Forest Sequestration 2.0

Climate Solutions Living Lab 2019

Team 4:
Martina Müller, Molly Wieringa, Olivia Staffon,
Sarah Zelasky, Ben Geyman

May 9, 2019
Cambridge, MA

TABLE OF CONTENTS

ACKNOWLEDGEMENTS:

We would like to thank Wendy Jacobs for her vigorous efforts to develop and organize this course. We are grateful for the support and constructive criticism that she provided throughout the origination and drafting of this proposal, and we appreciate the opportunities she created for us to meet with and learn from experts in the diverse fields related to voluntary carbon finance.

We would also like to thank the 2019 Teaching Fellows: Rebecca Stern, Drew Michanowicz, Debra Stump, Seung Kim, Julio Lumbreras, and the rest of the academic support staff. In particular, we would like to acknowledge Julio, who pointed us towards resources, helped direct our learning on this topic, and helped us maintain positivity during times where we felt stuck.

Finally, we would like to thank the many individuals who took time to share their own knowledge about aspects of our project and who came to give us feedback during our presentation. The assistance we received from Pam Templer, Terzah Tippin Poe, Eric Henson, Mark Friedl, Michael Maruca, and so many others was invaluable.

EXECUTIVE SUMMARY:

Over the past twelve weeks, our team has worked within Harvard Law School's *Climate Solutions Living Lab* to develop a carbon offset project that achieves quantifiable, verifiable, and monitorable greenhouse gas (GHG) emissions reductions while providing local health and social benefits. After assessing how to best develop a project of this type, we decided to pursue carbon sequestration through improved forest management (IFM) practices. Our project is a pilot initiative in coastal Alaska's Kodiak Island Borough that will demonstrate the potential for remote sensing technologies to reduce both costs and uncertainties associated with measuring forest carbon sequestration. In turn, this proof-of-concept for carbon remote sensing offers to improve trust in the validity of forest carbon offsets among offset buyers and increase economic viability for project owners by reducing or eliminating the need for ground-based carbon inventories. The project is designed with an academic institution in mind as the unregulated entity; Harvard University, which is committed to achieving carbon neutrality by 2026, is a good example of such an unregulated entity.[1]

While many carbon offset projects seek to reduce future GHG emissions, our project will directly sequester carbon dioxide that is already in the atmosphere. This is important because carbon dioxide removal is included in all mitigation pathways identified by the Intergovernmental Panel on Climate Change (IPCC) for limiting mean global warming to 1.5°C.[2] Unlike many carbon capture and storage strategies, IFM-based carbon sequestration is simple, harnessing the natural ability of trees to take up carbon and store it in biomass for centuries.

---

[1] An unregulated entity is an organization voluntarily buying carbon credits to offset its own carbon emissions.
[2] For all scenarios with no or minimal overshoot. Rogelj, J., D. Shindell, K. Jiang, ... and M.V. Vilariño, 2018: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. ... and T. Waterfield (eds.)]. In Press.

Our project is the first of its kind to use airborne and satellite-derived measurements to quantify forest carbon sequestration. These measurements will be validated using traditional ground-based carbon surveys conducted with the assistance of local citizen scientists. Once proven as an accurate replacement for traditional ground-based monitoring, our project's methodology will reduce the costs involved in forest carbon offset programs and lead to the adoption of newly viable sequestration projects that will be critical to the mitigation of climate change.

While our technological design can be applied to forest carbon measurements anywhere in the world, we chose to pilot our project in the Kodiak Island Borough of Alaska due to the region's level of climate change vulnerability and present-day concerns over deforestation. We will work with local residents of the Kodiak Island Borough as well as the Alaska Native Corporations who own the land to determine the best way to maximize benefits from our project while minimizing risks. If the project is implemented as planned, we expect that it will provide financial and public health benefits to the Kodiak Island Borough community at an affordable cost to the unregulated entity that invests in these offsets. This implementation plan will describe in detail the costs and benefits of our project and the proposed next steps to turn our project from a plan into reality.

Project Goals

1. **Design a forest carbon project capable of credibly sequestering 50,000 metric tons of CO_2 per year for twenty years**
2. **Develop remote sensing techniques to measure forest carbon sequestration with greater certainty and at lower cost than traditional ground-based surveys**
3. **Establish a citizen science monitoring initiative to provide place-based environmental education and traditional forest carbon measurements for comparison to techniques noted above**
4. **Supply a viable financial alternative to timber harvest for a forest landowner interested in sustainability but obligated to create economic returns from the land**

IMPLEMENTATION PLAN:

1. Project Scoping

Tasked with devising new approaches for measurement and monitoring in the carbon offset space, our team evaluated improvement potential across four projects in forestry and agriculture. To guide project selection, we considered the following criteria: scalability, replicability, social benefit, ability to create a novel solution, depth of pre-existing work to build on, and our team's expertise and interests. Forest carbon offsets emerged as the most promising option across nearly all of the criteria considered. We will briefly discuss the salient benefits of focusing on forest carbon monitoring here, and a full feasibility analysis describing our decision process is contained in Section II of this report. Further discussion of how these benefits will be achieved by our proposed project is included in the section following, titled '*Pilot Project Implementation*.'

2. Focus on Forest Carbon

a. Scalability

We identified the increasing cost of monitoring with scale and initial verification costs on the order of hundreds of thousands of dollars as a present barrier to forest carbon offset project development. We also recognized opportunities to reduce these costs through the application of novel remote sensing technologies. Such approaches, utilizing airborne and satellite derived measurements, offer to reduce monitoring costs by diminishing or eliminating the need to measure carbon biomass directly from the ground. Since the marginal cost of measuring a larger area by plane or satellite is relatively low, remote sensing technologies make individual forest carbon projects scalable by enabling protection and management of larger forests.

Remote sensing technologies may further increase the credibility and transparency of forest carbon measurements, which will bolster interest among offset purchasers. Traditional ground-based forest carbon measurements typically rely on measuring carbon in a few representative sections of the forest, then extrapolating the carbon storage in sample plots to the entire forest. Investors may be wary of this approach, which can be biased if the sampling plots do not accurately reflect the composition of the forest as a whole, or if unmeasured sections of the forest are impacted by disturbances such as fire or pest-induced mortality. Because remote sensing techniques can readily measure the entire forest, the issue of misrepresenting forest carbon storage due to sampling error is reduced. Additionally, since much of the satellite data used for remote sensing are publically available, outside groups will be more able to verify the methodology used to estimate carbon storage.

In summary, developing remote sensing techniques will make forest carbon management scalable by reducing monitoring costs and increasing perceived credibility and transparency.

b. Replicability

Once developed for the purpose of carbon offset monitoring, remote sensing techniques can be readily calibrated and applied to forests anywhere in the world. This project will be immediately replicable in other mid- to high-latitude forests with similar ecosystems to coastal Alaska, with new forest carbon monitoring requiring few to no additional ground-based measurements. When applied in different ecosystems, the relationship between carbon sequestration and remote sensing measurements made by air and satellite will need to be locally calibrated, but the methodology will be directly transferable.

c. Novelty

Remote sensing is a diverse and rapidly developing field that refers generally to the acquisition of information about an object from afar, generally from air or space.[3] Remote sensing techniques for measuring forest carbon storage have now been in development for decades, though to our knowledge these techniques have never been applied in the carbon offset domain.

[3] See 'Remote Sensing' in *Glossary*

d. Pre-Existing Work

Given tight time constraints, we identified value in incorporating a robust monitoring component into an existing project framework. In 2017, a *Climate Solutions Living Lab* team developed an implementation plan for a forest carbon sequestration project in coastal Alaska[4]. The focus of the project was to use forest carbon offsets as a mechanism to generate revenues to fund home weatherization efforts in Alaska Native villages. By providing a location and basic assumptions about how a forest sequestration project might be structured in Alaska, the 2017 project allowed us to narrow our focus on developing a monitoring scheme, and to build upon prior considerations of cost, social benefit, and partnership opportunities.

e. Social Benefit

The 2017 project in Kodiak Island particularly appealed to us in terms of social benefits because of the potential to work with Alaska Native communities. Alaska Natives live in a part of the world that is warming twice as fast as the rest of the world, and they are also particularly sensitive to the effects of climate change due to their reliance on subsistence fishing practices that depend on the stability of the ecosystem. By focusing our pilot project in such a sensitive area, we have the opportunity to tailor our forest offset solutions with input from the local communities in a way that not only mitigates global climate change, but has a direct positive impact on the financial and physical wellbeing of those who are most threatened by it.

---

[4] Bakshi et al, 2017. Implementation Plan: Forest Sequestration + Carbon Offset Proposal. Climate Solutions Living Lab, Harvard University Law School.

3. Design and Challenges

Forest carbon offsets hold enormous potential as a tool to help corporations, businesses, and private citizens transition to a fossil fuel-free future by allowing these entities to move toward significantly "reducing" their emissions even if they cannot at the present moment feasibly switch to renewable energy sources. Because forests naturally serve as a 'sink' of atmospheric carbon, they are already capable of addressing the carbon problem of today: we have already emitted carbon into the atmosphere, and regardless of whether or not we emit any more, the effects of the existing CO_2 have not yet been fully realized.[5]

Unfortunately, the cost of forest carbon offsets has historically been high in comparison to other offset generation methods,[6] while confidence in their credibility has decreased due to obstacles related to measuring and monitoring.[7] Current ground-based in-person measuring and monitoring techniques are expensive and relatively uncertain, as they require a statistical scaling of a few point-based measurements. Additionally, the unpredictability of natural disasters and human behavior cast doubts related to non-permanence and validity of forest carbon offsets. Even the most established standards of forest carbon offsets are being called into question: a recent policy brief from the University of California, Berkeley estimates that the California Air Regulatory Board's forest carbon crediting methodology may have overestimated actual sequestered carbon by as much as 80% of the credited amount.[8]

Despite these challenges, we believe that forest carbon offsets can still have a central role in climate change mitigation strategies – the technological trajectory of forest carbon measuring

---

[5] IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[6] "Unlocking Potential: State of Voluntary Carbon Markets 2017." Ecosystem Marketplace: A Forest Trends Initiative. May 2017.

[7] Nick Davies. "The Inconvenient Truth about the Carbon Offset Industry: In the Concluding Part of a Major Investigation, Nick Davies Shows How Greenhouse Gas Credits Do Little or Nothing to Combat Global Warming.(Guardian Home Pages)." *The Guardian (London, England)*, 2007.

[8] Temple, James. "Landowners Are Earning Millions for Carbon Cuts That May Not Occur." *MIT Technology Review*, MIT Technology Review, April 18, 2019, www.technologyreview.com/s/613326/californias-cap-and-trade-program-may-vastly-overestimate-emissions-cuts/

and monitoring is strongly positive, and current technologies are already available for deployment. By implementing these available tools in conjunction with a suite of Improved Forest Management techniques, we propose to make forest carbon offset crediting more accurate, trustworthy, easily scalable, and less expensive.

a. Improved Forest Management Practices

The Verified Carbon Standard, an established voluntary greenhouse gas reduction certification program administered by Verra,[9] defines Improved Forest Management (IFM) as "activities which result in increased carbon stocks within forests and/or reduce greenhouse gas emissions from forestry activities when compared to business-as-usual forestry practices."[10] Such practices can include setting aside previously managed land that would otherwise have continued under development for financial purposes, mitigating carbon emissions from inefficient logging practices, and reducing the impact logging has on the forest that remains (Table 1).[11,12,13,14,15]

Improved Forest Management can involve any relevant combination of the practices outlined in Table 1. The appropriate combination depends on the characteristics of the chosen project site. To maximize both crediting capacity and ecological co-benefits, we recommend that the project contract a certified forester, who will conduct a forest survey and compile a land management plan that includes a recommended suite of IFM practices. We expect the recommendation will

---

[9] "Verified Carbon Standard." Verra: Standards for a Sustainable Future. https://Verra.org/project/vcs-program/ (April 1, 2019).

[10] "Improved Forest Management (IFM)." Mongabay. https://rainforests.mongabay.com/carbon-lexicon/Improved-Forest-Management.html (April 2, 2019).

[11] Griscom, Bronson W., and Rane Cortez. "The case for improved forest management (IFM) as a priority REDD+ strategy in the tropics." *Tropical Conservation Science* 6, no. 3 (2013): 409-425

[12] Columbia Carbon, LLC. *Improved Forest Management Methodology for Quantifying GHG Removals and Emission Reductions through Increased Forest Carbon Sequestration on Non-Federal U.S. Forestlands*. American Carbon Registry, 2014. Accessed March 23, 2019. https://americancarbonregistry.org/carbon-accounting/standards-methodologies/improved-forest-management-ifm-methodology-for-non-federal-u-s-forestlands/columbia-carbon-acr-ifm-methodology_final-28aug2014_v1-1.pdf

[13] Gorte, Ross W. *U.S. Tree Planting for Carbon Sequestration.* Congressional Research Service, 2009. Accessed March 23, 2019. https://fas.org/sgp/crs/misc/R40562.pdf

[14]Davis, V., J.A. Burger, R. Rathfon, C.E. Zipper, and C.R. Miller. *Chapter 7: Selecting Tree Species for Reforestation of Appalachian Mined Lands.* United States Department of the Interior, 2012. Accessed March 23, 2019. https://www.fs.fed.us/nrs/pubs/gtr/gtr-nrs-169papers/08-Chapter7_gtr-nrs-169.pdf

[15] Byrne, Kenneth & Black, Kevin. (2019). Carbon Sequestration in Irish Forests.

involve a combination of protection practices for vulnerable areas such as slopes and riparian zones with better harvesting practices and extended rotation age; the appropriate Verra VCS protocols for these practices can be found on the Verra website.[16,17,18]

[16] Dangerfield, Mark, Charlie Wilson, Tim Pearson and James Schultz. *VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest*. Verra, 2016. Accessed March 23, 2019. https://Verra.org/methodology/vm0010-methodology-for-improved-forest-management-conversion-from-logged-to-protected-forest-v1-3/.

[17] The Nature Conservancy & TerraCarbon, LLC. *VM0035 Methodology for Improved Forest Management through Reduced Impact Logging.* Verra, 2016. Accessed March 23, 2019. https://Verra.org/methodology/vm0035-methodology-for-improved-forest-management-through-reduced-impact-logging-v1-0/

[18] Ecotrust. *VM0003 Methodology for Improved Forest Management Through Extension of Rotation Age (IFM ERA).* Verra, 2012. Accessed March 23, 2019. https://Verra.org/wp-content/uploads/2017/10/VM0003v1.2.pdf

Type of Practice	Key Points	Estimated Carbon Sequestered (tCO_2/acre/yr)	Measurable Carbon Benefits?	Reductions without leakage?
Better Harvesting		5		
Road and Skid Planning	Planning and construction of more efficient and less carbon-intensive roads and harvest removal practices	"	✓	✓
Water bars	NA	NA	x	x
Vine cutting	Cutting vines tangled in the tree tops so that a harvest tree does not bring several other non-commercial trees down with it	"	✓	✓
Directional felling	Cutting trees so that they fall in a specific direction to minimize damage to other trees and maximize timber recovery	"	✓	✓
Low impact logging	Using innovative logging equipment - such as the monocable winch system-that slide logs along the forest floor with long cables, reducing the damage to forests by conventional equipment (e.g. bulldozers)	"	✓	✓
Improved identification of commercial trees	Reducing the felling of defective (e.g. hollow) trees which have little or no commercial value using simple tests like the "plunge cut"; properly identifying commercial species before cutting so that non-commercial species are not cut down and abandoned (can be supported by a well-trained survey crew and emergent technologies)	"	✓	✓
Growth				
Extended rotation	allowing trees to grow beyond the minimum commercially-viable maturation age; provides a long-term source of timber production, income, and employment and reduces net emissions	5	✓	✓
Seedling establishment	supporting the initial planting and growth of seedlings (useful in afforestation and reforestation practices)	NA	x	x
Thinning	purposeful select cutting within forest stands to open up the canopy and allow for new growth and to encourage a dynamic and active forest	NA	x	x
Protection				
Riparian buffers	provide support via vegetative planting to areas where land meets streams or rivers, which are sensitive to erosion and have high plant and animal species diversity	0.7	✓	x
Slope avoidance	reduce risk of erosion on slopes and loss of carbon through destruction of biomass and soil disturbance	dependent upon slope and aspect	✓	x
Corridor set-asides	preservation of forest areas that connect two or more larger blocks of forest; helps to maintain biodiversity	8	✓	x
Logged-to-protected	shifting previously managed land to protected land, via an easement or state or federal delegation; allows for increased sequestration through unimpeded growth	8	✓	x

Table 1. Improved Forest Management practices by type and ability to provide measurable carbon benefits and limit leakage. Carbon sequestration values are based upon estimates from the literature.

b. Measurement and Monitoring Methods

On the voluntary market, the continual crediting of forest carbon offsets requires that the forest in question be regularly monitored to ensure that generated offset credits do in fact match sequestered carbon. The current monitoring methodology[19,20,21] involves on-the-ground collection of data relating to biomass, or how much the trees in question are growing over time. In practice, a technician or small team visits a predetermined number of survey plots within the forest, and sets up a radial perimeter on the plot. Every tree above a qualifying size that grows within that radius is then measured for height and diameter at breast height, which is used as a measure of average diameter of the tree. These measurements are fed into allometric equations, which are empirical, species-specific relationships that describe how much carbon is contained by a tree of a given size.

These kinds of measurements are attractive because they are simple and well established. However, obtaining measurements over whole-project timeframes by regularly sending technical crews into the field, particularly in remote areas, can be quite expensive and the measurements themselves have limited scalability within a required error range. We therefore propose to use existing but underutilized remote sensing technologies such as Light Detection and Ranging (LiDAR) instruments and satellites to improve upon the cost and quality of forest carbon measuring methodologies.

(i) Satellite monitoring

The technological trajectory of forest carbon measurements tends toward the eventual use of satellite data, which is, for the most part, freely available and highly accurate, even at survey plot scales of tens of square meters. However, as a form of carbon remote sensing, satellite data only become useful once a relationship has been established between forest carbon sequestration and

[19] *VM0010 Methodology*, pp. 53-81.
[20] *VM0035 Methodology*, pp. 16-26.
[21] *VM0003 Methodology*, pp. 44-59.

the parameters that a satellite can measure-- heat, light, and changes in height and topography. Currently, that relationship is not yet well-defined. However, the future of research in this area is promising, and this project can be a key player in achieving an understanding of the desired relationship.

A number of research institutions have already begun the process of creating algorithms that realize the connections between satellite data and biomass carbon sequestration. Unfortunately, they often lack the necessary ground-based or airborne evaluation data-- something this project can readily provide through a combination of traditional ground-based surveys and airborne LiDAR measurements (see section (ii) below). In turn, these research institutions can provide the project with more accurate and reliable quantifications of forest carbon sequestration.

In the near term, satellite data can be used to obtain canopy height altimetry[22], classify land-cover type, and track land-cover change over time. The first point can be considered the first step toward using satellite measurements to quantify change in biomass (and therefore carbon), while the second allows for a better selection of allometric equations and models that are forest-specific. The third component, tracking land-cover change, will help quantify leakage and permanence rates, allowing for adjustment over time of the buffers built into the offset crediting process that try to manage for each (see 'Legitimacy and Credibility of Offsets' below).

(ii) LiDAR monitoring

LiDAR, or Light Detection and Ranging, is a kind of remote sensing that uses the relationship between time the speed of light to determine distances to objects relative to the point of measurement. A LiDAR instrument will fire pulses of light at thousands to tens of thousands of times per second in a single scan, measuring the return time for that light to bounce off impeding objects and return to the instrument. The number and spacing of returns conveys information about the surface above or below (depending upon the kind of system is being used). These

[22] See Glossary

instruments can be ground-based (mounted on survey tripods), airborne (through the use of drones or airplanes), or part of a satellite's instrument array.

In a ground-based LiDAR survey system, the distance measurements from each scan can be used to recreate a very accurate three-dimensional version of the forest understory. In an airborne system, they can be used to characterize change in canopy cover and height. Satellite LiDAR takes measurements similar to the airborne systems, though these space-based data are not yet readily available and their fidelity has not been demonstrated. Additionally, while the ground-based systems are useful for gathering information regarding the understory and woody biomass of trees and are directly comparable to information gained from traditional surveys at the same plots, our research and conversations with experts indicates that the technology of airborne LiDAR systems is comparably accurate when it comes to quantifying biomass, with the added benefit of being less invasive, faster, and increasingly less expensive than the ground-based version. This is particularly true for our proposed pilot project, where the scale and remoteness of the project site make deployment of ground-based technicians and instruments a more expensive alternative. In order to minimize cost and still provide accurate evaluation data to our research partners, we recommend implementing the airborne LiDAR systems.

c. Legitimacy and Credibility of Offsets

The legitimacy and credibility of the offsets generated by our project depends on the accuracy of their measurement, the degree to which they are additional, the avoidance of leakage from the shifting of forestry activities to other locations, and the risk of non-permanence (i.e., the likelihood of reversal of carbon sequestration due to forest logging or destruction by natural disasters).

(i.) *Accuracy of Measurement*

The monitoring process proposed above will increase accuracy of carbon uptake measurement. Using traditional survey methods, project accounting uncertainty[23]ranges from 5-10%[24]when quantifying carbon uptake in land-based sequestration. The LiDAR approach described above has the potential of achieving uncertainties of less than 1%[25], giving all project parties more confidence about the legitimacy of the offsets generated.

(ii.) *Additionality*

The additionality principle states that only carbon emission reductions that would not already have taken place without the existence of the project can be counted towards carbon credits. This ensures that an offset project has real-life impact on emissions. In this case, the location is fundamental to ensure additionality. Our pilot project, described in the next section, is proposed in an area where the principle of additionality is respected. Please see next section for details.

(iii.) *Permanence*

The risk of non-permanence consists of the possibility that carbon sequestered through a forestry project might be released again in the atmosphere through the loss of forest biomass. This might happen due to a number of factors, both natural (such as wildfires and a pest infestation) and human-caused (for example encroachment or the landowners' decision to log the area themselves).

For IFM projects, Verra requires the project developer to set aside a certain amount of credits in a buffer pool for the case of reversal. These credits are held in reserve to draw from in the event

---

[23] Verra, 2010. IFM - LtPF Methodology: Estimating Greenhouse Gas Emission Reductions from Planned Degradation (Improved Forest Management), p. 83. Available at http://Verra.org/wp-content/uploads/2018/03/VM00011-Carbon-Planet-Methodology-Revised-Methodology-for-Second-Assessment-1.pdf. Accessed on April 23rd, 2019.

[24] Kim et al, Uncertainty Discounting for Land-Based Carbon Sequestration. Available at https://pdfs.semanticscholar.org/cabf/0a47a92d07120e8fd105a43f6c38d846a187.pdf. Accessed on April 23rd, 2019.

[25] Gonzalez et al, 2010. Forest carbon densities and uncertainties from Lidar, QuickBird, and field measurements in California. Remote Sensing of Environment, Volume 114, Issue 7, 15 July 2010, Pages 1561-1575. Available at http://www-sciencedirect-com.ezp-prod1.hul.harvard.edu/science/article/pii/S0034425710000702 . Accessed on April 23rd, 2019.

of an unexpected disturbance. The amount of credits to be held in reserve depends on a permanence risk assessment. Using the Verra Risk Assessment tool[26], in the present case, we would suggest a permanence buffer pool of 10%. For this percentage to be acceptable, it is important for the land owners (in this case, a Native Corporation), to enter into a legally enforceable agreement committing to continue the management practice that sequesters carbon/avoids emissions for a 100-year period - for this we propose a conservation easement (please see Annex for details). It is important to note that, past the initial 20 years of the project, the carbon offsets can be renewed up to four times for a total of 100 years. Given the easement, it will thus be in the interest of the Native Corporation to continue selling offsets on the market and benefitting from the incoming revenue stream.

(iv.) *Leakage*

The risk of leakage relates to the possibility of the project causing an increase in emissions outside of project's accounting system. There are two types of leakage an IFM project might be exposed to: market leakage and activity-shifting leakage.

Market leakage: Occurs when the project causes an uptake in the commodity production (in this case, of timber) somewhere else to make up for the lost supply from the project area. The scale of the pilot project, detailed in the next section, is too small to provoke serious market leakage considerations.

Activity-shifting leakage: Consists of the displacement of emissions through logging to an area outside of the project boundary. Verra standards require the monitoring of a so-called "leakage belt" surrounding the project area and a leakage buffer to be incorporated into the project. In the proposed project, we suggest incorporating a leakage buffer of 5%, bringing the total combined permanence and leakage buffers to 15%.

[26] Verra, 2016. AFOLU Non-Permanence Risk Tool: VCS Version 3. Available at http://Verra.org/wp-content/uploads/2018/03/AFOLU_Non-Permanence_Risk_Tool_v3.3.pdf. Accessed on April 22nd, 2019.

Recently, questions have been raised regarding leakage of forestry projects. In particular, the policy memo by the Center for Environmental Public Policy, University of California - Berkeley [27] referred to previously pointed towards earlier studies indicating that a much higher percentage of leakage might actually be occurring than is accounted for in systems like California's Air Resources Board (ARB) protocols, leading the the overestimation of up to 80% of the total credits claimed. ARB responded in defense of their protocols, stating that they are based on the best available science[28]-- we believe that our project can further advance the science behind these leakage buffers, avoiding these recent concerns.

While controlling for all leakage is impossible-- human behavior remains unpredictable and market forces are still strongly in favor of the logging industry-- the monitoring technology outlined in the section previous can help increase the certainty regarding activity-shifting leakage by closely tracking any land-use change in the area surrounding the project. This is important because such tracking will allow us to accurately adjust our buffers in a manner that does not overestimate carbon credits while also determining when and where leakage needs to be further discouraged.

We also believe that the leakage question can be mitigated in the earlier stages of our project by selecting a pilot project location that has both low market impact (unlike California, which is a prominent player in the U.S. timber industry) and low potential for/high incentives against activity-based leakage. More details about the site can be found in Section 4.a below.

California's Air Resources Board is scheduled to review the forestry protocol still in 2019. The process includes examining new studies and requesting contributions from academic experts. This might be a good opportunity for incorporating technologies such as the ones proposed here.

---

[27] Haya, 2019. Policy Brief: ARB's U.S. Forest Projects offset protocol underestimates leakage – Preliminary results. Available at gspp.berkeley.edu/assets/uploads/research/pdf/Policy_Brief-US_Forest_Projects-Leakage-Haya_1.pdf. Accessed on April 28th, 2019.

[28] Temple, James. *Landowner's are earning millions for carbon cuts that may not occur*. MIT Technology Review, 2019.https://www.technologyreview.com/s/613326/californias-cap-and-trade-program-may-vastly-overestimate-emissions-cuts. Accessed April 28th, 2019.

4. Pilot Project Implementation

For the initial implementation of a project incorporating the monitoring tools outlined above, we propose executing a relatively small pilot project on about 17,000 acres of land that can produce over one million offset credits over a twenty year period.

a. Kodiak Archipelago: Proof of Concept

To best demonstrate this project's viability and showcase how it might be constructed, we chose the island of Kodiak, Alaska as the location for our initial pilot project.

We chose to continue the 2017 *Climate Solutions Living Lab* pursuit of an Alaskan forest offset project for two main reasons:

(1) The state has vast amounts of forested lands (about 130 million acres, or one-third of the total state area[29]), many of which are at risk for logging. Although less remote forests in the contiguous United States might be easier to operate in, we believe that if this pilot project proves to be successful in Alaska, it will have demonstrated its potential for success in easier-to-access locations as well.

(2) Partnering with Alaska Natives on such a project can generate significant positive community benefits for a population which is largely underserved. The value proposition for the native community is centered around providing three key benefits:

- An additional stream of revenue that helps diversify their economy and increase the wellbeing of village residents;
- Health co-benefits related to the local preservation of forests, including the maintenance of healthy ecosystems and the reduction of wildfire risks through IFM practices (see Social and Health Benefits section);

[29] Alaska Farm Bureau. *Alaska Facts on Agriculture & Natural Resources.* Alaska Agriculture in the Classroom. Available at www.akleg.gov/basis/get_documents.asp?session=30&docid=13946, accessed on April 22nd 2019.

- Social co-benefits, by building out local technical expertise related to novel monitoring techniques, including a dedicated educational component and technical research partnerships.

(3) Traditional IFM projects within Alaska are already happening, with three big deals having been closed by different Native Corporations in the past few years, providing a good point of comparison for our proposed project:

- The Ahtna Corporation, in the southcenter region of Alaska, launched a project to create at least 15 million offset credits to companies such as BP, developed by US-based Finite Carbon.[30]
- Similarly, the Sealaska Corporation, which lands are located in the Southeast Inside Passage, is creating at least 11.4 million offset credits[31]also through the US-based Finite Carbon.
- The Chugach Alaska Corporation, also in the southcentral region of Alaska, started a project expected to generate 4- 5 million tons of offsets on 115,000 acres of forest in partnerships with the Australian-based sustainable forestry investment firm New Forests. [32]

Within Alaska, we chose to focus our efforts on Kodiak Island because:

- This area was already scoped for a potential project by the 2017 CSLL Forestry team, providing an initial basis of information that could be further refined.
- The area does not have significant mineral coal deposits underneath it, which might seriously imperil the project's long-term permanence.
- There is sufficient forested land on the island on which IFM projects could be carried out.

---

[30] Harball, 2019. Native corporations maintaining Alaska forests find a carbon credit buyer: oil company BP. Alaska Public Media. Retrieved from: www.alaskapublic.org/2019/01/21/native-corporations-maintaining-alaska-forests-find-a-carbon-credit-buyer-oil-company-bp/. Accessed on May 5th, 2019.

[31] Harball, 2019.

[32] Chugach Alaska Corporation, New Forests, The Nature Conservancy, Native Conservancy. Innovative deal sees permanent retirement of coal reserves while securing long-term income for Chugach community via forest carbon market. January 26th, 2017. Available at https://newforests.com.au/wp-content/uploads/2017/01/MEDIA-RELEASE-BRCF-Announcement-20170126.pdf. Accessed on May 7th, 2019.

- Significant deforestation has been observed on the island in the past 15 years[33]and there is documented pressure to increase logging in the area[34], reducing additionality concerns, but Kodiak's remote location and small impact on the state logging industry is likely to limit leakage concerns.
- There are educational and research institutions nearby, such as Kodiak College, a satellite campus of University of Alaska, and local high schools including Kodiak Island High School, Port Lions School, and Ouzinkie School, which might be interested in partnering with an unregulated entity to create a robust project with long-lasting effects.

b. Working with Alaska Native Corporations

The Alaska Native Claims Settlement Act of 1971 was the largest land claims settlement in US history at the time and allocated 12% of all the land in the State of Alaska to Alaska Natives. Twelve Regional Native Corporations and over 200 native village economic development corporations associated with a specific region were created to be the owners of these lands. These corporations together comprise the third biggest landowner in Alaska, only behind the national and state governments.

This 1971 Act constituted an innovative approach to native settlements, engaging Alaska Native tribes in corporate capitalism[35]. Shareholders of each corporation are the Natives, who are simultaneously villagers. Although Native Corporations are for-profit organizations, they were formed to use the financial and land resources conveyed to them to generate profits that help to

[33] Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from:http://earthenginepartners.appspot.com/science-2013-global-forest. Accessed through Global Forest Watch on April 28th, 2019. www.globalforestwatch.org
[34] Doogan, 2016. Neighbors, village corp. clash over Kodiak Island logging operation. Available at www.adn.com/business/article/kodiak-island-residents-still-railing-against-native-corps-clear-cutting/2014/12/08/. Accessed on April 28th, 2019.
[35] Linxwiler, James D. Chapter 12: The Alaska Native Claims Settlement Act at 34: Delivering on the Promise. In *ANCSA at 35*: 3–5, 2007.

care for the social, cultural, and economic benefit of their shareholders in the long term. An example of this is that their land is not considered as equity on their books[36].

c. Suggested approach for unregulated entity

This project includes suggestions that, before implementation, must be preceded by contacting and meeting with the Native Corporations on Kodiak Island. Ample consultations between the unregulated entity and the Native Corporations and villagers are recommended to inquire more about their own vision for the land and what type of project format they would be interested in.

Kodiak Archipelago Forest Characteristics

Terrain: Moderately rugged, with mountains from 2,000 - 4,000 ft

Climate: Mild annual temperatures (35-45 ℉), with ample precipitation (78 in. rain; 68 in. snow)

Land Cover: Coastal meadows, grasslands, shrublands, wetlands, wet tundra, and forest. The southern portion of Kodiak Island (largest island on the archipelago) is largely unforested, with the northern islands (Raspberry and Afognak) harboring most of the forested land.

Forest Composition[37]: Sitka Spruce, a commercially valuable tree is the dominant overstory tree. Sitka Spruce can live for 800+ years, and can grow to 220 ft in height and 16 ft in diameter at breast height (dbh; see Glossary). Other significant tree species include Alaska Yellow Cedar, Western Hemlock, and Black Cottonwood.

---

[36] Interview with Terzah Tippin Poe on April 9th, 2019.
[37] *Forests of Coastal Alaska.* U.S. Forest Service interactive overview of data collected by the Forest Inventory and Analysis (FIA) program. Accessed 2019. https://usfs.maps.arcgis.com/apps/MapJournal/index.html?appid=d0464406188740fb81e2e4c3d1b48915

Disturbance: The cool maritime climate and infrequent catastrophic disturbances (such as fire) are part of what enables the widespread distribution of old growth forests in the northern Kodiak Archipelago and Coastal Alaska. Studies of fire history over the past two millennia suggest a fire return interval of between ~89 and 600 years in Coastal Alaska, while spruce beetle outbreaks are slightly more frequent.[38]

Land Ownership: Nearly two-thirds of Kodiak Island is located within the Kodiak National Wildlife Refuge and has no road access. However, Alaska Native Corporations (Afognak, Leisnoi, Ouzinkie, and Shuyak and Natives of Kodiak own a combined land area of about 480,000 acres).[39]

More details about the physical and ecological characteristics, as well as the ownership can be found in Annex III.

d. Developing a Remote Sensing Method

Our three-part carbon monitoring program will combine traditional monitoring protocols with remote sensing data. At its core, 'remote sensing' is making one measurement (usually of the properties of light returning from a surface) and relating that measurement to a property of interest, such as the distance to an object, the temperature of a surface, or the amount photosynthetically available light being absorbed by a leaf. As a result, remote sensing data are not physically meaningful without calibrating the relationship between the measured property and the property of interest. As mentioned previously, our pilot initiative is designed to relate measurements by the best available sensors to forest characteristics such as the height and diameter of trees, land cover, the species composition of the forest, and eventually the direct exchange of CO_2 with the atmosphere. Below are short explanations of each component of our monitoring approach.

[38] Berg EE and Anderson RS. 2006. Fire history of white and Lutz spruce forests on the Kenai Peninsula, Alaska, over the last two millennia as determined from soil charcoal. Forest Ecology and Management 227: 275-283
[39] CSLL 2017 Team II Implementation Plan.

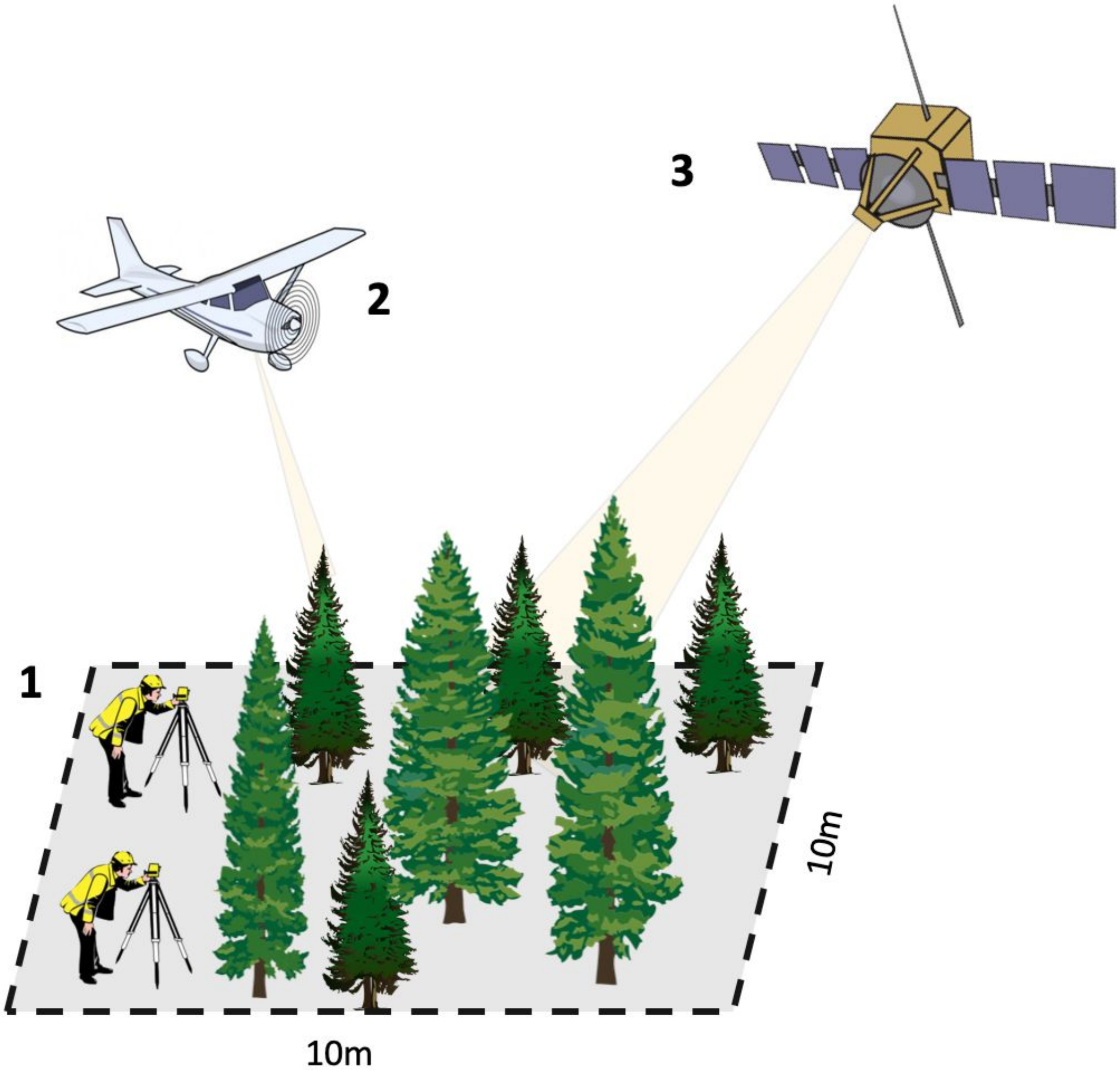


Figure 1: The components of our proposed monitoring scheme with (1) ground-based surveys, (2) airborne LiDAR, and (3) satellite remote sensing measurements over a small sample plot (grey box) within the project area.

(i.) Ground-based forest carbon survey

Among forest carbon offset verification standards, every methodology that we are aware of relies on ground-based carbon surveys in some form.[40] Measurement of forest carbon will be conducted on permanent sample plots laid out within the forest. By increasing the number of

[40] E.g. VM0012 v1.0 (2011) *Improved Forest Management on Privately Owned Properties in Temperate and Boreal Forests (LtPF).*

plots, we can reduce the overall uncertainty in our estimate of the amount of carbon stored in the forest. Once plots are established, above-ground biomass (comprising live trees and dead wood) will be estimated by combining standard volume and forest composition measurements with biomass allometric equations (Fig. 2).[41,42] The number of sample plots should be designed to produce forest-level uncertainties in the total carbon stock lower than 10% at the 90% confidence interval. This will minimize the loss of claimable carbon credits by reducing the size of the uncertainty factor deduction specified in forest carbon methodologies.[43] At the 10% uncertainty threshold, we can achieve the minimum uncertainty factor deduction of 1.5% calculated carbon sequestration.

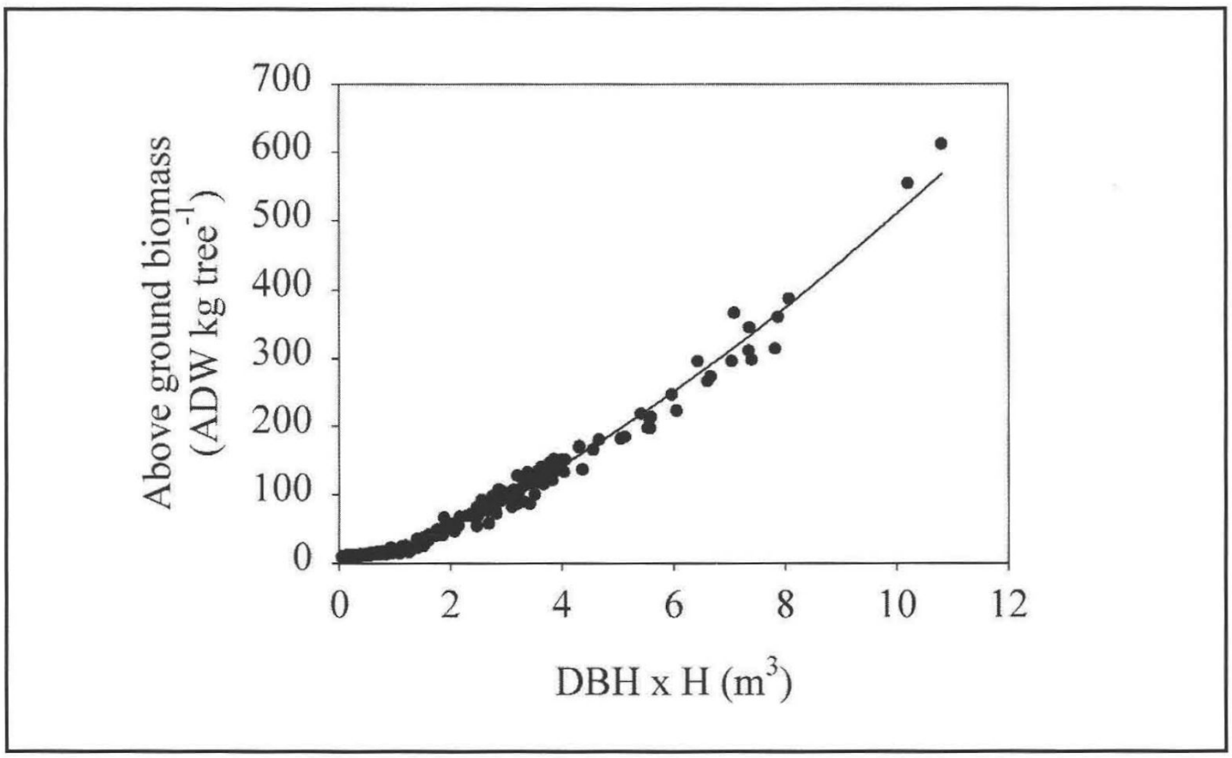


Figure 2: Observed relationship in Sitka Spruce between ground-level measurements (diameter at breast height, DBH and height, H) and aboveground tree biomass. The prediction line has the form: $ADW = \alpha(DBH \times H)^{\beta}$, where α and β are 20.76 and 1.39, respectively. This estimate has a

[41] *Allometric Equations* in Glossary
[42] Brown, S. (2002) *Measuring carbon in forests: current status and future challenges*. Env. Poll. 116, p. 363-372.
[43] E.g. VM0012 v1.0 (2011) *Improved Forest Management on Privately Owned Properties in Temperate and Boreal Forests (LtPF).*

standard error of 8.9% in the prediction of tree biomass for trees from 2 to 40cm in DBH. Figure from Black et al. (2004) "Improved Estimates for Biomass Expansion Factors for Sitka Spruce."

We will largely rely on citizen scientists to perform ground-based surveys (see section on 'Education and Research Potential' below). These citizen scientists will be supported and supervised by a full-time citizen science coordinator and educator. We prefer the citizen science structure for the myriad educational benefits, though we can pay professional surveyors to perform this work if the citizen science program proves unable to meet the survey needs of the project. Paying for professional surveying will likely cost an additional $5,000-10,000 every five years during the twenty-year project crediting window. In a situation where the citizen science program fails and professional surveyors are needed, the costs allocated to supporting the coordinator can be diverted to support professional surveying at no additional cost to the project.

(ii.) Remote Sensing Combination

Remote sensing allows the project manager to gather spatially-continuous data about the forest, which reduces uncertainties as plot-level survey measurements are scaled to reflect the entire forest. Within the scope of this proposal, the addition of remote sensing data will reduce the number of sample plots required to achieve 10% uncertainty at the 90% confidence level. Pursuant with our larger objective of demonstrating the viability of future monitoring designs relying solely on remote sensing data, ground-level survey plot estimates of forest carbon will be used to calibrate remote sensing-based carbon estimation techniques and to quantify associated uncertainties. The two components of our remote sensing strategy involve airborne measurement of forest height and density using a LiDAR instrument, and satellite measurement of land cover and forest composition.

LiDAR

LiDAR (Light Detection and Ranging) is immediately useful for forest carbon measurement because tree height is an important component of the tree carbon biomass calculation. For the pilot project, we propose utilizing airborne LiDAR until the time at which satellite LiDAR data become accurate and readily available. Doing so allows the project to take advantage of the research value in comparing air-based LiDAR measurements of forest height against satellite-derived measurements, while also demonstrating the viability of LiDAR as a replacement for traditional surveys.

At the beginning of the project, and every five years thereafter, we will survey the entire forest area using airborne LiDAR. The methodology should be developed in conjunction with and have the approval of the Alaska Native Corporations which choose to adopt this project. Implementation will involve mounting the LiDAR instrument on a small airplane and flying over the entire forest. By providing a spatially continuous measure of forest height over the entire project area, airborne LiDAR will allow us to extend the relationship between height and biomass (which will initially be calculated using ground-based survey data) across the entire forest. This will result in greater confidence in forest carbon storage estimates because we will have a measure that covers the entire forest.

Satellite Altimetry and Classification

Earth observing satellites are launched with specific measurement objectives, and are equipped with sensors that are suited to the specific mission. As a result, it will be useful to combine measurements from multiple satellites, taking advantage of their individual strengths for the purposes of classifying land cover (e.g. Landsat 8), classifying forest composition (e.g. WorldView-2), and measuring canopy height (e.g. ICESat-2 and GEDI).

We will use satellite remote sensing data acquired from the Landsat 8 satellite[44] to characterize what fraction of the forest is currently forested. These surveys will be conducted every five years

[44] Landsat 8 is the latest satellite launched for the long-running Landsat mission, which is a collaborative effort between the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS. The satellite collects multispectral images of Earth's surface using visible and infrared imaging instruments, and the data collected are freely available from NASA and USGS. Landsat 8 is able to image a point on Earth every sixteen days and has resolutions between 15m and 100m, depending on the sensor. https://landsat.gsfc.nasa.gov/landsat-8/landsat-8-overview/

and used to identify regions of the project area experiencing new growth, as well as those that have experienced disturbances/mortality due to fire, blowdown, pests, or unapproved logging. In this way, Landsat imagery will eliminate the need for whole-forest inventories, which are necessary to ensure that large-scale disturbances are not negating credited offsets. Without satellite data's ability to characterize land-cover, this process can be quite costly due to the size of the project area and the lack of roads and other access infrastructure.

We also plan to use color measurements of foliage reflectance at specific wavebands to map the distribution of tree species within our forests.[45] These data may be collected from a high spatial resolution satellite such as WorldView-2.[46] Characterizing compositional groups by species is important for the aforementioned reason that relationships between carbon biomass and measurements such as height and diameter at breast height are highly variable by species. These forest groupings will be used to inform the design of ground-level survey plots.

Finally, pending access to space-based LiDAR measurements from either NASA's ICESat-2 or the GEDI instrument aboard the International Space Station (ISS), we hope to measure annual changes to forest canopy height. This measurement will be validated using ground-based height measurements made within sample plots and against plane-based measurements of the whole forest. If, and only if, the new space-based measurements agree within acceptable levels of uncertainty, air-based LiDAR measurements will be phased out for the remainder of the project.

(iii.) Education and Research Potential in the Pilot Project

Our proposed pilot project has both capacity for community involvement and co-benefits and high research potential. We seek to take advantage of these factors by proposing a citizen science program and actively seeking collaborative research partnerships with remote sensing groups at institutions like Boston University and the University of Alaska during deployment.

---

[45] E.g. Immitzer, M. Atzberger, C., Koukal, T. (2012) Tree Species Classification with Random Forest Using Very High Spatial Resolution 8-Band WorldView-2 Satellite Data. *Remote Sens.*4(9), 2661-2693.
[46] Waser, L., Küchler, M., Jütte, K., & Stampfer, T. (2014). Evaluating the potential of WorldView-2 data to classify tree species and different levels of ash mortality. Remote Sensing, 6(5), 4515-4545.

(iv.) Citizen Science Initiative

Our citizen science model is designed to train and empower high school and undergraduate students to perform ground-based forest carbon surveys and learn about the project their communities are implementing. The citizen science model benefits our initiative by providing measurements that can be used both to validate carbon offsets according to traditional methods and to calibrate remote sensing data. Similar such citizen science models are being developed both by NASA explicitly for the purpose of calibrating satellite-derived tree canopy height measurements[47], and in Alaska by educators at the University of Alaska Anchorage College of Education.[48]

(v.) Program Structure[49]

The program would be administered by a full-time citizen science coordinator responsible for managing the program, maintaining contacts with teachers and administrators in Kodiak Island Borough schools, and leading annual forest survey trips. Through collaborations with educators at Kodiak College and/or research collaborators (see 'Research Partnerships' section below), the program coordinator may also develop grade-specific lesson plans incorporating forest measurement data into science and math curricula. Due to distance between Kodiak Borough Schools and our proposed forest site on Afognak Island (Fig. 3), surveying trips are best suited to

---

[47] Ramsayer, K. (2019) *Help NASA Measure Trees with Your Smartphone.*https://www.nasa.gov/feature/goddard/2019/help-nasa-measure-trees-with-new-app

[48] Ecojustice research supports place-based science and education (2012). http://greenandgold.uaa.alaska.edu/blog/10399/ecojustice_research_supports_placebased_science_education/

[49] We recommend at least considering a partnership with Mike Mueller, an associate professor of secondary education at the University of Alaska who has proposed work with Kodiak youth to build environmental monitoring programs as a way to translate scientific content knowledge into engagement with local environmental decision-making.
Ecojustice research supports place-based science education. University of Alaska Green and Gold News, 2012. http://greenandgold.uaa.alaska.edu/blog/10399/ecojustice_research_supports_placebased_science_education/. Accessed May 9, 2019.

multi-day trips, with lodging provided at the Discover Bay Cabin, a 10-person cabin in Afognak Island State Park.[50]

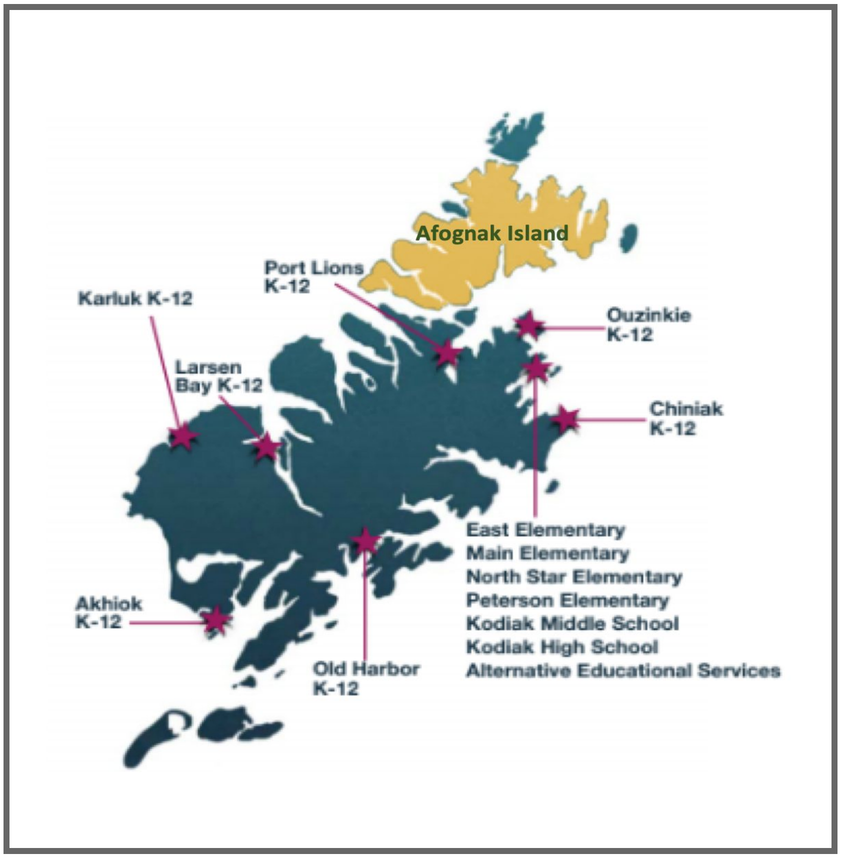


Figure 3: Proximity of Kodiak Island Borough schools (red stars) to Afognak Island (yellow). Image adapted from [*https://www.kibsd.org/Domain/39*](https://www.kibsd.org/Domain/39)

(vi.) Program Benefits

This program will provide place-based environmental education and a pathway to further training in forest management. Because forestry in Alaska supports more than 500 jobs in direct timber harvest and manufacture, with average wages $10,000 higher than the private sector average in Alaska,[51] such a pathway could lead to potential career opportunities for local students. Additionally, there are many more jobs in forest preservation, recreation, and related

[50] Alaska Division of Parks and Outdoor Recreation. http://dnr.alaska.gov/parks/aspcabins/discovererbaycabin.htm
[51] Alaska Resource Development Council. *Alaska's Forestry Industry*. Accessed April 22, 2019. https://www.akrdc.org/forestry

fields with Native Corporation, state, and federal agencies that could also become more accessible to student participants receiving an early background in the field.

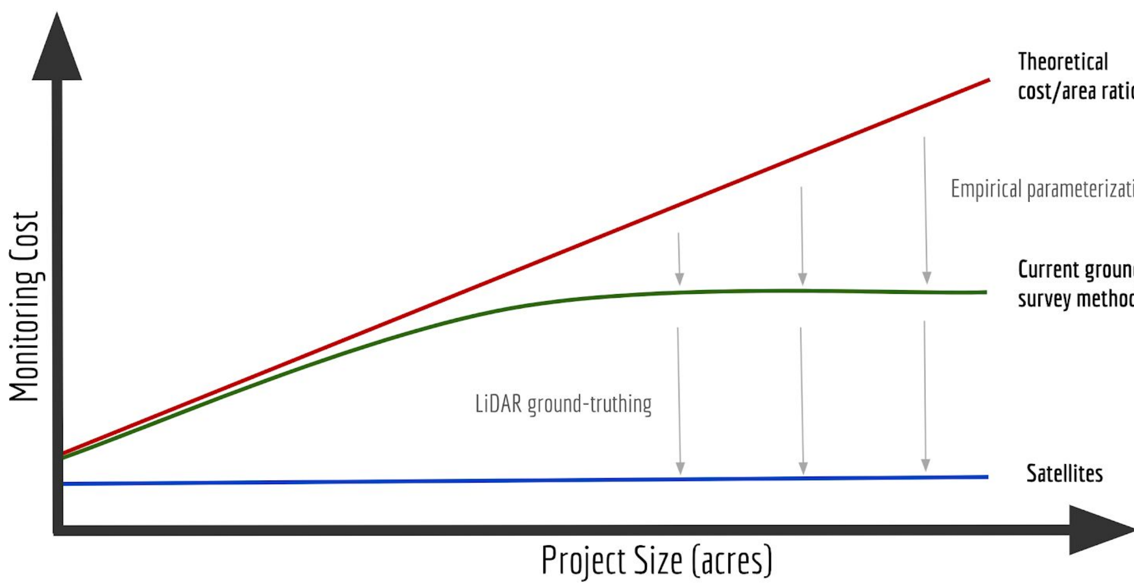
(vii.) Program Liabilities

The program faces a number of substantial transportation and safety hurdles. While Afognak Island is not far from the town of Kodiak (>100 mi from Kodiak to all points on Afognak), they are separated by water and Afognak Island is therefore not accessible by car. As a result, access to the site by citizen science teams will therefore require transportation by boat or float plane. When working in the project area, student scientists may encounter field-specific hazards, such as brown bears, inclement weather, and rugged and/or remote terrain. The bear hazard will require training students to carry and use bear spray before entering the field. Additionally, the citizen science coordinator may need to carry a firearm, and we recommend that members of the group be equipped with emergency beacons.

(viii.) Research Partnerships

Algorithm development for forest carbon monitoring is currently an active area of research in the remote sensing community. However, researchers in this field are often limited by the paucity of reliable ground-based measurements to train and evaluate remote sensing algorithms. This limitation presents a mutually-beneficial partnership opportunity between our project and remote sensing research groups. Utilizing the detailed forest carbon measurements collected through our citizen science monitoring initiative (above), we will have a rich evaluation dataset that our partners can use to develop satellite-based algorithms for classifying land cover, characterizing species composition, measuring the height of the forest as it grows, and estimating carbon sequestration. The success of these algorithms with provide an avenue for the implementation of satellites as cost-effective and accurate carbon offset measuring and monitoring tools.

This partnership will also benefit the broader community of landowners interested in preserving and managing forests for carbon storage by reducing or obviating the need for traditional ground-based measurements in the future. Today, small acreage projects (~ 4000 acres or less) are not feasible because the costs of monitoring are too large relative to the value of offsets produced by the parcel. We found this to be the case with a forest carbon offset project that was developed at the Harvard Forest, but ultimately never implemented.[52] At the same time, while larger acreage projects such as the one we are proposing (over 15,000 acres) achieve economies of scale whereby the monitoring cost per acre falls as acreage grows, the total monitoring cost still continues to grow with acreage (Fig. 4). The remote sensing tools developed through these proposed research partnerships will lower monitoring costs to both small and large project owners, opening carbon finance as a viable option for small forest owners and dramatically reducing costs for large forest owners. In short, the tools developed by project partners will reduce monitoring costs, increasing the financial viability of forest preservation, reducing carbon offset costs, and increasing the size of the IFM carbon offset market.



[52] Hogarty, Lisa & David Foster. *Briefing Memorandum: Recommendation to Establish Carbon Offset Project at the Harvard Forest.* 2013.

Figure 4: A theoretical relationship between project size and the cost of monitoring. If every tree were to be surveyed, the cost would increase linearly with increasing forest acreage (red line). Current forest carbon management methodologies rely instead on a sub-sampling scheme where small plots are established and measurements in those plots are scaled to represent the entire forest. This method usually requires a greater number of plots for a larger or more diverse forest, but the cost per acre decreases as the project grows (green line). Finally, publically-available data from satellites may enable scale-invariant carbon monitoring, with small upfront costs to set up the analysis (blue line).

Specifically, we propose to collaborate with the following institutions and research groups:

1. *Boston University Remote Sensing Group*
2. *Harvard University/Harvard Forest*
3. *Woods Hole Research Center*
4. *University of Alaska Geophysical Institute*

All of the above groups have substantial experience in carbon remote sensing, and are connected with Alaska (UA) or a Massachusetts-based academic unregulated entity (BU, Harvard, WHRC).

(ix.) Other Partnerships

Due to the long-term nature of forest carbon offset projects (often 100 years or greater), many project owners choose to place their land into a management trust with a state or federal government. While the team considered engaging the federal or state governments to ensure long-term protection of the forest, considering the land-dispute history between the Alaska Natives and the US and Alaska governments, the Native village corporations may be justifiably wary of this structure. Thus, the project allocates responsibility for long-term protection only to the Alaska Native Corporation. While strong contractual terms can help ensure the maintenance of the forest over time, the project will gain in legitimacy if the Corporation does a conservation easement of its rights to harvest the forest beyond the IFM practices determined in this project to a land conservation organization ("land trust").

e. Stakeholder Analysis & Project Finance

(i.) Stakeholder Engagement in Status Quo IFM Projects

Typically, IFM offset projects are initiated by a project developer and sold on a carbon offset registry, where they are then purchased by an unregulated entity. Because these projects can be complex, requiring a substantial effort in terms of project discovery and upfront feasibility assessments, the project developer serves a valuable role as an intermediary between the landowner or investor and the carbon offset market. As compensation for the effort, project developer will typically take a minority percentage of the carbon offset sale proceeds (15-25%), or will retain a commensurate portion of the offsets.

Status quo IFM projects, which have multiple co-benefits beyond the carbon sequestration effects, typically cost ~$9-10 per ton of carbon. As shown in Fig. 5 below, these are some of the most expensive offsets on the market. The native village or other local inhabitants usually receive an income stream once the offsets are sold in the market. However, these projects can take one to three years to develop, given the breadth and complexity of feasibility and planning steps required to sell the offsets on the market. Moreover, once listed, the offset credits can often go unsold on the market for another three to five years. Thus, local inhabitants might go up to nearly a decade without receiving the financial benefit of preserving the forest, while typically still facing the financial pressure to log the land instead. Additionally, they are often paid in a lump sum and must be diligent about spreading the wealth out so that future generations may also benefit from the decision to implement the project, often setting up endowments or charitable trusts to do so.

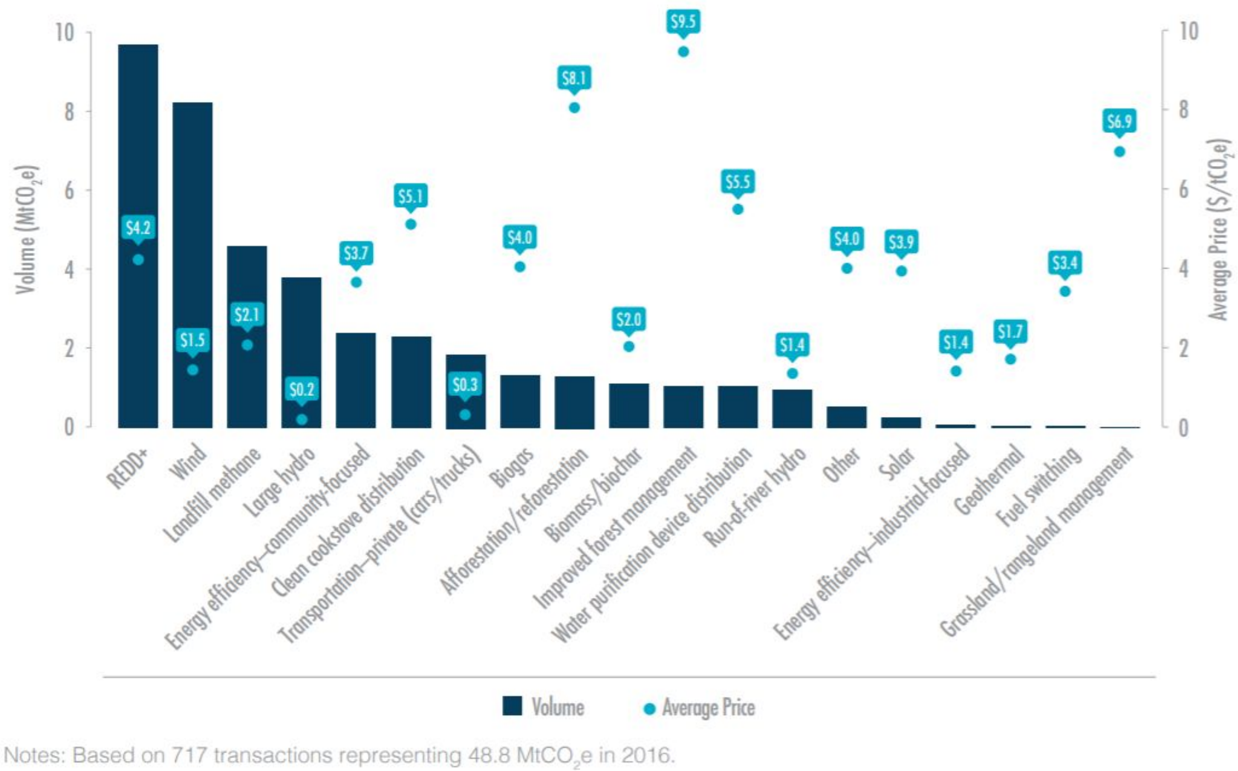


Figure 5: Transacted Volume, Average Price, and Price Range by Project Type of Carbon Offsets Sold in Voluntary Markets, 2016[53]

See Fig. 6 below for a schematic of a typical stakeholder map, using a Native Corporation as the example landowner and an unregulated entity as the example buyer. As noted in the figure, the unregulated entity pays a small premium by purchasing offsets on the market. This premium is mostly driven the developer's need to deliver a return to its investors. It is also driven, to a lesser extent, by the market forces or supply/demand economics: when sold in a marketplace, price is a function of supply and demand (i.e how many other projects are available on the market and how badly other buyers want your project), and thus stakeholders have less control over price clearing as they would if they work collaboratively outside the marketplace.

[53] "Unlocking Potential: State of Voluntary Carbon Markets 2017." Ecosystem Marketplace: A Forest Trends Initiative. May 2017.

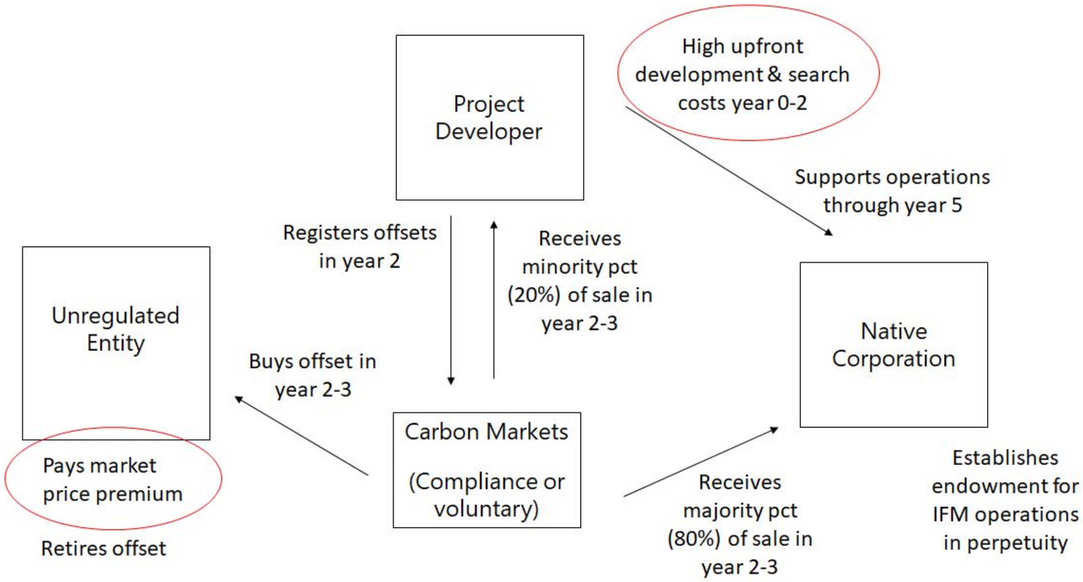


Figure 6: Stakeholders in Typical IFM Offset Project

(ii.) Proposed Stakeholder Engagement & Financial Structure

In implementing this project, we propose that the unregulated entity, as an academic institution, work directly with the Alaska Native Corporation rather than work through a project developer and/or buy IFM offsets on the market. Because the project is employing a novel technology and methodology for carbon monitoring, it is in the best interest of the academic institution and the Native Corporation to develop their internal capabilities in this new research area and be a leader in the emerging space. Moreover, by not engaging with a project developer or selling the IFM offsets through a registry, the parties can create value for themselves by retaining the full economic flow.

It is important that the academic institution and the Native Corporation share in project costs, as it is a partnership. To that end, we propose that the Alaska Native Corporation be responsible for upfront costs associated with project development and ongoing IFM operations. As stated in the Stakeholder Analysis section of the Feasibility study, in a previous iteration of the project, the 2017 CSLL team proposed that an unregulated entity serve as both the "project developer" and the offset buyer. This is not financially attractive for any unregulated entity, which would be better served to buy offsets on the market (wherein a separate project developer took on upfront costs). As such, we believe it is important for the Alaska Native Corporation to be the entity responsible for developing the project and paying the associated upfront costs. The goal is that the Native corporation can build up its expertise in this IFM project development and leverage that internal knowledge base future as a source of revenue for other IFM based offset sales (enhanced by the technology solution we are proposing). The Native corporation may want to consider debt financing to develop the project; however, without a deep understanding of the corporation's financial situation or cost of capital, it is beyond the scope of this project to recommend a financing model for project development.

To compensate the Native corporation for its commitment to preserving the forest, the academic institution will pay an income stream for the twenty-year life of the project. The two parties must come to an agreement about the specific dollar figure for the income stream, but based upon conversations with current project developers in the forest carbon offset space,[54] we recommend beginning the conversation at $6 per ton. Another benefit of this approach is that the Alaska Native Corporation constituents will not have to wait three to five years to receive a payoff, as is often the case with selling the offsets on a registry. Moreover, they can receive annual payments, which should help smooth the lumpiness of income that is typical in the status quo.

(iii.) Project Costs under Proposed Structure

Figure 6 below provides an overview of the project costs, which we expect cumulatively over 20 years to be $6.4 million dollars (in today's dollars). This includes $0.6 million in upfront development costs and ongoing technology reinvestments, $0.8 in ongoing IFM costs, $1.9 million in labor costs to develop the new technological method, and $3.0 million in a payment to the Alaska Native Corporation (all calculated on a net present value basis). Each of these components have been valued separately as distinct valuations should help the stakeholders (the Native corporation and the academic institution) parse out who is responsible for which costs.

[54] Conversation with Mark LaCroix, Executive Vice President of Client Solutions at Natural Capital Partners, on April 18th, 2019.

The project costs are determined by given set of assumption, outlined in Table 2 and Figures 7a and 7b. The upfront costs are informed by conversations with project developers and the 2017 CSLL team report. The technology investment is based around research on the average cost of high fidelity LiDAR units sold on the market today. The cost of IFM is based around U.S. Forest Service reports, which cost general forest management at $40 per acre per decade in high-management-intensity forests (i.e. those that could be harvested for timber).

To implement the new technology solution and refine the monitoring methodology, it will require at least three qualified individuals - one manager of the citizen scientist program, one satellite data analysis expert, and one LiDAR measurement expert. We propose that the academic institution (or a local institution in Alaska) may be able to provide one or more of these individuals and compensate him or her as a researcher or in course credit. Lastly, the payment to the Alaska Native Corporation is based on a $6 per ton of carbon assumption, which equates to $300,000 annual payment, growing with inflation. Notably, the individuals from both parties (Alaska Native Corporation and the academic institution) will need to appropriately validate all assumptions in Figure 6 and in the corresponding cost build in Figure 7. Please see CSLL Team 4 Financial Model (Excel document) for a dynamic cost build.

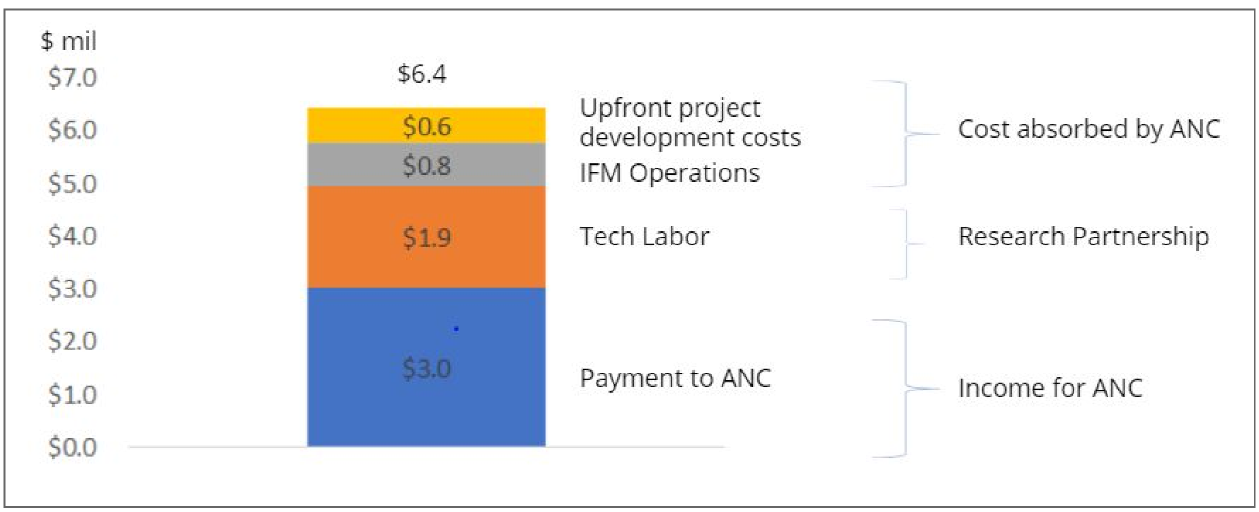


Figure 6: Breakdown of Project Costs

Assumptions		Notes
General		
Inflation	2.5%	
Discount Rate	10.0%	
Project		
Project years	20	
Target offsets per year sold/retired (tons)	50,000	
Buffer: Leakage	5.0%	
Buffer: Permanance	10.0%	Buffers equatable to project insurance (eg risk of fire captured in permance buffer)
Buffer: Project Uncertainty	10.0%	
Total required offsets to meet target with buffers	66,667	
Offset per acre	80	Based on metric of 4 offsets per acre per year (VERRA standard) for 20 years
Acres needed	16,667	
Cost of IFM per acre per 10yrs	$40	USFS estimate for general forest mgmt in high intensive forests (www.fs.fed.us/pnw/pubs/pnw_gtr684.pdf)
Technology		
Fixed cost for ground-based LiDAR unit	$70,000	Low fidelity LiDAR units costs $4-5K, high fidelity, research grade units average $65-75K
Average life of LiDAR unit (years)	4	
Number of employees	3	One citizen scientist manager, one satellite data analysis expert, one LiDAR measurement expert
Cost per employee	$60,000	Base salary of $45,000 plus benefits
Satellite data acquisition costs per year	$10,000	Most data is publicly available, included conservative estimate for data that may have usage fees
Upfront Project Costs		
Initial Feasibility Assessment	$25,000	Estimates based on 2017 CSLL team report and conversations with project developers
Project Development, Business Planning & Financ	$50,000	
Legal/Contracting Costs	$30,000	
Training Costs for IFM	$100,000	
Biodiversity Assessment	$40,000	
Health Impact Assessment	$100,000	
Offset Verification & Validation Costs	$70,000	Verification events are required every 6 years and cost $40,000; offset validation cots are an additional $30,000.
Total	$415,000	

Table 2: Assumptions for Project Cost Build

Total Project Cost: Years 0-10			2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
	NPV	Year	0	1	2	3	4	5	6	7	8	9	10
Upfront Costs													
Feasibility Assessments			($415,000)										
Technology Investment			($70,000)				($77,267)				($85,288)		
Total	($162,223)		($485,000)	$0	$0	$0	($77,267)	$0	$0	$0	($85,288)	$0	$0
Payment to Native Corporation													
Fee per Ton				($6)	($6)	($6)	($6)	($7)	($7)	($7)	($7)	($7)	($7)
Tons per year				50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Total payment	($3,025,720)		0	($300,000)	($307,500)	($315,188)	($323,067)	($331,144)	($339,422)	($347,908)	($356,606)	($365,521)	($374,659)
Cost of IFM													
Cost per acre				($40)									
Number of acres				16,667									
Total cost	($839,723)			($666,667)	$0	$0	$0	$0	$0	$0	$0	$0	$0
Ongoing Operating Costs													
Satellite data acquisition costs				($10,000)	($10,250)	($10,506)	($10,769)	($11,038)	($11,314)	($11,597)	($11,887)	($12,184)	($12,489)
Labor (Analytics)				($180,000)	($184,500)	($189,113)	($193,840)	($198,686)	($203,653)	($208,745)	($213,963)	($219,313)	($224,795)
Number of employees				3	3	3	3	3	3	3	3	3	3
Cost per employee				($60,000)	($61,500)	($63,038)	($64,613)	($66,229)	($67,884)	($69,582)	($71,321)	($73,104)	($74,932)
Total	($1,916,290)		0	($190,000)	($194,750)	($199,619)	($204,609)	($209,724)	($214,968)	($220,342)	($225,850)	($231,497)	($237,284)
Net Project Gain / Loss			($485,000)	($1,156,667)	($502,250)	($514,806)	($604,943)	($540,868)	($554,390)	($568,250)	($667,744)	($597,017)	($611,943)
NPV of Project - before Upfront Costs	**($5,943,957)**												
Upfront Costs	($485,000)												
Total Project NPV	**($6,428,957)**												
Effective Cost per Offset Sold/Retired ($/ton)	**($5.94)**												
*Assumes 50,000 offsets per year for 20 years													

Figure 7a: Detailed Cost Build, Years 0-10

Total Project Cost: Years 11-20	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039
	11	12	13	14	15	16	17	18	19	20
Upfront Costs										
Feasibility Assessments										
Technology Investment		($94,142)				($103,915)				($114,703)
Total	$0	($94,142)	$0	$0	$0	($103,915)	$0	$0	$0	($114,703)
Payment to Native Corporation										
Fee per Ton	($8)	($8)	($8)	($8)	($8)	($9)	($9)	($9)	($9)	($10)
Tons per year	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Total payment	($384,025)	($393,626)	($403,467)	($413,553)	($423,892)	($434,489)	($445,352)	($456,485)	($467,898)	($479,595)
Cost of IFM										
Cost per acre	($40)									
Number of acres	16,667									
Total cost	($666,667)	$0	$0	$0	$0	$0	$0	$0	$0	$0
Ongoing Operating Costs										
Satellite data acquisition costs	($12,801)	($13,121)	($13,449)	($13,785)	($14,130)	($14,483)	($14,845)	($15,216)	($15,597)	($15,987)
Labor (Analytics)	($230,415)	($236,176)	($242,080)	($248,132)	($254,335)	($260,694)	($267,211)	($273,891)	($280,739)	($287,757)
Number of employees	3	3	3	3	3	3	3	3	3	3
Cost per employee	($76,805)	($78,725)	($80,693)	($82,711)	($84,778)	($86,898)	($89,070)	($91,297)	($93,580)	($95,919)
Total	($243,216)	($249,296)	($255,529)	($261,917)	($268,465)	($275,177)	($282,056)	($289,107)	($296,335)	($303,744)
Net Project Gain / Loss	($1,293,908)	($737,065)	($658,996)	($675,470)	($692,357)	($813,581)	($727,408)	($745,593)	($764,233)	($898,042)

Figure 7b: Detailed Cost Build, Detailed Cost Build, Years 11-20

(iv.) Funding

As mentioned in the previous sections, it will be the joint responsibility of the Alaska Native Corporation and the academic institution to fund the project. Without knowing either parties' unique capital structure, we cannot recommend a financing vehicle (i.e. debt, equity, or cash). However, we recommend, especially for the labor costs, to rely upon internal resources (educational groups, research partnerships), wherever possible.

To that end, we propose that the parties (jointly or separately) apply for United States Department of Agriculture (USDA) and Natural Resources Conservation Service (NRCS) grants set aside for forestry land management projects that have demonstrable ecological and climate benefits. This funding could include, but is not limited to, the 2014 U.S. Farm Bill,[55] the McIntire-Stennis Capacity Grant for forestry research and training future forestry scientists,[56] the Renewable Resources Extension Act-National Focus Fund Projects Grant for pilot projects that

[55] United States Congress. *The Agricultural Act of 2014*. Washington, D.C., 2014. https://www.congress.gov/113/bills/hr2642/BILLS-113hr2642enr.pdf. Accessed March 2, 2019.
[56] USDA McIntire-Stennis Capacity Grant. https://nifa.usda.gov/program/mcintire-stennis-capacity-grant. Accessed March 2, 2019.

address emerging and nationally or regionally relevant forest resources issues,[57] and the AFRI Resilient Agroecosystems in a Changing Climate Challenge Area Grant designed to provide funding for projects that provide ecosystem services while also attempting to better understand ecosystems response in a changing world.[58] Funding from sources such as these would displace costs related to implementing the IFM- and citizen science- related components of the project, such as the contracts with the certified forester or the citizen science program coordinator, as well as the costs of any harvesting associated with ERA practices.

f. Social and Health Co-Benefits

While the IFM practices, monitoring, and carbon sequestered will be confined to the chosen area of land, there will likely be co-benefits that directly impact members of the local community and potential risks for those who choose to be involved in the monitoring processes.

Because our proposed project takes place in the close vicinity of community residential areas, it is important to understand the characteristics of the local community and the potential impacts that this project could have on their health and well-being. It is even more important because the local community of 13,592 residents that constitute Kodiak Island Borough is made up of 13% Alaska Native or American Indians.[59] This portion of the population is particularly vulnerable to impacts from the project because of their subsistence fishing practices as well as their vulnerability to having their culture disrupted by outsiders. Health-wise, the residents of this borough have social and health determinants that are above average when compared with national statistics on poverty, unemployment, obesity, and health care access, but there have been recently worsening outcomes concerning mental health and poverty.[60] Because the only

---

[57]USDA RREA-NFFP Grant. https://nifa.usda.gov/funding-opportunity/renewable-resources-extension-act-national-focus-fund-projects-rrea-nff. Accessed March 2, 2019.

[58] USDA AFRI Resilient Agroecosystems Grant. https://nifa.usda.gov/program/afri-resilient-agroecosystems-in-a-changing-climate. Accessed March 2, 2019.

[59] 2010 US Census.

[60] Kodiak Island Community Health Needs Assessment 2016, Providence Kodiak Island Medical Center. Available at: https://communitybenefit.providence.org/~/media/Files/Providence%20AK/PDFs/2016_Community_Health_Needs_Assessment_Providence_Kodiak_Island_Medical_Center_Kodiak.pdf

available health data was at the borough level, we were unable to obtain detailed health information that was specific to Natives in the region.

(i.) Main Project Benefit: Social Cost of Carbon

As with any large-scale project, there is a direct benefit (the reasons why we first became interested in doing the project) and multiple co-benefits and potential risks that likely to occur when doing the project. All aspects of these benefits and potential risks should be considered in order to responsibly understand the full impacts of the project. For our direct benefit, carbon sequestration, the social cost of carbon was calculated to quantify the many benefits to the planet that encompass climate change mitigation.

The Social Cost of Carbon (SCC) is a popular methodology that attempts to value and quantify estimated damages associated with an incremental increase (or damages avoided from a decrease) in CO_2 emissions in a given year. This measure is intended to include but is not limited to change in net agricultural productivity, human health as measured in morbidity and mortality, property damages from flood risk, and the value of ecosystem services.[61] The SCC does not have a universally accepted value because of debate on what is to be included in the calculation of estimated damages from an increase in CO_2 emissions. In 2017, Harvard worked to estimate its own SCC and settled upon $40/ton of CO2 as a conservative estimate to use in calculations of damages. This estimate will be used in this project because an academic institution such as Harvard is one of our primary potential investors in this project.

With an SCC of $40/ton, we can calculate the global benefits that will accrue from the sequestering of carbon in our IFM project. With an expected 50,000 tons CO_2/year sequestered from our 20-year project and considering net present values of carbon sequestration in our analysis, we obtain $16.2 million as the estimated value of our project's global benefits to health and welfare.

---

[61] https://www.epa.gov/sites/production/files/2016-12/documents/social_cost_of_carbon_fact_sheet.pdf

(ii.) Other Co-Benefits and Potential Risks

For the co-benefits and potential risks, we decided to consider performing a health impact assessment (HIA) due to the vulnerability of the Alaska Native populations to ensure that these populations do not incur substantial damages from the project implementation . After performing a brief literature review on the potential impacts of general IFM practices, we did not anticipate there to be any large harmful impacts to the community from IFM practices and changes in monitoring. Thus, we limited our analysis to a Rapid HIA.

In our Rapid HIA, we began by systematically considering impacts from six categories that were deemed relevant in a 2015 document by the Alaska Department of Health and Social Services: "Technical Guidance for Health Impact Assessment in Alaska."[62] The full results of this scoping of potential impacts is shown in the causal chain diagram below: Figure 8.

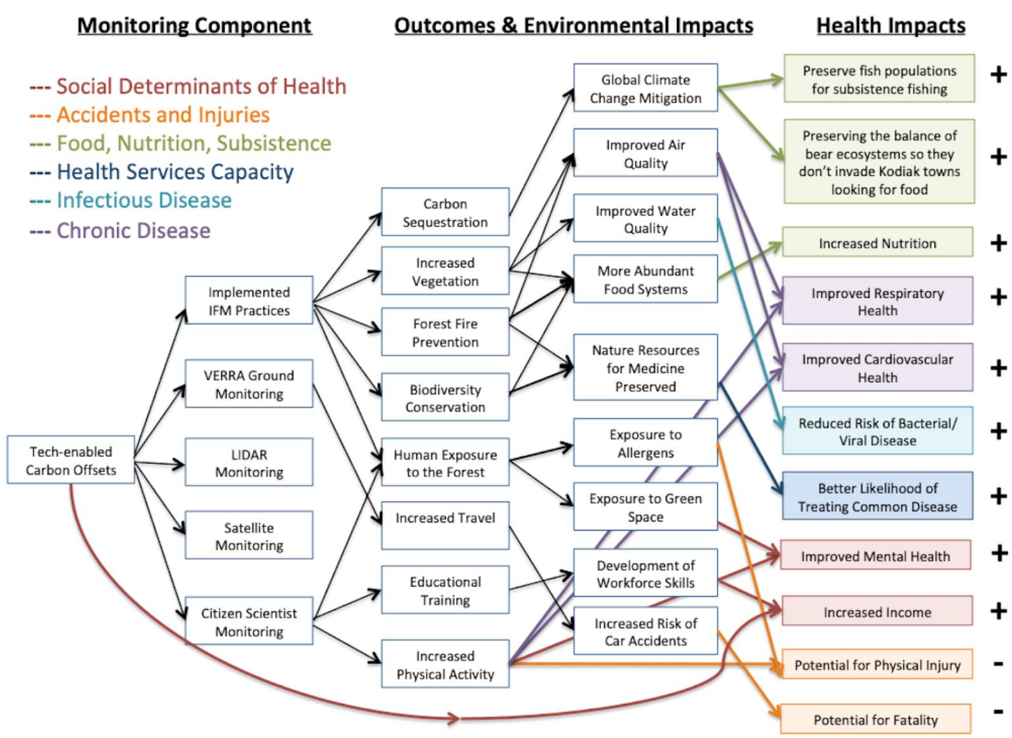


Figure 8: Causal Chain of Potential Environmental and Health Impacts from our Project

---

[62] HIA Publications. (n.d.). Retrieved April 23, 2019, from http://dhss.alaska.gov/dph/Epi/hia/Pages/pubs.aspx

As is shown by the lack of arrows stemming from LiDAR and satellite monitoring, our proposed tech-based monitoring techniques have no significant impacts to the environment or health of the community because they are non-invasive to the forest environment, monitor the forest from the air, and do not require in-person set-up or operation by humans. Thus, most of our impacts come from the IFM practices, the traditional Verra practices of ground monitoring, and citizen science monitoring. Although the particular IFM practices have not yet been chosen by a professional forester, these health impacts were derived from a general assumption that the IFM practices would consist of protection of riparian zones and slopes, extended rotation age, and better harvesting practices.

(iii.) Top 3 Health Impacts

Once the full range of potential health benefits and damages was scoped out, each impact was ranked based on its estimated impact on health, duration, magnitude, extent, and likelihood to better understand what the most significant impacts of the project might be using a ranking methodology from the "Technical Guide for Health Impact Assessment in Alaska"[63] (See Appendix for ranking and rating criteria). This ranking and rating process is briefly shown in the figure below and the top three impacts were identified and analyzed further.

[63] http://dhss.alaska.gov/dph/Epi/hia/Documents/AlaskaHIAToolkit.pdf

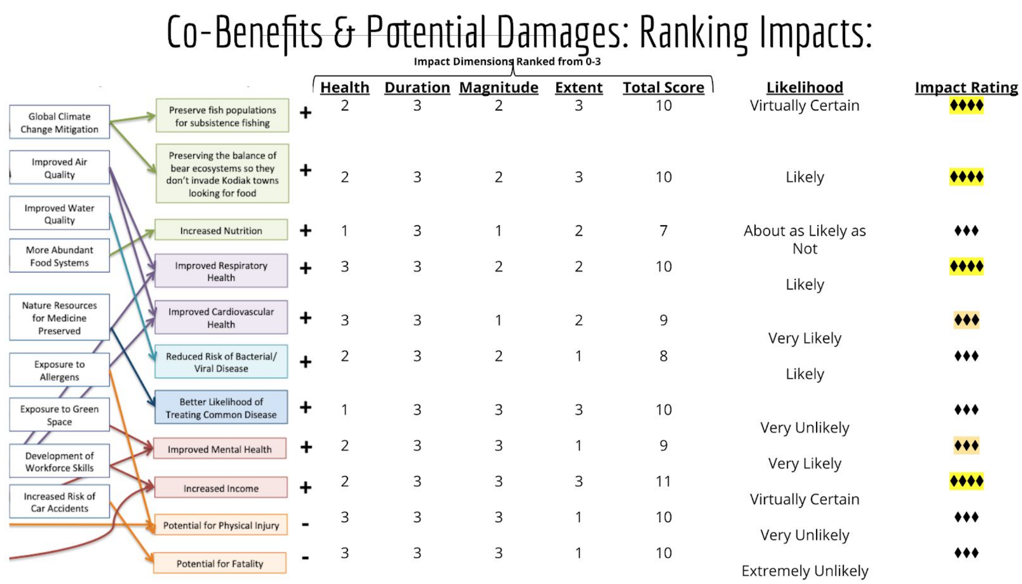


Figure 9: Results of Ranking Impacts Exercise

1. Preservation of Ecosystem & Subsistence Fishing

Due to the Alaska Natives' reliance on subsistence fishing and their cultural valuation of the natural environment in which they live, it is important to ensure that the ecosystem is preserved so as not to disrupt the ecological balance from which the residents thrive. Climate change is a direct threat to this ecological balance as climates warm causing growing seasons and pink salmon migration patterns to change. Effects have already been felt as the berries in the region have begun to become mature earlier in the year. The bears of the region typically eat both berries and pink salmon but prefer berries alternate between the two food sources at different times of the year. As berries become more abundant earlier, the bears have been found to stop eating pink salmon so that they can spend more time eating berries. Then when the berries are gone, the pink salmon season is close to an end and the bears do not have adequate time to meet their protein needs. This causes the bears to become hungrier than they otherwise would be, and they have been reported wandering into towns looking for additional food.[64] Meanwhile, the pink

64 https://www.anchoragepress.com/columnists/global-warming-and-climate-change-are-real-and-kodiak-bears/article_ee2747be-f39c-11e8-9090-e33054c253f9.html

salmon population is overpopulating leading to a risk of collapse of the other types of salmon that the Native residents rely on.

By sequestering carbon in our proposed project, we will be helping to slow the climate change that is causing these issues and thus will indirectly help to preserve the ecological balance that benefits the bears, salmon, and Native fisherpeople. In addition, the IFM practices in the forested areas can directly provide habitats for animals of the ecosystems and possibly provide additional sources of food for the bears to solve the issue of bears invading towns in the short-term.

2. Improved Cardiovascular and Respiratory Outcomes

Due to the implementation of IFM practices, there will likely be a decrease in both the frequency of severity of wildfires in the forested lands due to increased awareness of the forest's condition, thinning of highly combustible matter, and when appropriate, prescribed burnings.[65] This is great news for our project to ensure permanence of carbon sequestration, but beyond the interests of our project, fewer wildfires have the co-benefit of less air pollution from wood smoke.

As climate change warms Alaska at twice the global rate, the occurrence of large wildfires have increasing each year.[66] In some instances, fires have spread to nearby villages and have destroyed homes.[67] But while the property damage from wildfires only affects some residents in the Kodiak Island Borough, the larger effects are the health effects felt by all residents who breathe in high concentrations of toxic particulate matter from the smoke. Particulate matter has garnered attention in the past 20 years of research and has been demonstrated to cause respiratory inflammation, lung cancer, cardiovascular disease, and other forms of cardiorespiratory disease due to its ability to lodge deep within the cells of the lungs. Scientists have repeatedly found associations between wildfire occurrences and increased hospital admissions for asthma attacks.

---

[65] https://www.greenbiz.com/article/better-forest-management-wont-end-wildfires-it-can-reduce-risks-heres-how
[66] http://assets.climatecentral.org/pdfs/AgeofAlaskanWildfires.pdf
[67] https://www.adn.com/alaska-news/article/wildfire-destroys-library-kodiak-island-village-prompts-evacuation-advisory/2015/08/28/

On the chronic scale, exposure to particulate matter has also been associated with premature mortalities. The fewer particulate matter sources there are, the less exposure residents will have to the toxic particles that cause morbidities and mortalities. Thus, by implementing IFM practices, our project has the potential to decrease the likelihood of future fires in this region and subsequently protect the respiratory and cardiovascular health of the Kodiak Island Borough residents.

Our project also has the potential to improve respiratory and cardiovascular outcomes in an additional way: through physical exercise. With less smoke from wildfires, residents will have more opportunities to be outside and exercise. Also, the engagement of high school students in our citizen science program will require them to spend time outdoors walking in nature. These increased instances of physical activity can improve respiratory and cardiovascular functioning, especially in youth who are so susceptible to both damages from the surrounding environment and can improve the conditioning and functioning of their lungs and heart through exercise.

3. Increased Income for Native Shareholders

One of the most effective ways that our project has the potential to improve community health is simply by creating a revenue stream for the Native residents who have shares in Corporation. There is a clear and established link between poverty and health.[68] Those who do not live in poverty have the increased agency to obtain health insurance, seek medical care when needed, purchase healthier foods, and improve their immune system responses through decreased stress.

In Kodiak Island Borough, the Kodiak Island Community Health Needs Assessment reported that the percent of people with a household income of less than $20,000 has doubled between 2013 - 2016.[69] It is then apparent that increasing household income through the revenue streams of our project has great potential to increase residents' quality of life, health, and well-being

68
https://www.healthypeople.gov/2020/topics-objectives/topic/social-determinants-health/interventions-resources/poverty#5
69 HIA Publications. (n.d.). Retrieved April 23, 2019, from http://dhss.alaska.gov/dph/Epi/hia/Pages/pubs.aspx

(iv.) Recommendations

When implementing our proposed project, the unregulated entity should keep in mind that the current health status of Alaska Natives in the Kodiak Island Borough may differ from that which was measured of the entire borough's population in the 2016 Community Needs Assessment. Because of this reason, we recommend that stakeholders are directly involved in discussions about impacts of the project and that they are given time to convey their specific health concerns. These discussions should include considerations of any additional negative impacts that need to be addressed as well as brainstorming about ways to enhance and maximize positive benefits through the most appropriate IFM practices and community engagement. Fisherpeople, student and citizen scientists, Alaska Native shareholders, and Alaska Native Corporations managing the lands should be present at these discussions so that all types of local perspectives are considered.

g. Project Timeline and Plan

In order to ensure that all stakeholders are appropriately consulted and our proposed project is set up with adequate funding and contracts, the following five phases have been proposed for implementation:

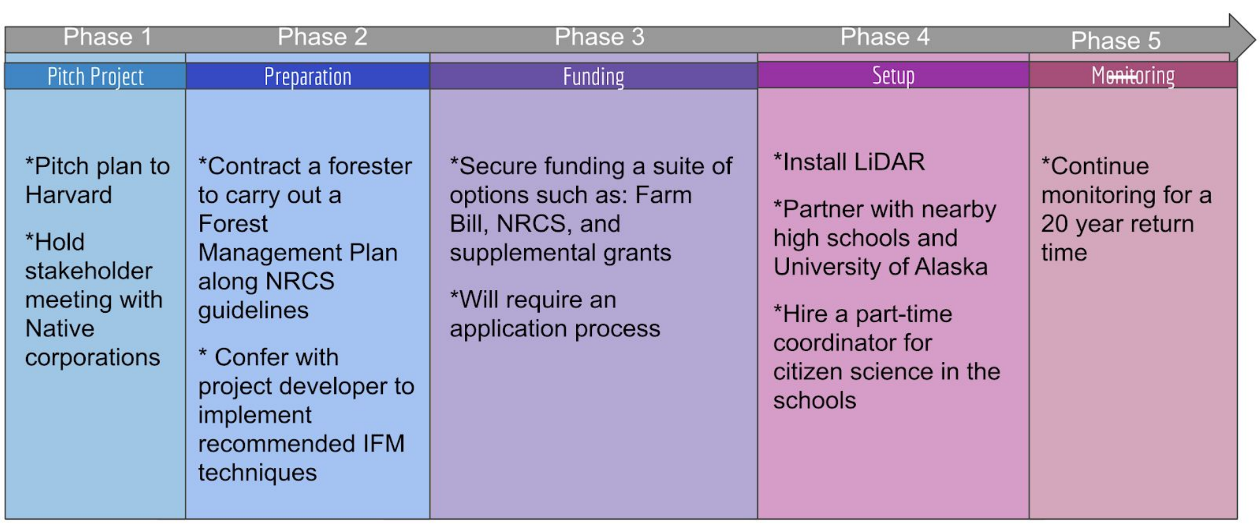


Figure 10: Project Implementation Timeline

(i.) Phase 1 - Pitch Project

In Phase I, we will pitch our proposed project to both the investors (Harvard or other academic institution) and the stakeholders who reside in the Kodiak Island Borough. At this time, we intend to address any new concerns about the impacts of our project on the community, and choose the Alaska Native Corporation with shareholder input that will benefit the most from improved forest management practices.

(ii.) Phase 2 - Preparation

Once the Alaska Native Corporation is chosen and the land is set aside for the project, a forester will be hired to carry out a NRCS compliant forest management plan that will assess the land and propose the most appropriate IFM practices that will be implemented. The chosen IFM practices will then be communicated to the project developer and a more detailed financial and health assessment can be made to inform the investors and stakeholders of the exact costs and benefits of the project.

(iii.) Phase 3 - Funding

With more accurate estimates of the financial costs and a more formulated project proposal, we will apply for federal and supplemental grants such as the Farm Bill to help with the additional setup costs of our tech-enabled monitoring pilot program.

(iv.) Phase 4 - Setup

Setup in the forest will consist of formally setting aside the land for the project and installing the airborne LiDAR technology in the forest at the most representative parts of the forest. Set-up in the community will consist of hiring a full-time coordinator for the high school citizen scientist program, identifying interested students who could benefit from the monitoring program, and partnering with local schools to engage in education about the project and assist with monitoring.

(v.) Phase 5 - Monitoring

Monitoring via traditional Verra ground-based methods will occur every 5 years for the 20-year length of the project. Also during that time, satellite data, LiDAR measurements, and supplemental citizen scientist data will be collected annually and analyzed to prove the concept of tech-enabled monitoring for forest carbon sequestration projects. If the tech-enabled monitoring proves to be as accurate or more accurate than the traditional Verra monitoring methods, then the methods will be proposed to Verra and will continue to be used during the required permanence period following the length of our pilot project.

FEASIBILITY STUDY:

1. Initial Project Screening

There are a variety of project types capable of generating legitimate, creditable carbon offsets; some are designed to directly reduce greenhouse gas emissions, others increase energy efficiency or decrease heat production, and still others employ land use management techniques in order to sequester additional carbon dioxide. During the initial project selection stage, our team was presented with potential project outlines from each of these areas, developed in earlier iterations of Harvard Law School's *Climate Solutions Living Lab* course. We chose to further develop a forest sequestration project based in Kodiak, Alaska for multiple reasons. First, we remained unconvinced by the scalability and economic practicality of the three alternative projects (alley cropping in Missouri, improved nitrogen fertilizer management, and urban forests as a mechanism for heat uptake). Second, forest sequestration projects exhibit demonstrable viability as investment projects within the voluntary carbon offset market, and interest in this project specifically by Alaska Natives specifically has already been expressed.[70] Finally, the previous version of this forest sequestration project leaves noticeable room for improvement in the the realm of sequestration measuring and monitoring, improvements which could be more widely applied in similar forest carbon offset programs across the globe.

The fact that many carbon offset projects generate co-benefits as well as offsets makes them even more attractive as investment options. Furthermore, in some cases, the value of the co-benefits actually outweighs that of the offsets. We found this to be the case with projects such as urban heat uptake and alley cropping.[71] While this is far from negative, we would like to emphasize the utility of our project toward greenhouse gas emissions reductions goals and develop a project whose central and most profitable component furthers those goals in the most

[70] Michael Haggerty, "Memorandum: Report on Site Visit to Anchorage, Alaska on May 15-17, 2018," Cambridge, MA, 2018.
[71] Johan Arango-Quiroga, Chan, D., Germ, A., Romero, H., Shields, A., Wagner, C., "Alley Cropping in Missouri," Cambridge, MA, 2018.

effective manner. In some sense, the nitrogen fertilization management proposal combines the best of both worlds. Improving nitrogen management limits nitrogen pollution and the accompanying suite of negative side effects while simultaneously reducing the generation of nitrous oxide, a greenhouse gas with a high global warming potential. On the other hand, nitrous oxide emissions comprise only 4.4% of global greenhouse gas emissions.[72] They are also difficult and expensive to measure and monitor-- satellites measurement is not an option and current methods are limited to such choices as soil chamber experiments (which are costly and not necessarily representative of landscape fluxes) and eddy flux tower measurements (limited in range and not well suited to quantifying diffuse agricultural fluxes). Moreover, we are limited in our ability to understand the broader realities of farming, including the everyday and long-term working economics. Therefore, in our view, the greenhouse gas emissions reductions offsets from a nitrogen management project would be minimal in comparison to those generated by a successful forest sequestration project.

The additional attraction of the forest sequestration project lies in the added value that could be obtained through the improvement of sequestration measuring and monitoring techniques and the minimization of verification costs. Currently, sequestration measurements are obtained from modeling exercises based upon field measurements of tree height, width, and species; monitoring consists of rerunning the models periodically. A less expensive, more expansive method of gathering parameterizing measurements could significantly improve the precision of carbon sequestration calculations. Furthermore, investors willing to forgo the official verification standards in favor of an alternative method may be able to avoid the added cost of standard verifications, increasing the value and desirability of the offset.

[72] Climate Action Reserve, "Nitrogen Management Project Protocol Version 2.0," 2018.

2. Alaska Project: Areas of Improvement

a. Narrowing down on locality

(i.) Specificity in IFM features based on location

Because IFM describes a suite of different management strategies designed to address disparate land-use concerns rather than a single generalized solution, incorporating any IFM practice requires careful consideration of the chosen project site due to variability in the natural conditions of the forest and the dominant tree species.

Regardless of all else, in order to apply IFM for the purposes of generating carbon offsets, the chosen site must be forested and previously managed in some form. A change in management resulting in otherwise unintended sequestration (that would not have been generated without the project) and additional carbon sequestration must be put into place. The change in management typically falls into one of three broad IFM categories: better harvesting practices, protection measures, and growth practices.

These practices have been outlined in detail in the Implementation Plan (see Design and Challenges: IFM Practices, Table 1). For the purposes of choosing a location where an IFM project is feasible, the following must be take into account:

Implementing better harvesting practices requires an in-depth knowledge of the terrain, existing road infrastructure, previous management practices, and forest composition to maximize the benefits of initializing a change in harvesting practice.

In order to successfully incorporate protection practices, a project must carefully select a site that will be truly additional. If there is sufficient proof of additionality -- demonstration that preserving the forest would not have happened without the incentive provided by an offset project -- the forest then becomes a valid source of carbon offsets.

Growth practices -- including low-to-high production (LtHP) projects and extended rotation age (ERA) strategies -- require either: (a) a site that has not approached peak productivity and is ecologically capable of responding to management (i.e. soil is amenable to seedling establishment); or (b) a forest that is relatively homogeneous and whose primary stock species reach harvestable age within a few decades.

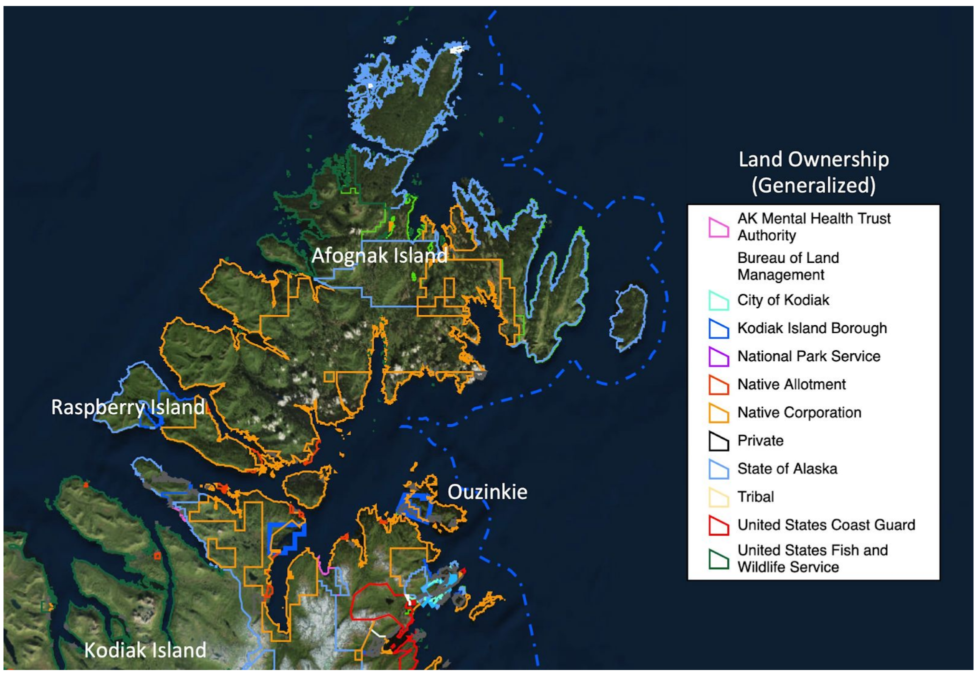


Figure 11: Land cover type and ownership on Raspberry and Afognak Islands. Afognak Island is by far the most heavily forested component of Kodiak Island (indicated by darker green cover types) and much of it is owned by Native corporations, shown in orange outlining.[73]

The Native-owned sites on Raspberry and Afognak Islands investigated by the previous Forest Sequestration+ project are dominated by Sitka spruce, a fast-growing and valuable timber species native to Alaska (Figure 11). Previous management practices are somewhat unclear from a first round survey, though the Afognak, Lesnoi, and Ouzinkie corporations have each actively logged some portion of their lands and have expressed interest in shifting management practices while maintaining their forests as resources for subsequent generations. A final feasibility

[73] http://kiborough.maps. arcgis.com/apps/Viewer/index.html?appid=2700ff448c8944 24941a203264c04e2f

decision regarding our project proposal will depend upon an accurate characterization of the land available for implementing any of the previously outlined IFM practices, and therefore depends upon the Alaska Native Corporations who choose to implement the project.

(ii.) Kodiak Island Community/Corporation Selection

To make the project more tangible, it is being piloted with the communities on Kodiak Island in mind, located roughly 250 air miles south of Anchorage. Meetings in Alaska carried out by the former project team pointed out that the initiative might be appealing to a smaller native village corporation like the Ouzinkie Native Corporation[74], for whom $2-3 million would be a significant sum. Ouzinkie owns a little less than 100 thousand acres and has around 500 shareholders. On the other side, the Afognak Corporation[75], which owns 321 thousand acres on the island and is a worldwide investor, might also be interested in this pilot project, with the intention of expanding it in the future. The Alaska Native residents of Kodiak are mostly of Russian Aleut ancestry, and engage in a traditional subsistence lifestyle.

(iii.) Stakeholder analysis

The role and interests of the main stakeholders which would be directly or indirectly engaged in this project are:

Unregulated entity

Role: Funds the project through the payment for carbon credits.
Interests: Is interested both in the carbon credits to offset its own carbon emissions and the additional social/environmental benefits of the projects. These additional benefits are what will make the project attractive the unregulated entity, since it could offset its emissions for a lower

---

[74] Corporation's website: www.ouzinkie.com
[75] Corporation's website: www.afognak.com/about/

price than the one being proposed in this project will cost by buying credits off the “shelf”. Considering that the unregulated entity is a research university such as Harvard, the project’s research will also increase the entity interest in the project.

Native village corporation

Role: Owner of the lands where the project will be carried out and manager of the implementation activities.

Interests: Alaska Native Corporations have a very particular focus, seeking to both preserve the Native culture and distribute profits to their shareholders[76]. The corporation will thus probably want to see a sufficient flow of revenue to engage in the project. As the landowner(s), they might also be skeptical as to what rights they are giving up to engage with this project, and what responsibilities they are be assuming. Since similar projects have been carried out in Alaska in the past few years (by the Sealaska, Ahtna and Chugach corporations), there is precedent for forestry carbon initiatives.

Villagers/stakeholders

Role: Main beneficiaries of the project. Part of them will be engaged directly in the project (see “Citizen Scientists” below).

Interest: Native people living in Alaska have a challenging dual position of both villagers and stakeholders in a corporation. In their role as villagers, their interest probably lie in increasing their quality of life (more employment, more leisure opportunities, higher education, health, etc.), and might look at this project as an opportunity to receive direct benefits which speak to these interests. As traditional hunter/gatherers, nature is part of their subsistence. In their role as stakeholders in the corporation, they are also concerned about partaking in economically advantageous projects, such as this is designed to be[77].

---

[76] Dombrowski, Kirk (2001). Against Culture: Development, Politics, and Religion in Indian Alaska. U of Nebraska Press. p. 75. ISBN 0803266324. Retrieved 1 December 2014.

[77] **Developing America's Northern Frontier**, Theodore Lane, ed. University Press of Amica, 1987. Chapter 7: Incompatible Goals in Unconventional Organizations: the Politics of Alaska Native Corporations, pp. 133-157. Available at: www.alaskool.org/projects/ancsa/t_lane/IncompatibleGoals.htm. Accessed on March 10th 2019.

Citizen scientists

Role: Support the monitoring process.

Interests: The group of citizens engaged in measurement/monitoring might be interested in learning a new skill set and having an additional income. They will probably be interested in understanding how much engagement is expected from them, what their possible additional revenue might be and how these skills might be useful in the future.

Research arm of the unregulated entity and partner research institutions

Role: Support the monitoring component of the project.

Interests: Researcher institutions might be interested in better understanding the carbon capturing capacity of Alaskan forests and producing knowledge around the topic.

Investor

Role: Enabling the project through investment of funds.

Interests: In the 2017 CSLL Forestry Team project, the role of the unregulated entity was not only as the offset buyer, but also as the "investor" in the project as it provided an upfront payment to the village corporation to complete the work (equivalent to half of the value of the offsets). In this configuration, the unregulated entity was responsible for too much - typically the "investor" or developer and the buyer are not the same entity. However, if the project can produce an alternative revenue streams (e.g. IFM with sustainable timber harvesting or remote sensing technology fees), as discussed in the Financial Analysis section, then the project may be able to attract an alternative investor (e.g. responsible investment firm). In such case, the unregulated entity would be solely the offset buyer (or could close any gap between investment and needs) and the investor would provide the upfront capital (likely through debt financing) and will see a return on that capital. The "return" could be payments back to the investor (i.e. interest payments) by the native corporation, derived from profits of the project (offsets, timber revenue, etc). If the native corporation can reduce its costs (i.e. through our tech-enabled solution with village-participation), this could lead to larger profits for the corporation and higher returns for the investor.

(iv.) Replicability of the case targeted

This project is being designed with two very particular elements:

1. Working with Alaska Native groups: Considering that Alaskan Native communities are one of the most underserved populations in the United States, this project can add significant social value by generating an influx of capital and other benefits such as technical training and improvements in the urban infrastructure. While a specific community on Kodiak Island (the Afognak Native Village) was investigated in more detail by the team, the project would most likely be easily adaptable to other Alaska Native Corporation groups that reside in Alaska due to their similar organizational structure.

2. An academic institution acting as unregulated entity: This project is designed for an academic institution as the unregulated entity buying the carbon offsets, which provides for the unique opportunity of adding a research component to the initiative and putting emphasis on the direct and indirect social benefits which it might yield. Specifically, we are working with the hypothesis that Harvard University might be interested in taking up this project to offset its carbon emissions and meet the GHG reduction goals it has set for itself. However, the project would most likely be suitable for many different academic institutions around the United States.

b. Improving measuring and monitoring

(i.) Forest Carbon Accounting Methods

Methods for estimating forest carbon sequestration differ substantially in terms of the costs of measurement, the scales that they are relevant over, and the degree of uncertainty that they carry. The simplest of these techniques is the **biome average**, whereby estimates of forest carbon stocks for broad forest categories are scaled to cover larger landscapes. These techniques can be performed at little to no cost, and are globally consistent, though they cannot be applied at smaller scales because they average out, and thus fail to capture smaller scale variability. Furthermore, most investors and carbon offset verifiers are unlikely to accept this technique for verification at the forest level because it does not require any measurements and carries the largest uncertainties. The second and most accepted technique is the **forest inventory,** whereby ground-based biomass measurements are collected in sample plots distributed within the forest. These measurements are then used to characterize variability between plots and to inform models of forest carbon growth based on observations from individual stands. Nearly all projects utilize this technique, though it requires building infrastructure to give surveyors access, is associated with high labor costs, and is not as readily scalable as remote sensing. The final technique that we hope to develop in this project is **remote sensing**, whereby spectral (ie. color) characteristics of forests are related to properties such as land cover, species composition, rates of primary productivity, and more. These data are regionally or globally consistent, but can be technically demanding and require careful validation to relate observed proxies to carbon storage.

Monitoring Opportunity #1: Remote Sensing

What is remote sensing?

Remote sensing is the process of collecting and interpreting information about the physical characteristics of a system from a distant location. These techniques are usually based on the measurement of reflected or emitted energy by a sensor, which can be mounted on a space-borne (satellite), airborne (plane, drone), or ground-based device (tower). Remote sensing techniques provide a means to gather spatially continuous information about forest characteristics such as land cover, forest composition, canopy height, and even photosynthetic activity rather than only monitoring portions of the forest and having to extrapolate information. While remote sensing techniques promise to dramatically reduce the costs associated with collecting forest data at large spatial scales, it is important to note that no current remote sensing system directly measures forest biomass or carbon sequestration.[78] Therefore using remote sensing to monitor biomass requires measuring one parameter (ie. spectral characteristics of canopy) and using it to predict

[78] Brewer, C.K.; Monty, J.; Johnson, A; Evans, D; Fisk, H. 2011. Forest carbon monitoring: A review of selected remote sensing and carbon measurement tools for REDD+. RSAC-10018-RPT1. Salt Lake City, UT: U.S. Department of Agriculture, Forest Service, Remote Sensing Applications Center. 35 p.

another (forest composition, biomass). The errors associated with this type of modeling can be minimized through calibration against on-the-ground forest biomass inventories.

(ii.) Forest Biomass Monitoring Applications of Remote Sensing

The term 'remote sensing' encompasses a wide range of technologies. In the interest of space, the following discussion highlights techniques that warrant further consideration during the design of a forest monitoring plan. The list is non-exhaustive and focuses on methods best suited to the scope and scale of our project.

1. Photo/Video Imagery

Overview: collected via plane or drone, photo/video imagery offer a method to measure many forest properties without the need for expensive sensors or instrumentation. A primary use for photo/video imagery is the classification of land cover and forest composition. This work can be performed manually by trained analysts (e.g. visual identification of species), or could be automated through the use of machine learning algorithms. Eventually, algorithmic approaches may be calibrated and trained to classify tree species within the forest, improving regression-based biomass estimates. Video imagery can additionally be used to generate 3-D topographic models of canopy height through structure from motion (SfM) techniques.[79] Combining these data with an elevation model of the ground surface can provide information about forest growth over time.

Strengths: equipment is cheap, and uses range from low- to high-complexity
Weaknesses: video imaging over large areas may be data intensive, analysis by human analysts is time-consuming, impractical at very large spatial scales.
Applications to our Project: Image classification may be useful for identification and removal of dead biomass (snags) and for characterizing disturbances during forest inventories. Depending

[79] M.J. Westoby, J. Brasington, N.F. Glasser, M.J. Hambrey, J.M. Reynolds, 'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications, *Geomorphology*, V. 179, 2012, Pages 300-314.

on image resolution and survey scale needs, imaging may be cheaper by drone or plane than by satellite. These techniques may be performed in conjunction with LiDAR surveying performed by plane.

2. Satellite Land-cover Classification

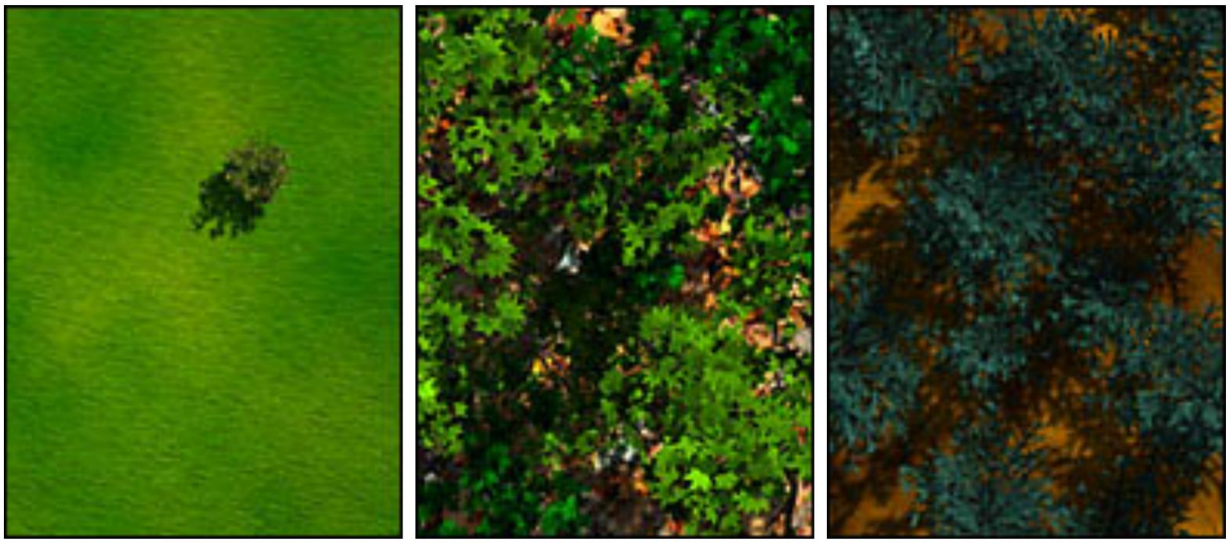


Figure 14: Images of grassland (left), deciduous forest (center), and coniferous forest (right). Land cover classifications rely on reflectance differences between these cover types across many wavelengths in the visible and near-infrared wavelengths.

Satellite-based classification of land cover is based on the identification of distinct spectral signatures between landscape types. Spectral signatures characterize the unique ways that surfaces absorb, emit, and reflect distinct wavelengths of light. These techniques allow us to classify vegetation indices because plants absorb light in the photosynthetically active radiation (PAR) spectral region to power photosynthesis, and they re-emit radiation in the near-infrared spectral region to avoid damaging their cells. From the perspective of a satellite, the PAR spectral region looks dark over vegetated areas relative to the known spectral properties of sunlight. Algorithms for satellite land cover classification are continuously improving, and approaches have been developed to estimate biomass, chlorophyll concentration, leaf area, and plant primary productivity.

Freely available satellite data can be used characterize land cover at spatial resolutions on the order of 10 - 1,000 meters. Monitoring protocols for most major carbon offset registries require that forests inventories be regularly updated to account for forest disturbances such as blowdown, pest infestation, and fire.[80] This satellite data may eliminate the need to map forest cover by plane, greatly reducing both the costs and carbon emissions associated with ongoing monitoring. Additionally, by developing classification algorithms specific to Alaskan forests, it may be possible to characterize the abundance and distribution of specific tree species, which could inform the design of ground-based sampling methods, improve biomass estimation equations, and help identify commercially valuable species in the case of improved forest management practices.

Strengths: satellite land classification is extremely scalable, with minimal marginal costs associated with increasing spatial coverage. New satellites are being launched all the time with powerful sensors designed for increasingly targeted measurements. Land classification algorithms will continue to be developed and calibrated over the coming years.
Weaknesses: processing satellite data requires expertise, though development of software for specific tasks can automate these tasks or can make it possible for an untrained user to generate data.
Applications to our Project: satellite-derived measurements of forest carbon biomass may allow us to reduce the number of ground-based surveying plots, and may reduce uncertainties associated with scaling plot-level data to the entire forest.

3. LiDAR

LiDAR (light detection and ranging) is a technique that can be used to measure the structure of the forest canopy by providing information about the height of the canopy top relative to the ground surface. The technique works by sending a light beam towards the ground surface and measuring the time it takes to return to the sensor and how much intensity is lost. Through repeat

[80] ie. Verra. Registered Afognak plan relies on aerial surveys.

flights of a LiDAR sensor, it is possible to track the vertical growth of a forest at spatial resolutions with greater than 1m accuracy. However, LiDAR data are fairly costly, with the largest costs associated with the transportation of aircraft and instrumentation to the survey site, and with the processing of LiDAR data to produce usable maps.

Strengths: Periodic (ie. decadal) LiDAR measurements would allow us to monitor the vertical growth of the forest over time, which combined with tree basal area is the measurement basis for biomass calculations. LiDAR is expensive compared to satellites data on a per acre basis, but at moderate to large spatial scales (eg. >10,000 acres) it may be cheaper than ground-based survey techniques.[81]

Weaknesses: LiDAR is expensive and does not independently provide enough information to track forest carbon. The instrument must be flown by an independent company or research group, and it may be expensive/carbon intensive to fly the people and instrument to remote sites.

Applications to our Project: Combinations of LiDAR and satellite spectral classification are among the most promising methods for forest carbon measurement at scales greater than 10,000 acres. Forest carbon models using these techniques still require careful regional calibration against traditional ground-based measurements. If we can establish a robust method for estimating carbon Alaskan forests, there may be an additional market for other offset projects in this area.

(iii.) Operational Readiness of Remote Sensing

Some remote sensing techniques are already being applied for forestry analysis worldwide. The predominant use of the technology is for inventory tracking, both on the micro/local and regional scales. Some applications have been for the purposes of carbon monitoring, but these are usually more expensive endeavors. The U.S. Forest Service produced a report in 2012 that overviews various applications of remote sensing; see the charts below of the existing methodologies.[82]

---

[81] Hummel et al. (2011). *A Comparison of Accuracy and Cost of LiDAR versus Stand Exam Data for Landscape Management on the Malheur National Forest*. Journal of Forestry. 267-273.

[82] Brewer, C.K.; Monty, J.; Johnson, A; Evans, D; Fisk, H. 2011 (revised 2012). *Forest carbon monitoring: A review of selected remote sensing and carbon measurement tools for REDD+*. RSAC-10018-RPT1. Salt Lake City, UT: U.S. Department of Agriculture, Forest Service, Remote Sensing Applications Center.

One main consideration is that the majority of these imagery-based methodologies are predominantly for the purposes of inventory tracking rather than carbon monitoring (related, but not entirely equivalent use cases). This is because robust relationships between imagery and carbon biomass have not yet been established. Moreover, the most cost-effective solutions are those that are completed for a large land area and utilize pre-existing, publicly available databases. The critical, outstanding question is if the imagery techniques for carbon monitoring on a sub-regional scale are cost-effective. Initial cost estimates of remote sensing techniques are included in the Financial Analysis section.

Monitoring Opportunity #2: Building Local Capacity in Ground-Based Surveying

Even if we pursue remote sensing as a means to measure forest carbon sequestration, some form of ground-based carbon inventory will be required in order to verify offsets. In existing methodologies, carbon inventories are performed by measuring the height, diameter, and species of trees within randomized sample plots. These measurements are then used as inputs to calibrate forest carbon models, and variability between survey plots are used to constrain forest-level uncertainties. Most forest carbon offset projects specify that sample plots (~400-1000 m^2 each) be remeasured at an interval of five to ten years throughout the lifetime of the project (~100 years).[83] The cost of forest inventory was projected to be $5,414 in the 2017 Afognak Forest Carbon Implementation Plan, which is small but non-trivial within the scheme of the project. Furthermore, a longer project term would cause inventory costs to take up a larger relative share of total project costs because of the need to inventory repeatedly. These costs would also likely grow in the case that contractors hired for carbon inventory are having to travel from beyond the Kodiak Borough.

A potential solution to this challenge would be to provide mechanisms to train and accredit local members of the partner group to conduct forest surveys. Once trained, these surveyors could be contracted to perform future surveys on this project, and would grow the local surveying

---

[83] E.g. VM0012 v1.0 (2011) *Improved Forest Management on Privately Owned Properties in Temperate and Boreal Forests (LtPF).*

capacity within the Kodiak Borough. These surveyors may find work on existing forest carbon projects around Kodiak (see 'Afognak Forest Carbon' in *Appendix 2*) in turn would make future forest carbon projects more feasible in the region. Trained workers may also have employment opportunities with state or federal government agencies in any of the numerous nearby public lands. Government work makes up nearly one-third of total employment in the Kodiak Borough, and the median pay is high. At a community level, development of forestry skills among locals may lead to health and economic benefits discussed above in the health impact section, in addition to building a sense of place centered on the value of environmental preservation and management. Finally, by having local members of the partner group perform forest inventories, we can avoid carbon emissions associated with transporting off-island contractors and equipment to the site.

Monitoring Opportunity #3: Research Partnerships

Existing forest carbon offset projects rely on ground-based carbon surveys because they are inexpensive compared to the cost of developing new methodologies. Once developed, remote sensing techniques may lower costs of monitoring and verifying carbon sequestration at regional scales, but the veracity of these techniques will face scrutiny. In order to convince the wider forest carbon community that remote sensing-based measurements accurately capture forest carbon dynamics, it will be important to calibrate and quantify the performance of these new tools. Many parts of the forest ecology research community are interested in these efforts, and it should be possible to partner with an academic research institution to perform remote sensing and ground-based monitoring in parallel. Research groups may be able to collect LiDAR and imagery data at low cost or for free, and they may be willing to subsidize other parts of the data collection effort. Research groups may also be interested in developing tools within an open-source structure that will allow wider access. Through this partnership, it will be possible to develop remote sensing tools that are calibrated against the best available ground-based data, and resulting publications will significantly improve the perceived legitimacy of any subsequent offsets claimed.

c. Providing a co-benefit/social impact

(i.) Kodiak Island Community demographics

In order to assess the potential impacts of our project on the community's health and well-being, we first sought to understand the characteristics of the community and their greatest areas of need. There are 13,592 residents of the Kodiak Island Borough (2010 census) with 13% of these residents being of Alaska Native or American Indian heritage. This Borough encompasses Kodiak Island and the surrounding islands including Ouzinkie, where the proposed IFM project is to be. In comparison to the other 18 organized boroughs and 10 unorganized census areas, the health of the Kodiak Island Borough ranks highly with only 8.3% of residents living in poverty, and 97% of residents having at least a high school diploma or GED.[84] These statistics are strides ahead of the United States average population statistics that means that the health of the Kodiak Island Borough residents is likely to be better than many other regions in Alaska and in the United States.

However, from within the Kodiak Island Borough, health appears to be getting worse among residents. The following are statistics from Kodiak Island Community Health Needs Assessment that document changes in health indicators in the Kodiak Island Borough from 2013 - 2016:

Health Indicator	**2013**	**2016**
Percent of residents with poor mental health	10%	13%
Percent of residents with household income < $20,000	3%	11%
Percent of residents who have binge drinked within the last month	10%	14%
Percent of resident who did not have a health screening in the past 12 mos.	23%	33%

[84] **Kodiak Island Community Health Needs Assessment 2016**, Providence Kodiak Island Medical Center. Available at: https://communitybenefit.providence.org/~/media/Files/Providence%20AK/PDFs/2016_Community_Health_Needs_Assessment_Providence_Kodiak_Island_Medical_Center_Kodiak.pdf

In addition to these statistics, obesity has risen. When asked about the top 3 greatest health care needs in community surveys, residents were most interested in improving substance use rehabilitation and counseling, increasing the number of specialists especially male specialists in clinical settings, and improving mental health services and counseling (2016 Health Needs Assessment).

(ii.) Health Impact Assessment Screening

Given the large size and length of our proposed IFM project, the recent decline in health among Kodiak Island Borough residents, and the prior knowledge that Native Americans are a sensitive group that could be especially vulnerable to changes in health outcomes, a Health Impact Assessment (HIA) should be conducted. In this HIA, potential health effects from our chosen IFM practice and our new measuring/monitoring methods should be systematically assessed. Additionally, part of our project deals with re-investing revenues into community projects in order to maximize the social and public health co-benefits of the project, so these benefits (and potential harms) should be assessed as well. The results of this HIA will allow us to best decide which IFM practices and reinvestment projects will be able to maximize the benefits and minimize the harms of this project.

(iii.) Health Impact Assessment Scoping

The 2017 *Climate Solutions Living Lab* team that originally developed our project provided us with the following causal chain of health benefits and risks that were considered as potential outcomes of the IFM project. As there are multiple practices that can be done as part of IFM, it will be important to consider the environmental and health impacts given that the magnitudes of the impacts will be different for each type of IFM. Below is the previous team's causal chain of impacts:

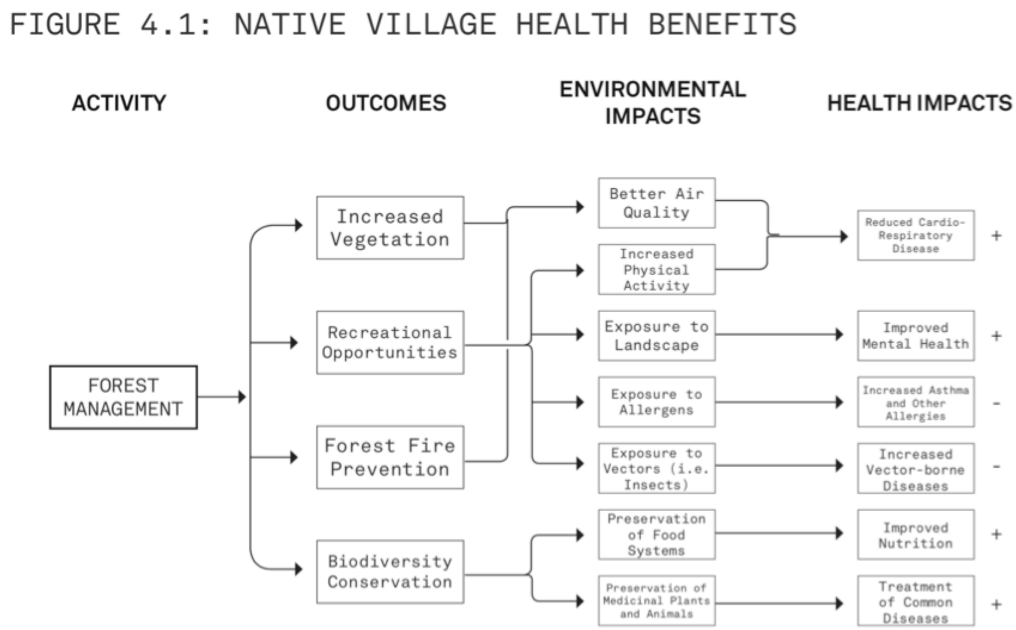


Figure 12: Identified Potential Health Impacts from the 2017 Team's Study

In addition to these potential health outcomes, our improved measuring and monitoring methods could lead to a new set of potential health outcomes. While many of the impacts from new measuring and monitoring methods are the same as the impacts from the original project, it is important to remember that having citizen scientists in addition to having other residents using the forest for leisure will increase the environmental and health impacts at all levels. Below is the preliminary causal chain we created that depicts potential impacts from the addition of new measuring and monitoring methods (the updated and more complex one created for the Rapid HIA can be found in Section I):

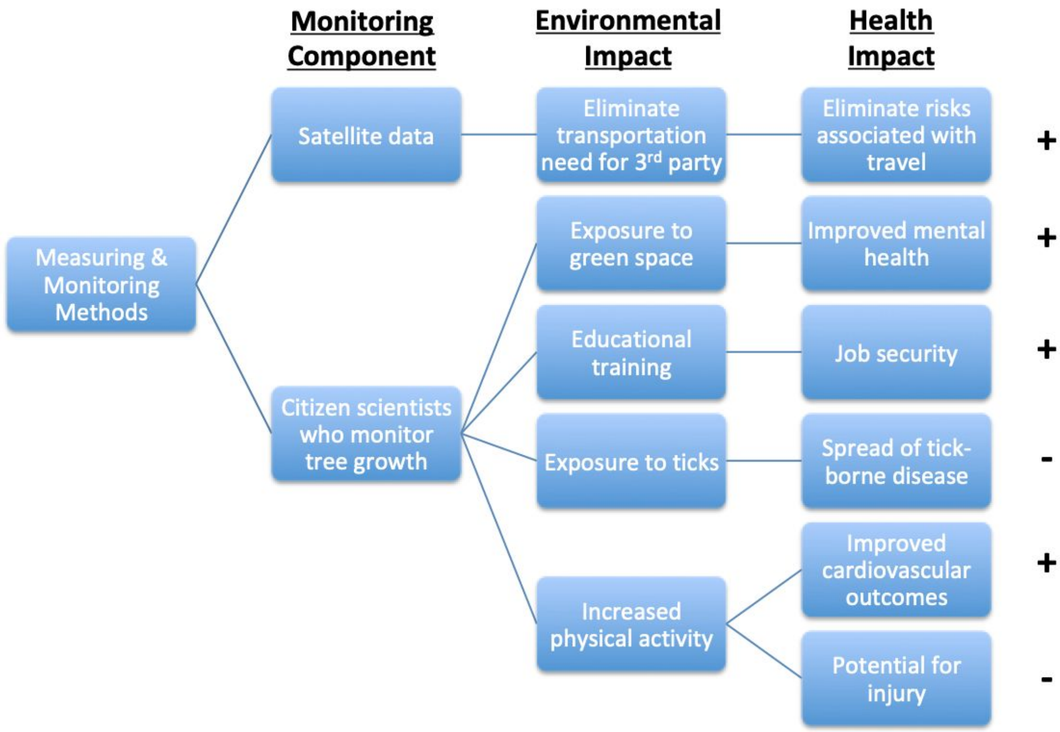


Figure 13: Newly Identified Potential Health Impacts at a Glance

In addition to the potential impacts expected from our IFM project, we originally considered using revenues from the IFM project to create additional positive benefits for the community through reinvestment projects. The reinvestment projects that were considered were 1. Improved mental health via "nature walks," 2. Obesity reduction via the promotion of nutrition with local farming, and 3. Weatherization of homes (as previously considered by the 2017 team). Ultimately, we decided against doing a reinvestment project with the revenue streams and instead opted to allow the Alaska Native Corporations to directly provide their shareholders with increased dividends. The first reason we decided against reinvestment was because we felt that the reinvestment project took away from the main goals of the forest carbon sequestration project. The 2017 team only included a reinvestment project because their main goal was originally to weatherize homes in Alaska; our main goal was to sequester forest carbon, and so a weatherization reinvestment project (or any other reinvestment project for that matter) would not be necessary to achieve this. The second reason we decided against reinvestment was because of discussions with an Alaska Native who helped us understand that putting money directly back into the hands of locals would be preferred over spending their money for them. This way, the locals can have increased agency to use increased dividends in the way that they feel is best for themselves and for their community.

Although we ultimately chose not to include reinvestment in our final project plan, reinvestment plans for mental health and obesity improvements were still explored and the summaries of these prepared plans can be found here:

Reinvestment project #1: Improved mental health via "nature walks"

To improve substance use rehabilitation and mental health counseling, the citizen scientists that collect data on tree growth could be patients who are receiving therapy through the Kodiak Island Counseling Center. This reinvestment project would thus improve the mental health of those who seek counseling by means of exposure to nature. Improvements in mental health after exposure to nature have been documented in studies such as in Karjalainen et al. 2010 and Barnes et al. 2019.[85,86] Given that 13% of Kodiak Island residents have poor mental health, a partnership with the Kodiak Island Counseling Center has the potential to begin improving the mental health of the target population of 1,766 resident with poor mental health that are eligible to seek therapy services

Reinvestment project #2: Obesity reduction via the promotion of nutrition with local farming

As a final issue to consider targeting in a reinvestment project, obesity is especially present among Native American tribes due to lack of available affordable nutritious foods. In September 2018, a 3-year federal grant from the Administration for Native Americans ended for Kodiak's first local farm where they grow fruits, vegetables, and chickens. Prior to this project, the community's only source of food was that which was flown in by plane or shipped in on a barge. Not only did the new farm initiative provide fresh food, but the prices of the food were the same or cheaper than those paid for the same type of foods on Kodiak Island.[87] Despite further

---

[85] Karjalainen, E., Sarjala, T., & Raitio, H. (2010). Promoting human health through forests: overview and major challenges. Environmental Health and Preventive Medicine, 15(1), 1–8. http://doi.org/10.1007/ s12199-008-0069-2.
[86] Barnes, Michael R. et al. 2019. "Characterizing Nature and Participant Experience in Studies of Nature Exposure for Positive Mental Health: An Integrative Review." *Frontiers in Psychology*9: 2617.
[87] KMXT-Kodiak, Daysha Eaton. 2018. "Kodiak Farm Bears Fruit, Residents Hope to Keep It Going." *KTOO*. https://www.ktoo.org/2018/08/29/kodiak-farm-bears-fruit-residents-hope-to-keep-it-going/(March 15, 2019).

research, there is no indication whether the farm has continued as intended without the funding of the grant. This would be worth looking into during a HIA given that a previous analysis cited community farming as the most feasible strategy in the "pre-planning" stage of tackling obesity on American Indian Reservations.[88] Although obesity was not identified by resident in the 2016 Community Health Needs Assessment as one of the top 3 health concerns, it is of interest to both the state and federal governments due to the growing projections of Medicaid spending attributable to obesity. Among all of Alaska's 739,795 residents, the state and federal government contributed $233 million in Medicaid funding during 2015 that was attributable to obesity. That number is projected to increase to $381 million in 2020, $516 million in 2025, and $684 million in 2030 if obesity continues to rise at its present growth rate. If we assume that the costs of Medicaid are evenly spread among the population, then Kodiak Island which has approximately 2% of the population would account for $4.66 million in 2015 Medicaid spending, $7.62 million in 2020 spending, $10.32 million in 2025 spending, and $13.68 million in 2030 spending attributable to obesity. These numbers imply that reinvesting in initiatives that seek reduction in obesity have the potential to save the government millions of dollars in Medicaid expenses. And while the assumption that costs are evenly spread across Alaska's population is likely to be very inaccurate, there is currently no Kodiak Island specific Medicaid spending estimates, and any reduction in the need for medical expenses could make a large impact.

Summary and Next Steps

As is obvious from the discussion above, there are many health and social co-benefits of the IFM project, the improved monitoring, and also from the initially proposed reinvestment projects. In order to fully quantify these impacts, a more detailed Health Impact Assessment will be necessary. Furthermore, it would be most beneficial to obtain health data specific to the local Alaskan Native communities as well as details on the number of people served by the Kodiak Island Counseling Center, local high schools, and the Nuniaq Farm project. Partnerships will be

[88] Jernigan, Valarie Blue Bird et al. 2016. "Assessing Feasibility and Readiness to Address Obesity through Policy in American Indian Reservations." *Journal of health disparities research and practice*9(3): 168–80.

crucial so that benefits that are created through the project are retained beyond the length of our proposed project. Once gathering more data on the specifics of our project and the community, quantitative estimates of benefits will be calculated to give stakeholders an idea of the depth and breadth of their investment impacts and help the community of Kodiak Island prepare for changes due to the new practices of IFM.

d. Addressing leakage and permanence

From a financial point of view, in the current design of the project, leakage and permanence buffers also add considerably to the cost of the offsets. The first iteration of the project foresees a buffer of 5% of the amount of carbon sequestration for leakage issues and 10% for permanence issues. This amounts to a reduction in the claim of carbon offsets of 15%.

(i.) Activity-shifting Leakage

Addressing the issue of leakage is crucial to guarantee the robustness of an IFM project. Leakage occurs when a carbon offset project, although decreasing carbon emissions of a certain area, is also responsible for shifting activities and create emissions outside the boundaries of the project. The intensity of leakage risk depends on the uses currently made in the area surrounding the project. If the surrounding area is already under environmental protection, for example, leakage risks are reduced. On the other land, if lands are already being heavily logged, this also decreases the risk of leakage, since logging activities cannot be increase further. On Kodiak Island, some areas are already under conservation easement and others are being heavily logged[89].

Our project keeps the leakage buffer of 5.0% proposed by the 2017 CSLL Forestry Team, consistent with the buffer pool requirements by the CARB Protocol, and proposes new

[89] Doogan. *Neighbors, village corp. clash over Kodiak Island logging operation.* Anchorage Daily News, 09/26/2016. Available at www.adn.com/business/article/kodiak-island-residents-still-railing-against-native-corps-clear-cutting/2014/12/08/ Accessed on March 15th 2019.

monitoring technologies which can help increase the certainty regarding activity-shifting leakage by closely tracking any land-use change in the area surrounding the project. This can help not only avoiding an over-estimation of carbon credit but also detect early where needs to be further discouraged.

(iii.) Permanence

Non-permanence is the risk that emission removals of a project are reversed because the forests are either cut down or destroyed by natural disaster, such as wildfires, blight, earthquakes, or bug infestations. Thus, the project design must incorporate mechanisms to address non-permanence risks.

The common procedure for this, described in methodology protocols such as the Planet Carbon one[90], is to first assess the risk of permanence (What is the probability of a wildfire occurring in the region? How common are bug infestations on Alaskan islands? Etc.), and then use this assessment to determine a non-permanence buffer withholding percentage which is discounted from the total amount of carbon offsets to be claimed.

The first iteration of the project incorporated a permanence buffer of 10%, which corresponds to the standard practice and to be adequate for the region being considered.

e. Forest Carbon Management Practices

(i.) Overview of Forest Offsets and IFM

Forestry and land use projects account for 26.9% of all offsets sold within the voluntary carbon markets in 2016 worldwide, reflecting the importance of forests as a global carbon stock and

[90] Carbon Planet, 2010. *Estimating GHG Emission Reductions from Planned Degradation (IFM)*. Available at http://Verra.org/wp-content/uploads/2018/03/VM00011-Carbon-Planet-Methodology-Revised-Methodology-for-Second-Assessment-1.pdf. Accessed on March 15th 2019.

sink.[91] If all of the carbon so far released by land-use changes could be restored to the terrestrial biosphere, atmospheric CO_2 could be reduced by 40-70 ppm by the end of the century.[92] Land-use change continues to be a source, however, with deforestation dominating this estimated 1.3 GtC/yr anthropogenic flux.[93]

Carbon offset registries have responded by providing guidelines for verification of projects that reduce emissions from agriculture, forestry, and other land use (AFOLU). Based on our understanding of current management practices in Alaskan Native Corporation-owned forests on Kodiak Island, we believe that these forests are most qualified to generate offsets through implementation of improved forest management (IFM) practices. IFM represents one class of AFOLU mitigation strategies, allowing landowners to quantify emissions reductions by shifting management of forests that are legally eligible for timber harvest.[94] IFM practices broadly fall into three categories: sustainable harvesting, forest protection, and promotion of new growth to increase biomass.

(ii.) Analysis of Verra-verified Forest Carbon Projects Registered with CARB

To assess the potential of different forest management practices, we surveyed all offset-generating forestry projects registered on the Verra/VCS database. Of the thirteen forest management methodologies approved by Verra, only three are currently utilized in the United States (*Annex IV*). Of these three, extension of rotation age and afforestation/reforestation of degraded and agricultural lands are most commonly implemented. Among these projects, managed land parcels range from 143 - 31,603 acres and generate between 531 and 101,874 tCO_2e per year. Given the small sample size (n=8), it is hard to draw strong conclusions about the relationship between management type and carbon reduction potential. Future communication with forestry professionals and project developers will be needed to establish a quantitative understanding of this link.

---

[91] Forest Trend's Ecosystem Marketplace. Unlocking Potential: State of Voluntary Carbon Markets (2017), p. 10. www.cbd.int/financial/2017docs/carbonmarket2017.pdf. Accessed on April 22nd 2019.
[92] The Carbon Cycle and Atmospheric Carbon Dioxide – IPCC.
[93] Le Quere et al. (2018) Global Carbon Budget 2018, *Earth Syst. Sci. Data,* 10, 2141-2194.
[94] Eg. American Carbon Registry IFM Methodology v. 1.3 (April 2018)

Our analysis shows that the highest reductions per acre are claimed by the Ecotrust IFM project in Western Oregon (5.09 tCO_2e/acre/yr), reflecting the high forest productivity of the region. Afforestation projects in the Lower Mississippi are the next most productive, with Pennsylvania extended rotation age projects generating the smallest reductions. While carbon sequestration potential varies strongly by location, the value of carbon credits generated must be weighed against independent variations in timber and land value. Interestingly, there appears to be strong regional clustering of projects, with Nature Conservancy-sponsored afforestation projects dominating a small section of the Lower Mississippi Valley and municipality-led extended rotation age projects existing in Pennsylvania. It's not clear how robust these trends are given the small sample size, but communication with proponents of these projects could point to market barriers currently preventing wider development in other regions. These barriers could include transactions costs associated with developing an initial forestry plan in a region, or lack of local awareness of the economic potential of C offset-generating management practices. In the above cases, the barriers would be reduced in the wake of the first project in the region, incentivizing additional project development and leading to the observed regional clustering.

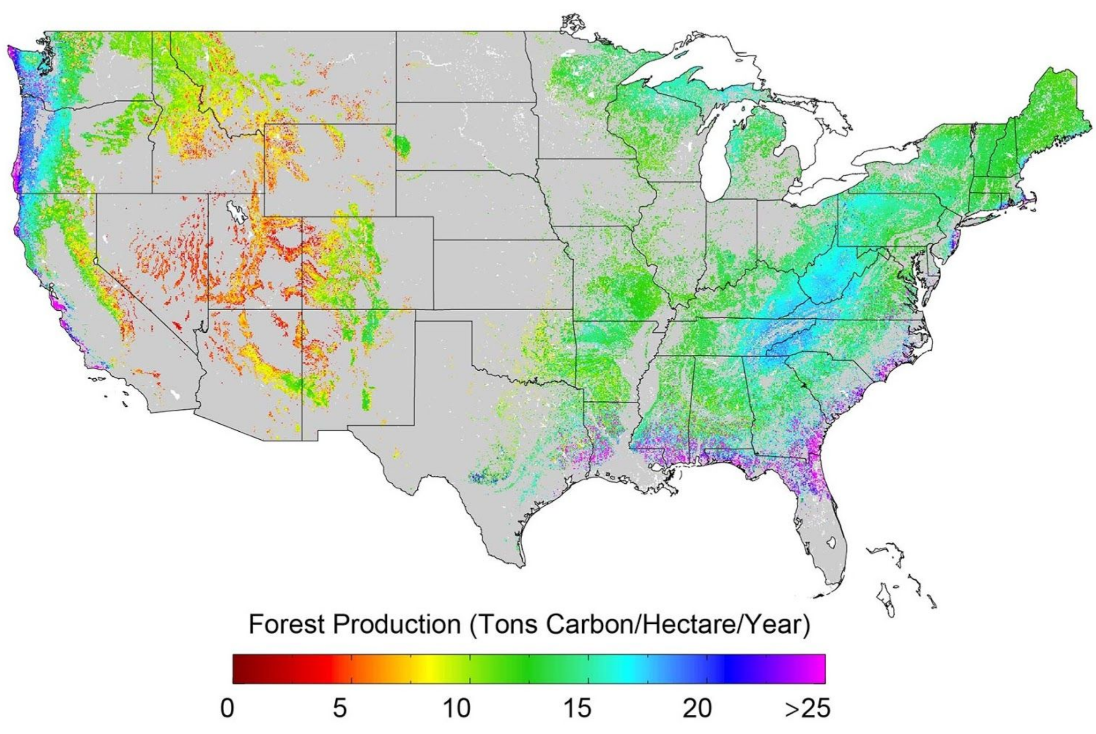


Figure 15: Map of carbon sequestration potential of forests in the contiguous U.S. Forest productivity varies as a function of light availability, precipitation, species composition, soil properties, and many other factors. Note: 1 hectare = 2.47 acres.[95]

Prospective Management Strategies for Kodiak Island Forests

While there are many existing methodologies for forest management, the list of practices applicable to forest management on Afognak or Raspberry Island is fairly short. Management practices include fire-management and promotion of higher productivity forest, though we are not currently considering these strategies. This leaves extended rotation age (ERA)[96] techniques, conversion from logged to protected forests (LtPF)[97], and selective removal of dead biomass. Descriptions of each technique follow below:

(iii.) Extended Rotation Age (ERA)

By extending the age at which trees are cut, ERA is designed to increase the average carbon stock. Carbon emission reductions are weighed against a baseline emissions scenario, which usually is set to clear-cutting a forest at the timber financial optimum (see below 'note on timber finance'). Based on VCS-registered ERA projects (*Appendix 2*), the financial optimum for harvesting trees is ~30-35 years. ERA traditionally involves postponing harvest across the entire forest stand, though it is also possible to selectively harvest under ERA. The selective harvest approach is designed to promote a mixed stand age, which may have ecosystem benefits and enables the landowner to generate non-offset revenue throughout the course of the project. The Ecotrust IFM project is a notable example of the mixed stand age management strategy, whereby timber is harvested regularly, but 70% of pre-harvest basal area is retained at each cut.

ERA is a desirable approach because it allows the landowner to retain the most autonomy over their land, with the value of the offset promoting best forestry practices and net carbon

---

[95] Joyce, L. A., et al., 2014: Ch. 7: Forests. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 175-194. doi:10.7930/J0Z60KZC.
[96] VM0003: *Methodology for Improved Forest Management through Extension of Rotation Age,* v. 1.2 (2013). VCS Methodology.
[97] VM0010: *Methodology for Improved Forest Management: Conversion from Logged to Protected Forest,* v. 1.3 (2016). VCS Methodology.

reductions. Furthermore, since the timber continues to gain value as it grows, the value of the offset needs only to cover the difference between the value of harvest every thirty years compared to the value of harvest at some later date (ie. year seventy or one-hundred). This desirable quality is also attached to concerns of additionality, since the carbon savings from harvesting at a later date need to be additional to the carbon that would be stored and then removed while logging on a shorter period. Demonstrating savings will be sensitive to uncertainties in the growth model for the forest, and to projections about the fate of timber carbon after it is harvested.

(iv.) Conversion from Logged to Protected Forests (LtPF)

This method generates carbon reductions by protecting forests currently under management for timber harvest. Out of concern for additionality, it must be possible to show that logging or clear-cutting would have occurred in the forest in the absence of carbon finance. The forest protection is achieved by placing the forest under a conservation easement, which can either be permanent or can have a fixed term. This approach is desirable because it is more tangible to investors and the public. However, this strategy may not be appealing to the landowner because in this case carbon offsets are the sole source of revenue. Additionally, due to the long-term or permanent nature of the easement terms, the landowner may feel that they are, in effect, losing control over their land. This land transfer seems particularly inappropriate in the context of working with Native groups, where historical land seizure may be a sensitive part of the collective memory. This type of transfer appears to have occurred in the Rocky Mountain Elk Foundation-led Afognak Forest Carbon project, where the timber rights on 8,219 acres were placed under a permanent federal conservation easement and the remaining surface title rights were transferred to the State of Alaska *(Annex IV).*

(v.) Biomass Removal Through Snag Management

A substantial fraction of carbon biomass in Alaskan forests is stored in dead wood (‘snags’; *Fig. 3*). Left undisturbed, these snags will decompose and the carbon they contain will be released to the atmosphere largely as CO_2. However, if the snags can be efficiently removed and sold as low-grade timber products (eg. pulp, fuel), they offer an opportunity to reduce forest carbon emissions associated with decomposition and displace the need to harvest live trees for fuel and pulp. Harvested snags may also be used to generate heat or power. An additional carbon benefit is that snag removal reduces the severity and magnitude of emissions in the likely event of an Alaskan forest fire. Fuel reduction is already an actively area of management in fire-prone areas, [98] and methodologies have been developed to quantify emissions reductions achieved through fuel management.[99]

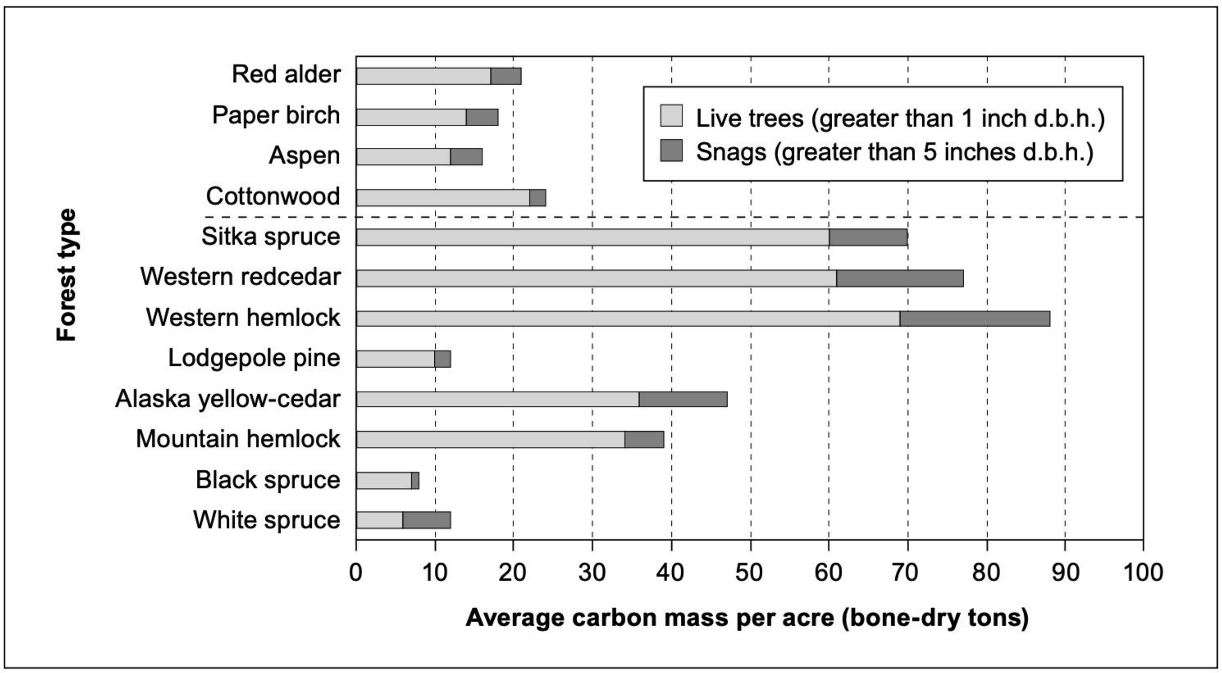


Figure 16: Partitioning of carbon biomass between live trees and snags by Alaskan forest type.

Harvesting snags will be a challenge if it proves to be unprofitable, which is likely given the low value of the product. The project also faces barriers if accessing and removing the snags causes significant forest disturbance (eg. road construction, brush clearing for machinery, etc.) or is an independent source of emissions. Finally, mapping and inventorying the distribution and

[98] CalFire: Fuel Management (2018) http://calfire.ca.gov/resource_mgt/resource_mgt_EPRP_FuelsTreatment
[99] VM0029: Methodology for Avoided Forest Degradation through Fire Management v1.0 (2015) http://Verra.org/wp-content/uploads/2018/03/VM0029-Methodology-for-Avoided-Degradation-through-Fire-Management-v1.0.pdf

availability of snagwood will be a challenge. Remote sensing and machine learning may offer a viable solution to this barrier through image classification. Unlike the challenge of relating forest color to productivity, where uncertainties are magnified due to the need to develop a continuous color:carbon model, snags should present a distinct spectral signature, and need only to be classified as ‘snag’ or ‘not snag.’ To our knowledge, snag management has not been widely developed as a forest carbon management strategy, so more work will be necessary to assess the feasibility of this proposal.

f. Initial Financial Feasibility

(i.) Overview

Using remote sensing technology to monitor carbon sequestration can have meaningful impact on the project economics and investor interest. The primary driver through which the technology impacts economics is in the price per ton of the offsets. For context, the 2017 CSLL team assumed that the offsets would be verified through Verra/VCS and would be sold on the California compliance market. Accordingly, the estimated price per ton in their financial analysis was $14/ton. Today, this figure is $15.10 per ton (see figure below). Alternatively, the offsets could be sold on the voluntary markets. Offsets on voluntary markets fluctuate between $1 to $10 per ton (typically $8 in South Carolina); the improved forest management projects globally are, on average, at the high end of this range, priced at $9.5 per ton (see Fig. 5). Thus, the unregulated entity should desirably pay ~$9 per ton (i.e. what they can pay on voluntary market) if they seek an IFM project, while the native corporation should not want to sell offsets for anything less than $14-15 per ton (i.e. what they can make selling it on the compliance market). Thus, the critical question is: how to close that gap? The section below provides a hypothesis that a remote sensing based solution may help narrow this gap.

Figure 17: Future Carbon Price on California Compliance Market as of 3/15/2019[100]

(ii.) Remote Sensing as Driver of Offset Prices

One logical explanation for the price variation between the compliance and voluntary markets, discussed above, is based on supply and demand economics. Presumably, verified, compliance based offsets are in higher demand (or lower supply) than those in the voluntary markets. This is likely due to a) the premium or value that buyers put on verification of their purchases and/or b) the oversupply of projects in the voluntary market. Our hypothesis is that an improved monitoring and measuring system (e.g. imagery-based analytics), if done cost-effectively, can help bridge the price gap between compliance and voluntary markets. The mechanism through which this could happen are a) it provides reliable verification on-par with standards of Verra/VCS used in compliance markets and/or b) it raises the value of project placed in the voluntary market to the top of "over-supplied" pile of projects. In such case, the native corporation and the unregulated entity may be able to agree upon a price in the mid-range of the

[100] California Carbon Dashboard. Climate Policy Initiative. http://calcarbondash.org. Accessed 3/15/2019

gap, closer to $10-12 per ton, which would increase the buyer willingness and thus attract an outside investor. An outside investor may also be attracted to this project because it is an attractive first-of its-kind project to employ a tech-based monitoring solution which can be scaled to other contexts.

In terms of this project, the technological solution needs to be value-additive to the native corporation to incentivize them to be willing to sell for less than the compliance market rates. If the solution engages the community and provides a source of economic empowerment, either through job creation, or is employed as a form of citizen scientist nature therapy, the native corporation may accept lower that market rates. One piece of information that we need is the exact cost that the native corporation would incur for IFM. If the solution can help lower these costs (or potentially provide an alternative revenue source through timber harvesting), they may be willing to accept lower than market rates on the revenue stream coming from the offsets.

(iii.) Cost Estimates of Remote Sensing Technologies

Preliminary estimates signal that the cost will be a function of the acreage size of the project, wherein operating at a small scale is expensive and cost decreases as the acreage size increase. For example, with LiDAR, one study estimated that purely acquiring and processing the data would be $2-4/acre for a 30,000 acreage plot whereas costs decrease to $1.5-3 per acre for a 90,000 acre plot.[101] Our hypothesis is that we can operate a smaller acreage plot (15,000-20,000 acres) effectively with crowd-sourced imagery data and then combine that with satellite or LiDAR data to optimize for a combined top-down and bottom-up solution at a reasonable, scalable price point.

[101] "A Comparison of Accuracy and Cost of LiDAR versus Stand Exam Data for Landscape Management on the Malheur National Forest." Susan Hummel, A.T. Hudak, E.H. Uebler, M.J. Falkowski, and K.A. Megown. *Silviculture*. March 2010.

(iv.) Target Offset Volume as Project Cost Driver

One other key driver to evaluate to determine the financial feasibility is the target offset volume of the project. The previous work assumed a target of 50,000 tons of offsets per year. This greatly impacts the scope and cost of the project. Firstly, by selecting a relatively small target, the acreage required to produce those offsets is also relatively small, which negates the feasibility of sustainable logging as a form of IFM and an additional profit stream.

By comparison, two other recent IFM projects in Alaska generated 11.4 and 14.9 million offset credits respectively. While the project is propose to create 500,000-600,000 tons of offsets over its project life, it is still small in scope. Moreover, the size and scope is critical because it exacerbates the relative difference between selling the offsets at $9 per ton vs. $14 per ton. In other words, the larger the offset project, the more attractive if we are able to lower the price per ton (from the buyers perspective). This should also be attractive to an investor as incentivized buyers are critical to project success.

It might be more attractive to have larger offset project from cost perspective, however, we may not be able to increase the project acreage, considering the technology will likely need to be implemented on a micro-scale initially to test feasibility of the tech and willingness of native tribes to participate. That said, the design is that the technology would be scalable and replicable and thus could drive investment in larger offset projects down the road.

g. Legal Analysis

Finally, the IFM project is also feasible from a legal point of view. No permits will be required for the type of IFM chosen, but strong contract mechanism are essential for the success of the proposed project. The primary contract governing the project is the master agreement between the unregulated entity and the native village corporation. Since our project is designed for forested lands under which there are no ground minerals, this contract would not require the engagement of any regional corporation (which typically hold subsurface rights). The engagement of seasoned lawyers who understand the particularities of Alaska Native contexts and the pertinent tribal law will be required to draft agreement terms that satisfy the needs of both the unregulated entity and the Alaska Native Corporation.

GLOSSARY

Allometry/Allometric Equations: Allometry is the study of how the characteristics of living creatures scale with size. In forest science, **Allometric Equations** are used to describe the size relationship between one part of a plant and another part of the plant. Because some parts of a plant are easier to measure than others, allometric equations allows field scientists to quickly and accurately estimate the volume of a tree using (species-specific) relationships between the volume of a tree and common measurements such as diameter at breast height (d.b.h) and height. An additional term relating the volume of a tree to the carbon that it stores can also be added.

Altimetry: the measurement of height or altitude

LiDAR: LiDAR stands for Light detection and ranging, and is a form of active remote sensing. LiDAR is designed to measure the distance between the sensor and an object by firing rapid pulses of laser light and measuring the time and characteristics of the light as it is reflected. LiDAR instruments can be ground-, air-, or space-based, and can be used to map both the height of the tree canopy and the underlying ground surface.

Remote Sensing: Remote sensing refers to acquiring information about an object from a distance. Remote sensing is used widely in many disciplines, including military intelligence and Earth science. A distinction is often drawn between *active* remote sensing, in which a signal is emitted by a satellite or aircraft and its reflection is detected by a sensor, and *passive* remote sensing, in which the reflection of sunlight and the re-emission of energy from the Earth's surface is detected by the sensor. The characteristics of the signal (usually light) detected by the remote sensor are then related to a variable of interest, such as the temperature of the surface, the height of a forest canopy, or the type of land cover.

ANNEXES:

I. Contracts

Below are three examples of contracts necessary for the successful development of this project.

1. Improved Forest Management Contract

Master agreement between the village corporation and the unregulated entity to implement an IFM project on the lands of the village corporation through which carbon credits will be generated to offset activities by the unregulated entity.

Primary Parties: Unregulated entity and Native village corporation.
Additional Parties: Tribal government, municipal government, local educational and job training organizations.
One Key Representation: The Native Corporation is the full legal owner of the land on which the IFM project will be carried out.
One Key Warranty: The unregulated entity warrants that it is paying the first installment as described in the Financial Annex at the signature of this contract and will continue making yearly payments as described in the Financial Annex throughout the duration of the contract.
Remedy: Failure to pay by the due date each year will result in a late payment fee of [X%]/month. If the unregulated entity defaults on its obligation for a period of over six months, the village corporation has the right to terminate the Agreement.
One Key Covenant: On or before [date] and each 6 months thereafter through the Term of This Agreement, the Village corporation shall demonstrate that it is implementing the IFM provisions determined in the Technical Project Description. Such demonstration is to be established by submitting a detailed report on activities executed in the previous 6 months.

2. Contract Between Citizen Scientists and Native Village Corporation

Individual agreement through which each citizen scientist participating in the project commits to perform measuring activities on a periodic basis in exchange for learning opportunities and an hour-based stipend.

Primary Parties: Native village corporation and high school/undergraduate students who will engage in monitoring efforts. Minors will be represented by their parents or legal guardians.
Additional Parties: Local academic institution (such as University of Alaska - Kodiak College), partner research institutions (such as Boston University Remote Sensing Group), and the unregulated entity's pertinent research group (Harvard Forest in case of Harvard University).
One Key Representation: If signing the contract themselves, the citizen scientist is 21 years of age or older.
One Key Covenant and its remedy: The Native village corporation is not responsible for any injury to the citizen scientist suffered during the citizen scientists program activities, excluding ordinary negligence of the Native village corporation and/or its representatives. **Remedy:** In case the citizen scientist gets injured or dies due to ordinary negligence of the Native village corporation and/or its representatives, the Native village corporation is responsible for all costs related to the citizen scientist's rehabilitation and/or family compensation.
One Key Warranty: The citizen scientist warrants that they will perform the research tasks assigned to them to the best of their ability.

3. Sales Contract Between LiDAR Manufacturer and Native Village Corporation

Agreement between the LiDAR manufacturer (seller) and the Native Village Corporation (buyer) for the exchange of LiDAR instruments for the payment of a certain amount.

Primary Parties: LiDAR manufacturer and Native village corporation.
One Key Representation: The LiDAR manufacturer is authorized to build and sell LiDAR instruments under the American intellectual property legislation.
One Key Covenant: The manufacturer promises to deliver the LiDAR instrument by [date].

One Key Warranty and its remedy: The manufacturer warrants that the equipment sold to the Native village corporation meets a certain level of quality and reliability for a certain timeframe. **Remedy:** In case the LiDAR instrument does not meet the pre-established level of quality and reliability at any point in time between its purchase and the end of the warranty period, the manufacturer shall repair it at no cost (also being responsible for the shipping costs) when the defect is inherent to the product and not caused by its misuse.

II. HIA Ranking Methodology

Section 8 of the "Technical Guide for Health Impact Assessment in Alaska" found at: http://dhss.alaska.gov/dph/Epi/hia/Documents/AlaskaHIAToolkit.pdf

Figure 8.1 Step 1 of a Four-Step Impact Assessment Matrix

Step 1				
	Impact Dimensions			
Impact Rating Score	A – Health Effect (+/-)	B- Duration	C-Magnitude	D- Extent
0	Effect is not perceptible	Less than 1 month	Minor	Individual cases
1	(+/-) minor benefits or risks to injury or illness patterns (no intervention needed)	Short-term: 1-12 months	Those impacted will 1.)be able to adapt to the impact with ease and maintain pre-impact level of health, 2.) see noticeable but limited and localized improvements to health conditions	Local: small limited impact to households
2	(+/-) moderate benefits or risks to illness or injury patterns (intervention needed, if negative)	Medium-term: 1 to 6 years	Those impacted will: 1.) be able to adapt to the health impact with some difficulty and will maintain pre-impact level of health with support, or 2.) experience beneficial impacts to health for specific population some maintenance may still be required	Entire Potentially Affected Communities (PACs); village level
3	(+/-) severe benefits or risks: marked change in mortality and morbidity patterns (intervention needed, if negative)	Long-term: more than 6 years/life of project and beyond	Those impacted will 1.) not be able to adapt to the health impact or to maintain pre-impact level of health 2.)see noticeable major improvements in health and overall quality of life	Extends beyond PACs; regional and state-wide levels

Figure 8.2 Steps 2, 3, and 4 of Four-Step Impact Assessment Matrix

Step 2	Step 3						
Impact Level (Use Score from Step 1 to choose range)	Likelihood Rating						
	Extremely Unlikely (<1%)	Very Unlikely (1-10%)	Unlikely (10-33%)	About as likely as Not (33-66%)	Likely (66-90%)	Very Likely (90-99%)	Virtually Certain (>99%)
1-3	♦	♦	♦	♦	♦♦	♦♦	♦♦
4-6	♦	♦	♦	♦♦	♦♦	♦♦	♦♦♦
7-9	♦♦	♦♦	♦♦	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦
10-12	♦♦♦	♦♦♦	♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦
Step 4	Impact Rating						
	Category 1 = ♦	Category 2 = ♦♦	Category 3 = ♦♦♦	Category 4 = ♦♦♦♦			

III. Kodiak Island Forest Characteristics

Terrain and Climate

- Moderately rugged, mountainous (2000-4000 ft elevation)
- Glacially sculpted, soils are sandy, glacial till, ashy
- In proximity to areas of tectonic and volcanic activity driven by a subduction zone between the Pacific and North American plates
- Maritime climate, mild temperatures (35-45 degrees on average), ample precipitation (78 inches of rain, 68 inches of snow on average) (https://www.usclimatedata.com/climate/kodiak/alaska/united-states/usak0133.)
- Terrain types include: coastal wildflower meadows, grasslands, shrublands, wetlands, wet tundra, and forest
- Tree line ranges from 500-1000 ft.

Kodiak Forests

- The southern end of the island is lightly or not at all forested, Raspberry and Afognak Islands comprise most forested land.
- In these northeast regions, the forest is unique in the world-- almost exclusively sitka spruce.
- Forest is moving south, either successionally or following a southward shift in habitable range due to warming average annual temperatures at a rate of 1 mi every 100 years (AK Dept of Natural Resources and University of Alaska, Fairbanks)
- Central, western, eastern Kodiak are black cottonwoods and Kenai birch, joining willows and sitka alder in riparian habitats and slopes (would be avoided in IFM anyway)
- Southern end of the island is grassland, wetland, and wet tundra (also of lesser interest to use because it is owned by the federal government)
- Widespread catastrophic disturbance is infrequent on the islands (US Forest Service FIA)
- FIA field crews are/have been present supplying data for Forest Service analysis based on allometric equations

Species, Commercial and Other Value

Sitka Spruce

- Dominant overstory species, coniferous, pioneer and climax species, fast-growing
- Long lived (800+ yrs) and native, requires soils high in calcium and magnesium
- Reaches sexual maturity in 20-40 years, forest is capable of moving from regeneration to canopy closure in 20-30 years, germination rate is 54%. Shade intolerant.
- Can reach 210 ft in height and 16 ft d.b.h., average closer to 6 ft d.b.h.

- Most important timber species in AK
    - High strength to weight ratio, large, straight tree, light and soft wood
    - Few branches below canopy in full-growth forest
    - Commercial uses in: construction wood (but low relatively low resistance to decay), pulpwood, ship-building, turbine blades, and musical instruments (pianos, etc. due to good resonant qualities)
    - Survived 1912 eruption and subsequent fall of volcanic tephra 30 cm deep, aggressively regenerated due to lack of overstory and other vegetation
    - Vegetation disturbances are important to sitka spruce seedling establishment
- Susceptible to:
    - Sitka spruce weevil, white pine weevil, spruce aphid, spruce beetle, root rot
    - Hybridization with white spruce (Lutz hybrid) F1 generation is completely immune to weevil, but grows at a much slower rate
    - Windthrow: wind events can cause up to 80% stand mortality, but regeneration is rapid
- Fire concerns: little to none, not ecologically important for the life cycle of the species
    - Using a fire regime has been shown to favor sitka spruce regeneration in its northern range, but the regeneration following is comparatively slow, and therefore the process seems redundant in an area that is already dominated by Sitka spruce (US Forest Service FEIS)
    - Forests that are predominantly western hemlock and Sitka Spruce have a low return period for fire events (200 yrs)

Forest Ownership

- Afognak Native Corporation-- 321,280 acres on Raspberry and Afognak Islands
  9 total lands tracts, 1 currently used for timber harvest, 1 with active economic potential
  Interested in or already implementing reforestation, afforestation, pre-commercial thinning, pruning, and commercial thinning practices (Afognak corporation website)
- Ouzinkie Native Corporation-- 98,560 acres on Kodiak and Afognak Islands
- Lesnoi, Inc.-- 47,360 acres on Kodiak Island
  Looking to cease timber harvesting (2015) but interested in a second-growth resource for future generations (Lesnoicorporation website)
- Natives of Kodiak-- 16,000 acres on Afognak Island
- Koniag Incorporated-- 40,000 acres of Afognak Island

Afognak Native Corporation, Ouzinkie Native Corporation, and the Natives of Kodiak operate under a single permitting umbrella administered by the Afognak Native Corporation.

IV. Snapshot of Registered U.S. VCS Forestry Projects

Name (Proponent)	Methodology	Annual Emission Reductions (tCO2e)	Acreage	Reductions (tCO2e)/Acre	Crediting Period (yrs)	Cumulative Salable Reductions (tCO2e; buffers not included)	Description
Lock Haven IFM (Lock Haven City Authority)	VM0003	6,384	4,905.6	1.30	58	370,301	Project in Clinton County, PA, put under a conservation easement, in perpetuity, with the TNC
Ecotrust IFM (Ecotrust Forest Management)	VM0003	5,001	982.0	5.09	30	15,032	Project in W. Oregon to promote uneven-aged management approach, where 70% of pre-harvest basal area retained at every 'entry.' Pushes average age of harvested trees from 30-35 years to 70-100 years.
Bethlehem Authority IFM (Bethelem Authority)	VM0003	21,770	17,591.0	1.24	39	849,033	Project area placed under a 60 year term conservation easement with the Nature Conservancy. Promotion of older age classes of northern hardwood forest (100-120yr stands). Promotion of timber value through thinning to control species and spacing, successful regeneration to overcome deer browse pressure on seedlings
Afognak Forest Carbon (Rocky Mountain Elk Foundation)	VM0012	40,451	8,219.7	4.92	30	1,213,532	RMEF acquired properties and related timber rights, attached a permanent federal conservation easement, and transferred remaining surface title rights to the State of Alaska
Lower Mississippi Valley Grouped Afforestation (The Nature Conservancy)	AR-ACM0001	926	220.9	4.19	32	29,629	Conversion of degraded land, including pasture and abandoned agricultural land to bottomland forest. Enrollment in USDA conservation program, placed under permanent conservation easement held by TNC.
Bayou Bartholomew Climate Action (The Nature Conservancy)	AR-ACM0001	531	143.6	3.70	64	34,037	Afforestation of former pasture land in Morehouse Parish, LA, owned by The Nature Conservancy.
Tensas River Basin (The Nature Conservancy)	AR-ACM0001	1,196	408.7	2.93	70	83,705	Afforestation of former agricultural land in Franklin Parish, LA, owned by the Nature Conservancy
Reforestation Across the Lower Mississippi (Dynegy Inc)	AR-ACM0001	101,874	31,603.0	3.22	60	6,112,428	Afforestation of former agricultural lands in the Lower Mississippi Valley, LA

V. A Top-Down Estimate of AK Timber Value

Identification of credible alternative use cases is critical in order to demonstrate that an IFM project provides additionality. One end-member usage would be to maximize immediate revenues by selling timber for harvest. Accurate valuation of timberlands requires on-the-ground assessment by a forestry professional. This is because the value of timber varies widely according to properties of the trees being harvested (species, volume, and quality) and the site that the timber is grown on (accessibility-related costs). As an alternative approach, we derive a first-order estimate of the value of immediate timber harvest using state-level timber production and sales data from U.S. Forest Service technical reports.[102,103]

<u>Inputs</u>
A. Harvest Total: 268,281,000 BF
B. Primary Wood Product Sales: $150 Million
C. Alaska Mill Conversion Factor: ~5.1 BF/CF
D. Timberland Productivity: 20 – 164 CF/acre
*BF = board feet, CF = cubic feet

<u>Equation</u>
Value ($/acre) = (Sales/Harvest) * Timberland Productivity * Mill Conversion

<u>Estimate of Immediate Harvest Value</u>
Low Productivity Scenario (20 CF/acre): **$57/acre**
High Productivity Scenario (100 CF/acre): **$285/acre**

Caveat: these numbers likely represent a substantial overestimate of value to landowner because they neglect the costs of harvest and of milling.

[102] Halbrook et al. (2009) Alaska's Timber Harvest and Forest Products Industry, 2005. USFS General Technical Report PNW-GTR-787.
[103] van Hees (2003) Forest Resources of Southeast Alaska, 2000: Results of a Single-Phase Systematic Sample. USFS Research Paper PNW-RP-557.

VI. A Brief Note on Timber Finance

From the perspective of the landowner (Alaskan Native Corporation), the social, environmental and financial merits of incorporating IFM into a forest management plan must be weighed against a suite of alternative use cases. One important point of comparison in this decision framework is the management strategy that maximizes profit over a relatively short time horizon. Consideration of the profit-maximizing case is also important for investors and verifiers concerned with the additionality of an offset, where the concept of additionality stipulates that the offset-generating management strategy must not be profit-maximizing in the absence of the value generated by the offset. To assess the question of profitability, we briefly touch on financial overview of timber management below.

Throughout the lifetime of a forest, timber value and volume (ie. tree size) do not grow at a constant rate. As trees grow, they add value faster than they add volume, which is to say that large trees are more valuable per board foot (BF) than small trees are (Fig. 4). The difference in value stems from the different uses of timber products, with large diameter, high quality trees being sold as veneer logs and small diameter trees being sold as pulpwood for use as paper and fuel. In the case of hardwood trees, high-quality veneer logs may be three to ten times more valuable per board foot than a lower quality tree of the same species.[104]

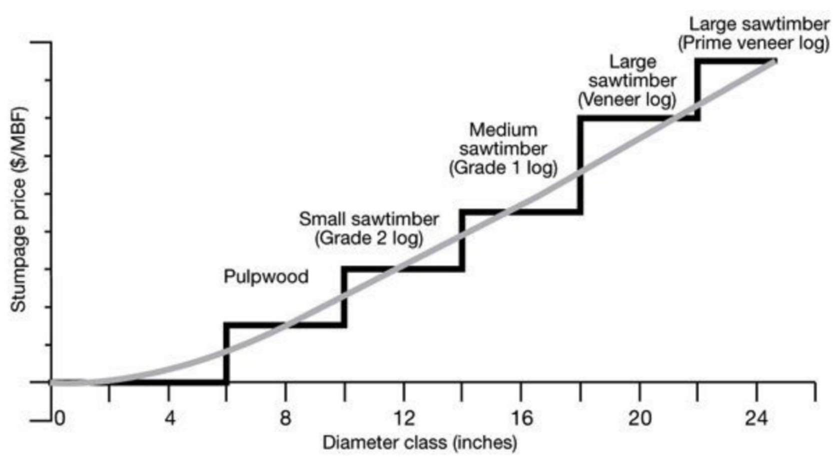


Figure 4: Cartoon illustration of relationship between timber size, grade, and stumpage price (dollars per thousand board feet). Trees become more valuable per unit of wood as they get larger because the timber can be sold to higher-value markets.

[104] Jacobson, M. (2008) "Forest Finance 8: To cut or not to cut- deciding when to harvest timber." Pennsylvania State University Extension. https://extension.psu.edu/forest-finance-8-to-cut-or-not-cut-deciding-when-to-harvest-timber

The trend of increasing value does not continue indefinitely because forests eventually reach a biological maximum or steady-state. At this point, old trees begin to die and be replaced by younger trees, and the value of the forest for timber may actually decrease (Fig. 5). In considering when to cut, there are three maxima: (1) the financial optimum, (2) the maximum sustained yield (MSY), and (3) the biological maximum. The financial optimum is the point at which the the rate of return on the timber dips to an alternative rate of return (expressed as the discount rate). The maximum sustained yield occurs after the rate at which forest growth begins to level off, at the point where mean annual increment (volume/stand age) is maximized. This point is often called the biological rotation. The final point, the biological maximum, is the point at which the forest ceases to add timber volume and is likely only to be achieved through very long-term easement strategies. These economic considerations are most relevant to the extended rotation age (ERA) IFM strategy, which pushes the harvest date beyond the financial optimum.

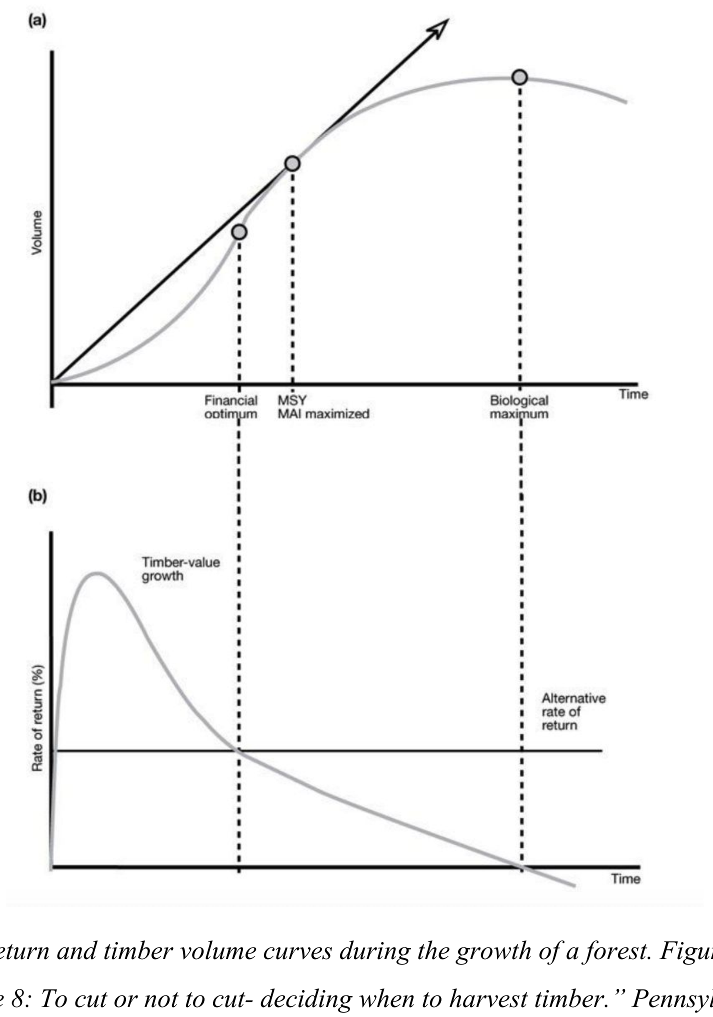


Figure 5: Economic return and timber volume curves during the growth of a forest. Figure from Jacobson, M. (2008) "Forest Finance 8: To cut or not to cut- deciding when to harvest timber." Pennsylvania State University Extension.

All viable IFM projects will cause the landowner to forgo profits, either by letting the forest grow beyond the point of financial maturity, or by causing the manager to invest in additional carbon sequestration beyond that otherwise achievable through non-intervention. In order for the project to be attractive to the Alaska Native Corporation, however, the forgone timber profits must be compensated through a combination of offset revenue and social/environmental benefits achieved by the project. We believe that such a balance is possible through appropriate forest-specific project design.