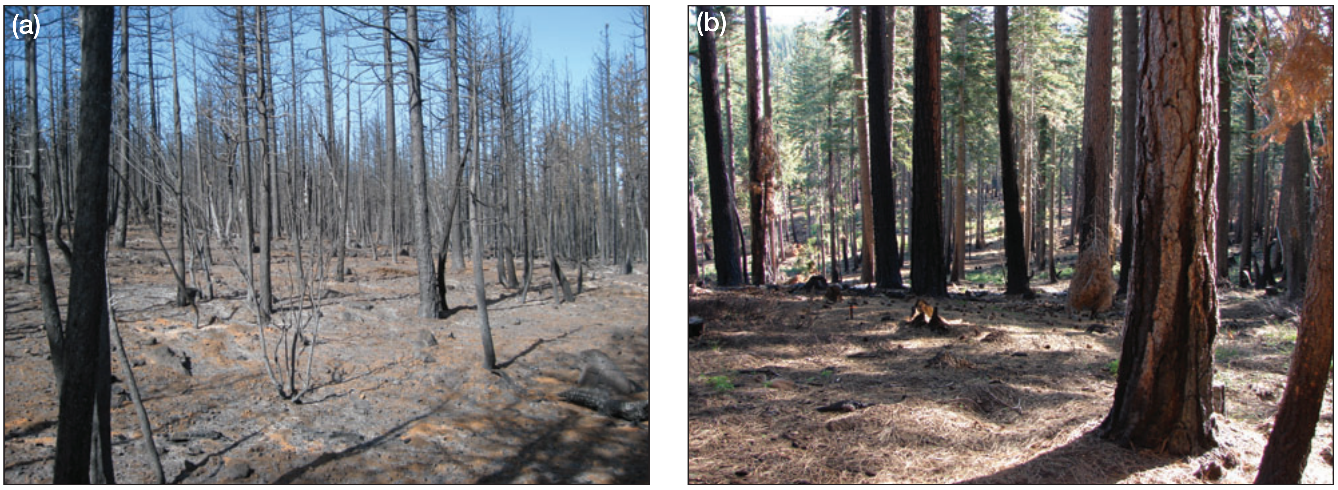

Figure 2. *The Hat Creek Complex Fire burned approximately 4500 ha in California's Lassen National Forest in 2009. The photos were taken post-fire in (a) untreated and (b) treated portions within the perimeter of the 755-ha Brown Fire section of the complex.*

treatments (thinning and prescribed fire) can reduce direct emissions and avoid near-term post-fire declines in productivity (Hurteau and North 2009; Mitchell *et al.* 2009). Given the low probability of high-severity wildfire occurring at most forest locations (McKelvey *et al.* 1996; Rhodes and Baker 2008), thinning a forest to reduce the risk of C loss may not "pencil out" as a net C gain from a global perspective. However, what may appear to be a very low risk from a global perspective may be perceived quite differently by a C registry.

If a unit of forest C is monetized and sold, and then a disturbance releases that sequestered C, that unit must be replaced with an equivalent unit of C to ensure that the climate-change mitigation goal of the C registry is met, thereby maintaining system integrity (Hurteau and North 2010). As a society, when the consequences are serious, we often insure against low-probability events; for example, the probability of a building fire occurring in London is low (0.0038 per year; Holborn *et al.* 2002), yet mortgage companies still require building owners to insure against that risk. The probability of property loss due to fire can vary by location, with increased probability at the interface between urban and natural areas (Radeloff *et al.* 2005; Brillinger *et al.* 2009; Price and Bradstock 2011). Similarly, the probability of a large wildfire increases in areas with low road density and high topographic complexity (Dickson *et al.* 2006). Thus, if a registry views its offset portfolio from a risk-based perspective, there is a disincentive for projects in fire-prone areas and a positive incentive to base projects in less-flammable forests (eg US northern hardwood forests). To maintain system integrity, which ensures that financial obligations are met and real climate benefits derived, C registries, including the Climate Action Reserve (CAR) and the Verified Carbon Standard, require insurance against project-specific risk in the form of offset contributions to a buffer pool (a reserve of offsets, contributed to by each registered project, that is used by the registry to replace offsets lost to disturbance). In the case of the CAR's Forest Project Protocol (FPP) (Climate Action Reserve 2010), actions taken to lower the risk of high-severity fire can reduce the size of the buffer pool contribution. Thus, wildfire mitigation actions that have been shown to improve the stability of forest C stocks, such as forest thinning and burning (Hurteau and Brooks 2011; North and Hurteau 2011), are valued within the protocol (Figure 2). Yet, the global C-cycle perspective that is common in the forest science literature often fails to consider the consequences of wildfire occurring in a specific project, for example, by (1) classifying thinning as forest degradation (Law and Harmon 2011), (2) discounting the effects of fire-induced tree mortality because of the delayed nature of indirect emissions (Meigs *et al.* 2011), (3) viewing emissions and treatments in a regional context (Campbell *et al.* 2007; Hudiburg *et al.* 2011) or over centuries of forest succession (Campbell *et al.* 2012), and (4) comparing the magnitude of wildfire emissions with anthropogenic emissions (Wiedinmyer and Neff 2007; Price and Bradstock 2011). Although relevant in both a global context and for quantifying leakage, these studies do not provide information pertinent to strengthening forest C protocols. The following example demonstrates one way scientists can contribute to informing forest C policy development.

Under the CAR's FPP, foregoing tree harvesting is considered to be improved forest management. In our hypothetical example, we use a 1000-ha mixed-conifer forest in California with a stock of 120 000 tons of carbon (tC) and a C sequestration rate of 1 tC per hectare per year (ha^{-1} yr^{-1}), from which one-sixth, or 20 000 tC, of the C is harvested and removed every 20 years. Thus, the baseline against which C credits are awarded on this 1000-ha project fluctuates between 100 000 and 120 000 tC (Figure 3) and is calculated as the average stock over the life of the project (110 000 tC). By placing the project in a conservation easement and foregoing harvesting, we expect the C stock to increase by 58% over the

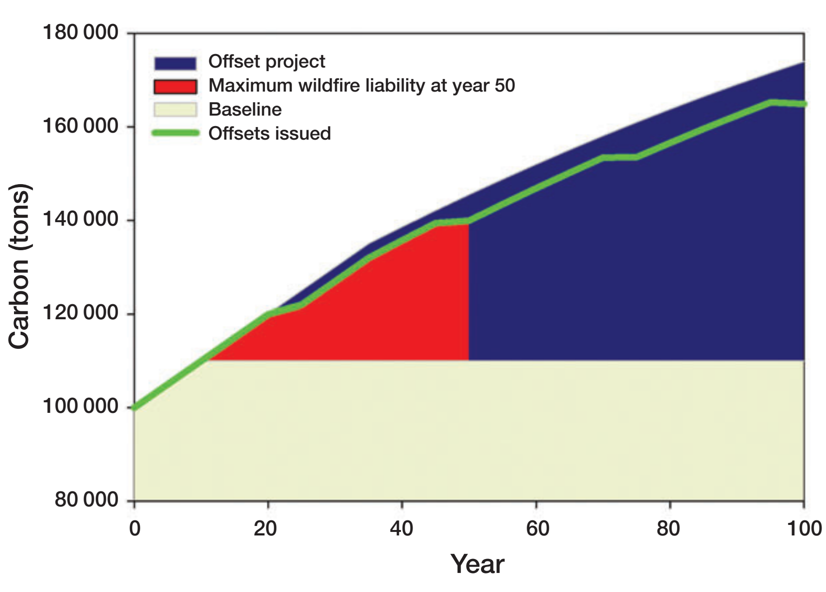

Figure 3. *A hypothetical forest C offset project on 1000 ha of land over a 100-year period. The baseline represents the mean Climate Action Reserve C stock under a business-as-usual scenario of forest harvesting. The offset project is the projected C stock if harvesting ceased and the entire 1000 ha were placed in a conservation easement. The offsets issued represent the total C sequestered when the forest land is placed in an easement minus the buffer pool contribution of 12.3%. The maximum wildfire liability is the amount of C for which the system would require compensation if a wildfire occurred on the 1000 ha in year 50.*

100-year life span of the project, assuming that net primary productivity declines by 1% per year beginning in year 40. This increase qualifies as an offset because it is net sequestration that would not have occurred if the project had not existed. The required buffer pool contribution for this project is calculated following the CAR's FPP (Climate Action Reserve 2010), which is a product of the risk rating and total offsets. We calculate the risk rating using CAR default values for each risk, with the exception of fire risk, where we use a mean fire return interval of 30 years, based on the historical mean (McKelvey and Busse 1996). The cumulative C sequestered above the baseline (*FC*) for any given time period is calculated as:

$$FC = FG - B \quad \text{(Eq 1)},$$

where *FG* is equivalent to the project C stock and *B* is equivalent to the baseline C stock. The resulting buffer pool contribution is 12.3% of all C credits awarded over the 100-year period.

The cumulative buffer pool contribution (*BPC*) for a given point in time is calculated as:

$$BPC = FC \times RR \quad \text{(Eq 2)},$$

where *RR* is equivalent to the risk rating. The difference between the C sequestered above the baseline by the project and the offsets issued for sale is the effective offset liability given a fire event. If a wildfire occurs during year 50, the maximum liability would be approximately 45 500 tC (all C above the baseline that has been counted as offsets). In reality, wildfire releases only a fraction of the C stored in the forest (Campbell *et al.* 2007). Yet, since the C in the project is registered, fire-induced mortality is part of the risk equation. Research in this forest type has shown that with high tree density, 90% of the *live* trees can have greater than a 75% chance of being killed by fire during extreme weather conditions (Stephens *et al.* 2009). Thus, the registry is liable for direct emissions and the offsets lost (eg C lost and trees killed by fire) resulting from mandatory project termination because of a drop in standing live tree C below the baseline (Climate Action Reserve 2010). In this case, the total liability (offsets awarded minus the buffer pool contribution) would be 39 903 tC (Figure 3) and would require buffer pool contributions from more than seven comparable projects to fully protect the registry. From a global C-cycle perspective, one could argue that if this forest is accumulating C at the rate of 1 ton ha^{-1} yr^{-1}, then 39 903 ha of comparable, undisturbed forest would sequester the C lost on the 1000 ha in 1 year, yielding no net change in C for this area. Yet, the growth on those 39 903 ha does not qualify to offset the loss within the 1000-ha project because that C does not represent additional sequestration.

If the same project implemented treatments to reduce high-severity wildfire risk, the total offset creation potential would be reduced by the amount of C removed and emitted during treatment. However, the wildfire-related risk is diminished because a smaller fraction (≤ 20%) of the live trees now has a greater than 75% chance of being killed (Stephens *et al.* 2009). Assuming that 20% of the live trees are killed, the project remains viable because the live tree C stock continues to exceed the baseline. This simplified example demonstrates that because the GHG value of a natural system is inversely related to the probability of disturbance (Anderson-Teixeira and DeLucia 2011), the reversal risk associated with disturbance needs to be carefully evaluated to ensure system-level integrity (Galik and Jackson 2009).

Think globally, value locally

There are very few indications that the US will institute a national cap-and-trade program, so it is unlikely that a global market will arise soon; yet regional and voluntary markets in the US and elsewhere are evolving.

Concerns have been raised regarding this patchwork approach to reducing GHG emissions, including the reduced ability to distribute emissions reductions across space (known as "where flexibility") and the potential for market leakage (Chen 2009; Frankhauser and Hepburn 2010). Although expanding the geographic scope of the market may buffer against these concerns in some sectors (eg power generation and manufacturing), such issues can be overcome in the forest sector, negating the need for a national program. In the forest sector, a more practical framework than expanding the market scope may be to use registries modeled on successful social–ecological systems (SES; Ostrom 2009a) to value forest C. A key element of sustainable SES is the alignment between management rules and local ecological conditions. In forests, these conditions are strongly influenced by disturbance dynamics. Research that accounts for differences in scale between market-based systems and the global C cycle and that considers the impacts of disturbance on registry integrity will improve policy development for regional markets. As shown by the fire-prone forest example, scientists have the tools necessary to quantify the probability of disturbance events and the associated consequences in a given geographic location, and this will help registries to manage the systemic risks they face.

Reconciling the science–policy divide

There are numerous areas in which science can inform forest C offset protocols and many ways in which scientists can assist with protocol development. As an example, the CAR's FPP relies on growth-and-yield models for projecting a baseline forest condition. Often, these models are sensitive to tree mortality and regeneration dynamics (Crookston *et al.* 2010), factors that are already being influenced by the changing climate (van Mantgem *et al.* 2009). During their development, many registries provide a public comment period prior to adopting protocol revisions, and our experience suggests that registries welcome input from the scientific community that will improve their protocols. At the same time, we suggest that offset-project developers and registries could assist the scientific community in this process by making data from their projects publically available. Most forest offset projects are being implemented in the developing world; project-level data include information on species composition and C stock changes, among other factors, and these parameters are monitored over time. If freely available, data from these regions could improve C-cycle science at local to global scales.

Understanding how climate change interacts with stocks and fluxes in the global C cycle is within the domain of science, whereas developing and implementing mechanisms for climate mitigation is within the realm of policy makers and project developers; however, neither of these can operate in a vacuum. An iterative approach, with scientists bringing their knowledge to bear on technical issues in C accounting and registries making their wealth of data publically available, will provide both mitigation-relevant research results and improved data resources. In turn, this will further our understanding and improve management of the global C cycle.

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