SUPPLEMENTARY DATA SET

Table 1: External experts who provided review of the literature summaries

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Mark Friedl	Boston University	Boreal Forests
Charles Miller	Jet Propulsion Laboratory, California Institute of Technology	Boreal Forests
Eric Kasischke	University of Maryland	Boreal Forests
Judith Rosentreter	Yale School of the Environment	Coastal Blue Carbon
Kevin Kroeger	United States Geological Survey	Coastal Blue Carbon
Budiman Minasny	University of Sydney	Croplands
Pete Smith	University of Aberdeen	Croplands
Ann Bartuska	Resources for the Future / EDF	Croplands, Grasslands
Jon Sanderman	Woodwell Climate Research Center	Croplands, Grasslands
Amy Hughes	EDF	Croplands, Temperate Forest
Jorge Villa	University of Louisiana at Lafayette	Freshwater Wetlands
Blanca Bernal	Winrock International	Freshwater Wetlands
Richard Conant	Colorado State University	Grasslands
Isabella Arzeno Soltero	University of California, Irvine	Macroalgae (Aquaculture)
Grace Saba	Rutgers University	Open Ocean Blue Carbon
Andrew Pershing	Climate Central	Open Ocean Blue Carbon
Hans Joosten	University of Greifswald	Peatlands
Susan Page	University of Leicester	Peatlands
Austin Rutherford	University of Arizona	Shrublands
Grayson Badgley	CarbonPlan	Temperate Forests
Winston Hansen	Cary Institute of Ecosystem Studies	Temperate Forests
Anna Trugman	University of California, Santa Barbara	Temperate Forests
Francis Putz	University of Florida	Tropical Forests
Richard Houghton	Woodwell Climate Research Center	Tropical Forests
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Britta Dosch	EDF	Tropical Forests
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Agroforestry

Agroforestry, defined as the deliberate establishment of woody perennials such as trees and shrubs on agricultural lands (crop or animal production systems), is thought to have a major climate mitigation role through C sequestration in perennial biomass and soil (Nair, 2012; Minang et al., 2014; FAO, 2015; Artaxo et al., 2019; COWI et al., 2021; Mayer et al., 2022). This land-use type also provides multiple co-benefits (economic and social) to smallholders (Anderson and Zerriffi, 2012).

Agroforestry systems (AFSs) cover about 1×10^9 hectares of land (Nair et al., 2010; Zomer et al., 2016). The global C stock stored in AFSs is estimated to be 46 Mg C ha^{-1} in tree biomass (aboveground and belowground) (Ma et al., 2020) and 126 Mg C ha^{-1} in the soil pool (Shi et al., 2018). Nair et al., (2010) estimated that soil C stocks of AFSs between 30 – 300 Mg C ha^{-1} up to 1 m depth in the soil. Most of the newly sequestered C resides in the aboveground tissues (Schoeneberger, 2009).

Carbon stocks of AFSs strongly depend on the system type, age, climate and vary drastically from region to region (Montagnini and Nair, 2004). Globally, AFSs are considered strong C sinks with a C sequestration potential that ranges between 0.1 Pg CO_2e yr^{-1} – 5.7 Pg CO_2e yr^{-1} (Artaxo et al., 2019; Roe et al., 2021). Nonetheless, business-as-usual projections for C dynamics in agroforestry under future climate change and management regimes is uncertain. A recent study suggests that current AFSs will remain sinks into the future (Nath et al., 2021) while others have suggested that they might become C neutral by 2030 (Griscom et al., 2017). Like C stocks, carbon sequestration potential of AFSs changes significantly with geography and system (Montagnini and Nair, 2004; COWI et al., 2021).

In the U.S., alley cropping, where food or forage crops are grown in alleys formed by hedgerows of trees and shrubs (Smith, 1992), has a larger C sequestration potential (0.082 Pg CO_2e yr^{-1} in) than windbreaks[1] (0.005 Pg CO_2e yr^{-1}) (Udawatta and Jose, 2012). Certain management practices such as planting of nitrogen-fixing perennials crops, fertilization, adoption of conservation tillage or no-till, and pruning or thinning could increase the C sequestration potential of AFSs (Montagnini and Nair, 2004; Udawatta and Jose, 2012).

By 2040, it is believed that AFSs could sequester an additional 2.20 Pg CO_2e yr^{-1} if the 6.30×10^8 hectares of marginal croplands and grasslands were converted to agroforestry (Dixon, 1995; Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Zomer et al., 2009; Jose, 2009; Jose and Bardhan, 2012). However, there are some knowledge gaps, such as a lack of data on the spatial and temporal patterns of soil organic C (SOC) across agroforestry landscapes and lack of a standard set of methods and procedures to monitor C stocks in AFSs that have contributed to our assessment of medium uncertainty in our ability to understand the C storage potential of AFSs (Nair et al., 2010; Fargione et al., 2018; Artaxo et al., 2019).

Despite those knowledge gaps, markets for agroforestry C credits have grown. There are both voluntary and compliance markets for agroforestry C credits. carbon crediting protocols for generating credits can generally be divided into jurisdictional and project-based approaches.

[1] Barriers of trees planted on cropland edges to slowdown wind velocities to protect crops (FAO,1989).

These protocols have been developed by several international organizations including Verra, Clean Development Mechanism, American Carbon Registry, Gold Standard, Climate Action Reserve and FAO. Most of the protocols account for additionality, permanence, leakage, reversals, and uncertainty in varying ways. A sizeable of credits have been generated for agroforestry across the world, detailed descriptions of projects and credits can be found by referring to registry websites.

The increasing popularity of agroforestry C credits has spotlighted concerns surrounding protocols and project approaches. For example, experts have raised concerns about additionality, permanence, and land tenure rights for project-scale REDD+ activities. Additional concerns are described in more detail in the associated table.

Agroforestry

Global Areal Extent: About 1×10^7 km^2 (Zomer et al., 2009; Nair et al., 2010). The exact area under agroforestry practices is difficult to estimate because of the lack of proper procedures for delineating the area influenced by trees in a mixed stand of trees and crops (Nair et al., 2010; Udawatta and Jose, 2012).

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?

- The available estimates of C stored in agroforestry range from 1.29 – 20.50 Mg C ha^{-1} in plant roots (Nair et al., 2009). Shoot C stocks can range between 6.3 – 172.0 Mg C ha^{-1} and soil C stocks range between 30 – 300 Mg C ha^{-1} up to 1 m depth in the soil (Nair et al., 2010; Mbow et al., 2014). Nevertheless, most studies only report aboveground C in AFSs and belowground/soil C are often omitted. Most of the C sequestered by AFSs is stored in the aboveground biomass pool (Schoeneberger, 2009).
- Ma et al., (2020) reported that on average AFSs store 46 Mg C ha^{-1} in tree biomass (aboveground and belowground).
- Verchot et al., (2007) reported that AFSs in the humid tropics contained 50 – 75 Mg C ha^{-1}.
- Average C stocks also vary a lot across AFSs (Montagnini and Nair, 2004; Nair et al., 2009, 2010).
- Average C stock in AFSs also varies by region. AFSs contain on average 9, 21, 50, and 63 Mg C ha^{-1} in semiarid, subhumid, humid, and temperate regions respectively (Montagnini and Nair, 2004).
- AFSs in tropical highlands contain between 77 and 634 Mg soil C ha^{-1} while their soil C stocks range between 21 and 149 Mg C ha^{-1} in humid lowlands (Nair et al., 2010; Stavi and Lal, 2013; Atangana et al., 2014a). AFSs in semi-arid and arid lowlands store between 5 and 90 Mg soil C ha^{-1}.
- Shi et al., (2018) estimated by conducting a meta-analysis of 427 soil C stock data pairs that the mean soil C stocks in AFSs at one meter depth at a global scale was 126 Mg C ha^{-1}.
- Mayer et al. (2022) showed that temperate AFSs sequestered more SOC in topsoils (0. 21Mg C ha^{-1}) than in subsoils (0.15Mg C ha^{-1}).

At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?

- Current AFSs are C sinks at a global level (Atangana et al., 2014b; Zomer et al., 2016; Artaxo et al., 2019). Carbon stocks of AFSs have significantly increased from 2000 to 2010 (+7.33 Pg CO_2) (Zomer et al., 2016).
- AFSs such as alley cropping, silvopasture, riparian buffers, windbreaks and woodlots are considered C sinks in both temperate and tropical regions (Atangana et al., 2014b). AFSs which include perennial crops like coffee alongside trees are thought to be stronger C sinks than systems composed of both trees and annual crops (Artaxo et al., 2019).
- Nevertheless, not all AFSs have proven to be C sinks. Some agroforestry practices such as ruminant-based silvopastoral and rice paddy agrisilvicultural systems might be net C sources (Dixon, 1995; Montagnini and Nair, 2004; Atangana et al., 2014a; Mayer et al., 2022). Mayer et al. (2022) revealed that temperate silvopastoral systems might be weak carbon sources by losing SOC at both the topsoil (-0.17 Mg C ha^{-1} yr^{-1}) and subsoil levels (-0.03 Mg C ha^{-1} yr^{-1})
- Atangana et al. (2014) explained that the different activities and practices carried on in AFSs as well as their previous land use, climatic conditions, socioeconomic context and species composition explicated the difference in the carbon source-sink relationship between.
- AFSs at low latitudes can be significant C sources (Dixon, 1995). Montagnini & Nair (2004) warned that alley cropping systems might be C sources if they are not properly managed and if pruning residues are not left on the ground.

Business-as-usual projections

- Griscom et al. (2017) predicted that under a BAU scenario, the baseline flux in 2030 of AFSs such as windbreaks and alley cropping will be 0 Pg CO_2e yr^{-1}.

	• Nath et al. (2021) projected that under a BAU scenario (current agroforestry area will remain the same in the next 30 years), Indian AFSs will become stronger C sinks. They estimated that Indian agrisilvicultural, agrosilvopastoral and silvopastoral systems will sequester 4.3, 4.6 and 1.6 Pg CO_2e respectively by 2050. They computed that this "represented an increase of 53 – 127% from 2020 levels" (Nath et al., 2021, p. 8).
Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	*Yes, increases in C sequestration and decreases in emissions from AFSs are both possible* • Carbon sequestration potential of AFSs depend on plant species (trees and crops), age/rotation length, site quality and tree management (Nair et al., 2009). The association of certain crops and trees might be more beneficial from a C sequestration perspective. Planting of nitrogen-fixing tropical crop species with commercial timber trees could also promote aboveground biomass production in AFSs and thereby increase the C sequestration potential of those systems (Nair et al., 2009; Udawatta and Jose, 2012; Jose and Bardhan, 2012). • Selection of complementary grasses, shrubs and trees in silvopastoral systems could enhance C sequestration by these systems (Udawatta and Jose, 2012). Proper stocking rates as well as fertilization and rotation grazing could also promote C sequestration rates of silvopastoral systems (Udawatta and Jose, 2012). • Silvicultural operations like thinning and pruning can promote aboveground C but could also induce soil C losses (Nair et al., 2009, 2010). • Adoption of no-till or conservational tillage practices instead of conventional tillage can promote net C sequestration in AFSs. • Planting of perennial crops in AFSs such as coffee and cacao instead of annual crops proved to increase their C sequestration rates and potential (Artaxo et al., 2019). • Planting of broadleaf trees in AFSs rather than coniferous induces higher SOC sequestration rates (Mayer et al., 2022).
What is the range of estimates for how much additional C could be sequestered globally?	*Global estimates of C sequestration potential of AFSs* • *Maximum carbon sequestration potential of Trees in Agriculture: 1.844 Pg CO_2e yr^{-1} (Nature4Climate, 2022)* • *Cost-effective carbon sequestration potential of Trees in Agriculture: 0.816 Pg CO_2e yr^{-1} (Nature4Climate, 2022)* • *Technical carbon sequestration potential of agroforestry: 5.61 Pg CO_2e yr^{-1} (Roe et al., 2021)* • *Cost-effective carbon sequestration potential of agroforestry: 1.12 Pg CO_2e yr^{-1} (Roe et al., 2021)* • The global C sequestration potential of agroforestry ranges from 0.08 Pg CO_2e yr^{-1} – 5.7 Pg CO_2e yr^{-1} (Zomer et al., 2016; Griscom et al., 2017; Artaxo et al., 2019). IPCC special reports revealed a medium confidence index in this estimate. This estimate of the C sequestration potential of AFSs takes into account biophysical, economic and social factors (Artaxo et al., 2019). The high estimate arises from the combination of four agroforestry solutions (silvopasture, tree intercropping, multistrata agroforestry and tropical staple trees) (Artaxo et al., 2019). • The carbon sequestration potential of agroforestry ranges from 0.11 to 5.68 Pg CO_2e yr^{-1} (Roe et al., 2019) • The carbon sequestration potential of agroforestry ranges from 0.1 to 0.55 Pg CO_2e yr^{-1} (Roe et al., 2017) • Trees in croplands have a C sequestration potential of 1 Pg CO_2e yr^{-1} by 2030 (Griscom et al., 2017). • Zomer et al (2022) estimated that an increase of tree cover by 1%, 5% and 10% on all agricultural land (incremental change) would increase total biomass carbon by 6.72, 33.51 and 67.06 PgCO_2e respectively. • Zomer et al (2022) computed that increasing tree cover by no more than 10% in agricultural areas that are currently below median tree cover (which represents 45% of all agricultural land) would increase global total biomass (aboveground and belowground biomass) by 16.88 Pg CO_2 • Widespread adoption of agroforestry practices or other practices which systematically incorporate increased tree cover for habitat management, riparian restoration, or erosion control (systematic change) would increase biomass carbon on agricultural land by 45.91 to 71.60 Pg CO_2e ((Zomer et al., 2022).

By 2040, AFSs could sequester an additional 2.22 Pg CO_2 yr^{-1} if the 6.30×10^8 hectares of marginal croplands and grasslands were converted to AFSs (Dixon, 1995; Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Jose, 2009; Jose and Bardhan, 2012).

- (Dixon, 1995) stated that the C sequestration potential of agroforestry ranged between 55 and 726 Mg CO_2 ha^{-1}, with a medium value of 125 Mg CO_2. Ha^{-1}.
- agroforestry sequesters from 110 – 1181 Pg CO_2 yr^{-1} (Agevi et al., 2017). An additional 4.404×10^{-5} Pg CO_2. yr^{-1} could be sequestered by 2040, increasing to 6.239×10^{-5} Pg CO_2 yr^{-1} by 2040, if tree management practices are improved (Jose, 2009; Agevi et al., 2017).
- Cardinael et al. (2018) showed that the conversion of croplands to AFSs increased soil C stocks by 2.75 Mg CO_2 ha^{-1} yr^{-1}. De Stefano & Jacobson (2018) also showed that the shift in land use from cropland to agroforestry increased SOC stocks by 26, 40, and 34% at 0 – 15, 0 – 30, and 0 – 100 cm respectively.

Regional estimates of C sequestration potential of AFSs

- The C sequestration potential of each AFS also depends on the climate and varies by region (see Table 3 in Nair et al., 2009).
- Trees in Agricultural lands (tropical regions) have a sequestration potential of 930.82 Tg CO_2e yr^{-1} between 2030 and 2050 (Cost-effective mitigation potential: (<100 USD $MgCO_2e^{-1}$) (Griscom et al., 2020)
- Trees in Agricultural lands (tropical regions) have a sequestration potential of 1807.15 Tg CO_2e yr^{-1} between 2030 and 2050 (Maximum mitigation potential) (Griscom et al., 2020)
- AFSs in the U.S. such as alley cropping could sequester 0.082 Pg CO_2e. yr^{-1} in 2025 (Fargione et al., 2018).
  - *Note: Nevertheless, these authors warned that this mitigation potential might not be achieved because of the insignificant current adoption of such systems. Low adoption rates are explained by a combination of cultural, economic and technological factors* (Fargione et al., 2018).
- AFSs in the Europe Union have a climate mitigation potential that ranges between 0.008 – 0.24 Pg CO_2e yr^{-1} (COWI et al., 2021).
- Udawatta & Jose (2012) estimated that four major agroforestry practices (alley cropping, silvopasture, windbreaks, and riparian buffers) in the U.S. combined, could sequestered 1.95Pg CO_2 yr^{-1} (include soil C pool) which could help offset 33% of current U.S. emission arising from fossil fuel burning (5.87Pg CO_2. yr^{-1}). They also stated that the C sequestration potential of, alley cropping, silvopasture and windbreaks in the U.S. was 1.72, 0.19, and 0.031 Pg CO_2. yr^{-1} (including soil C pool), respectively. Additionally, research proved that riparian buffers could sequester an additional 0.017 Pg CO_2. yr^{-1} while protecting water quality (Jose and Bardhan, 2012).
- Canada: Mitigation potential in 2030
  - Tree Intercropping: $3.92*10^{-3}$ Pg CO_2e. yr^{-1} (Drever et al., 2021),
  - Silvopasture: $2.83*10^{-3}$ Pg CO_2e. yr^{-1} (Drever et al., 2021).
- Aboveground / belowground and soil components of AFSs have different C sequestration potentials. For example, soil C sequestration potential of an AFS in Oregon was 351.91 Mg CO_2. ha^{-1} while the C sequestration potential of biomass tissues (aboveground and belowground) of the same system was 44Mg CO_2. ha^{-1} (Nair et al., 2009).
- (Mayer et al., 2022) revealed that hedgerows have a higher soil C sequestration potential in both topsoils and subsoils (0.32 Mg C ha^{-1} yr^{-1} and 0.28 Mg C ha^{-1} yr^{-1}) than alley cropping systems (0.26 Mg C ha^{-1} yr^{-1} and 0.23 Mg C ha^{-1} yr^{-}).
- Carbon sequestration potential of AFSs vary significantly by region with tropical regions being highest. AFSs in tropical regions could sequester 7.7 Pg CO_2 yr^{-1} in their aboveground tissues while 6.97 Pg CO_2 yr^{-1} could be sequestered in the same C pool in temperate regions.
- Dickie et al., (2014) estimated that the implementation of agroforestry practices and especially mixed crop-livestock systems in tropical and humid highlands could sequester 0.105 Pg CO_2e. yr^{-1} by 2030. To come up with this estimate they assumed an adoption rate of agroforestry practices of 1 percent per year and a per hectare sequestration potential of 1.39×10^{-7} Pg CO_2 (Dickie et al., 2014).
- The C sequestration potential of tropical AFSs ranged between 44 and 836 Mg. ha^{-1} with a median value of 348 Mg CO_2 ha^{-1} (Albrecht and Kandji, 2003).

	• In humid areas, AFSs can sequester up to 183.5 Mg CO_2. ha^{-1}, and smallholder agroforestry in the tropics can sequester between 5.5 and 12.8 Mg CO_2 ha^{-1} yr^{-1} (Montagnini and Nair, 2004). • (Oelbermann et al., 2004) estimated that agroforestry activities can sequester 7.7 Pg CO_2. yr^{-1} in tropical regions and 6.97Pg CO_2. yr^{-1} in temperate biomes. • Brown et al., (2012) assessed that the C sequestration potential of agroforestry in East and West Africa was 22–81 Mg CO_2. ha^{-1} yr^{-1}. • C sequestration potential of park land, live fence, and home gardens in sub-Saharan Africa ranges from 0.73 – 2.94 Mg CO_2. ha^{-1} yr^{-1} whereas rotational woodlots have higher C sequestration rates; from 8.07 – 21.29 Mg CO_2 ha^{-1} yr^{-1} (Luedeling et al., 2011).
How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that?	In AFSs both aboveground and belowground C must be measured to assess current ecosystem C stocks to detect any potential changes (Nair et al., 2009). We lack confidence in our estimates of C stocks and changes in C stocks because of the lack of standard set of methods and procedures to monitor C stocks in AFSs (aboveground and belowground C stocks, including soil C) (Nair et al., 2009, 2010; Jose and Bardhan, 2012; Tumwebaze and Byakagaba, 2016). *Aboveground C estimation challenges* • Use of existing allometric equations to estimate aboveground biomass of agroforestry trees might lead to erroneous results (underestimation of biomass C) since agroforestry trees differ from forest-grown trees in their morphology, structure and composition (Nair et al., 2010; Jose and Bardhan, 2012; Zhou et al., 2015). There is an urgent need for species specific allometric equations for different agroforestry practices to be able to accurately assess current C stocks and potentials of agroforestry practices (Jose and Bardhan, 2012). • AFSs are different from one another, each composed of different plant species, having different structures and densities which makes difficult to estimate the biomass content of each system and extrapolate estimates from one system to another (Nair et al., 2010). *Belowground and soil C estimation challenges* • Belowground biomass C estimation proved also to be a challenging task (Nair et al., 2010). Belowground and soil C dynamics are still not very well understood especially in fine roots (Nair et al., 2010). • C stocks of belowground vegetation and soil components are not usually reported, and those that have been reported lack the required scientific rigor because of a lack of consistency in methods used to assess C stocks across studies (size of aggregates not standardized, lack of uniformity in soil-sampling depth, lack of uniformity in breaking points between soil-horizon depth, and because indirect estimation of belowground biomass C based on aboveground biomass C (using root to shoot ratio) can be misleading due to differences in growth form of agroforestry trees and management practices that can lead to underestimations of root biomass) (Nair et al., 2009, 2010; Udawatta and Jose, 2012). • Expensive and intensive to quantify and measure changes in SOC stocks (COWI et al., 2021; Oldfield et al., 2021). • Soil C models are not necessarily calibrated for AFSs; Roth C and CENTURY were developed for agricultural, forest, and grassland systems separately (Diels et al., 2004; Nair et al., 2010). When they are used in AFSs, models might underestimate/overestimate SOM decomposition rates and thus impair our ability to accurately detect changes in AFSs C stocks (Nair et al., 2010; Schoeneberger et al., 2017). • High spatial variability of SOC across a field further hampers detection of SOC changes (Tumwebaze and Byakagaba, 2016; Oldfield et al., 2021). • Changes in SOC are small in comparison to the existing stock; it can take a long time before enough SOC has been accrued to be detected (Oldfield et al., 2021). *Carbon tools* • Several carbon tools (eg. EX-ACT tool, US AID Carbon Calculator, CO_2Fix tool, GEF-6 CC Mitigation Tracking tool, Cool Farm Tool) provide quick and rough estimates of carbon sequestration potential of certain land uses including agroforestry activities (Montagnini et al., 2015). They simulate the amount of additional C sequestered each

	year by agroforestry activities for different C pools, including aboveground and belowground biomass as well as soil C. Some of them (eg. CO2Fix) also simulate C fluxes between C pools over time (Montagnini et al., 2015). However, they don't provide the level of accuracy needed for C financing (Winrock International, 2014). They are more commonly used as planning tools rather than monitoring tools at various scales (country, regional or project). Overall: The lack of standard procedures of measurement or estimation decreases the confidence we have in our ability to detect any net changes in C sequestration in an AFS.

C Markets	
Is there a market (or proposed market) for carbon credits from the system?	Yes, voluntary and compliance C markets exist. AFSs qualify as a small-scale afforestation/reforestation practices under the CDM (Clean Development Mechanism), as defined in the Kyoto Protocol (Stavi and Lal, 2013; Atangana et al., 2014a). Several C accounting methodologies developed for REDD+ activities also include agroforestry as an eligible project activity and the C benefits generated by agroforestry projects are quantified using them.
Are there protocols (or proposed protocols) for such credits?	For agroforestry projects, there are both project based and jurisdictional approaches for credits. To date, project-based protocols and methodologies have been the only ones to generate credits but a growing number of jurisdictional and nested approaches demonstrates the increasing demand for this broader and more comprehensive approach that has the potential to address several issues raised with project-based protocols. *Jurisdictional approaches* = government-led, comprehensive approach to forest and land use across one or more legally defined territories (CIFOR) **Voluntary** • ART's TREES (The REDD+ Environmental Excellence Standard)[d]; international • ACR Nested REDD+ Standard; international ACR Nested REDD+ Standard[d]; international • CARB's California Tropical Forest Standard; international CARB's California Tropical Forest Standard[a]; international • FCPF's Carbon Fund[d] (pilots results-based payments for REDD+ activities in developing countries); international • Verra Jurisdictional and Nested REDD+ Framework[a] (webinar); international

Project Based = receive credits on a project level basis

Voluntary

- American Carbon Registry (REDD Methodology Modules)[a]; international
- Gold standard Afforestation/Reforestation GHG Emissions Reduction & Sequestration Methodology v1[c]; international
- Climate Action Reserve's Mexico Forest Protocol [a]; Mexico
- Verra VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.2[a]; international
- Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1[e]; international
- Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1[c]; international
- Verra VM0017 Adoption of Sustainable Agricultural Land Management, v.1[b]; International
- Verra VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0[a]
- Verra VM0042 Methodology for Improved Agricultural Land Management v 1.0[b]; international
- Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)[f]; China
- Plan Vivo Plan Vivo Climate Benefit Quantification Methodology- Small-holder Agriculture Mitigation Benefit Assessment (SHAMBA): Afforestation/Reforestation/agroforestry[a]; international
- FAO GSOC MRV Protocol[b]; international

Compliance

- Clean Development Mechanism (AR-AMS0007: Afforestation and reforestation project activities implemented on lands other than wetlands v3.1[a]; international

[a] Protocol applies to agroforestry and tropical forest systems
[b] Protocol applies to agroforestry and cropland soil systems
[c] Protocol applies to agroforestry and multiple forest systems
[d] Protocol applies to agroforestry, tropical forest and peatland systems
[e] Protocol applies to agroforestry, tropical forest, peatland, coastal blue carbon and freshwater wetland systems
[f] Protocol applies to agroforestry, multiple forests, grassland and cropland soils systems

Note: The Panda Standard Sectoral Specifications applies to AFSs, however, we have not been able to verify that the protocols have been approved by the Chinese government, and/or have generated agroforestry credits to date. Additional protocols that cover the agroforestry pathways in China may exist, but we have not been able to review all of them due to limited publicly available information

If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	*Jurisdictional Approaches* **ART TREES** • Permanence: 5-year crediting periods, risk assessment considers a period of 100 years • Additionality: Performance-based approach in that only emissions achieved below a conservative historical baseline will be eligible for crediting • Reversals: ART maintains a combined buffer pool that includes contributions from all ART Participants. Reversals are reported and a volume of credits from the buffer pool equivalent to either the reversed volume or the total number of ERs previously issued to the Participant (whichever is lower) is retired to permanently remove the ERs from circulation and negate the reversal. If a participant exits ART, any unused buffer pool contributions are retired to account for any possible future reversals. TREES establishes a starting level of reversal risk for Participants of 25% (which can be lowered if demonstrated mitigating factors exist). After a reversal is reported, a Participant must increase its buffer contribution for a period of five years by 5%. • Leakage: Where TREES participants submit a subnational Crediting Level, then negative leakage of emissions to outside the accounting area can occur. Participants must apply specified TREES leakage deductions. Participants are classified as high, medium, or low leakage risk and are assigned a deduction of 20%, 10%, or 5%, respectively. • Uncertainty: A conservative approach is applied whereby, beyond an allowable uncertainty (15% at the 90% confidence level), the Crediting Level is reduced by the calculated percentage uncertainty quantified in terms of the half-width of the 90% confidence interval as a percentage of the estimated emissions. **ACR Nested REDD+ Standard** • Eligible Activities: REDD+ • Permanence: 40 years • Reversals: calculates risk of non-permanence using the VCS AFOLU Non-Permanence Risk Tool – project proponents may contribute to a buffer pool OR purchase insurance for their credits • Leakage: Where the jurisdiction is monitoring leakage within the jurisdiction, nested REDD+ projects shall use the jurisdictional leakage accounting framework. The jurisdictional accounting framework must outline how leakage will be addressed within the jurisdiction. Where there is a jurisdictional crediting system, jurisdictions shall have clear policies and procedures in place for attributing leakage to nested projects. a Leakage Buffer Account for nested REDD+ projects, modeled on but separate from the ACR non-permanence buffer account. All nested projects will be required to calculate leakage per the requirements of the applicable project-level methodology, but rather than simply being deducted from net emission reductions, leakage tons will be created in the Leakage Buffer Account • Additionality: Additionality as described in the ACR Forest Carbon Project Standard does not need to be separately demonstrated at the nested project level, since a jurisdictional baseline meeting minimum criteria by definition indicates that in the absence of the project activity a given area would be deforested • Uncertainty: ± 10% of the mean at 90% confidence interval. **CARB Tropical Forest Standard** • Eligible Activities: REDD+ • Permanence: 100 years, risk calculated through jurisdictional risk assessment. • Additionality: to demonstrate additionality implementing jurisdiction must reduce deforestation beyond a crediting baseline that is below historical emissions. Implementing jurisdictions must establish a crediting baseline that begins at least 10% below the reference level described in the Standard and linearly declines to a jurisdictional-specific 2050 GHG emissions target for the forest sector.

- Leakage: Projects must demonstrate how economic activities driving deforestation in the implementing jurisdiction have been either replaced with more sustainable economic activities, or improved in their sustainability, is important in assessing and transparently estimating leakage; suggests that ETS create a Sector Based Crediting Program Buffer Pool.
- Reversals: implementing jurisdictions must contribute a minimum of 10 percent of the total credits issued by the implementing jurisdiction per year, or the amount of credits identified by the buffer pool contribution equation, which must be based on the reversal risk rating factors identified in the Standard, whichever is higher.
- Uncertainty: Standard states that "A percent credit deduction shall be taken prior to issuance corresponding to the results of the uncertainty calculation" but does not state exact parameters.

FCPF Carbon Fund

- Eligible Activities: REDD+
- Permanence: if an ER program transits into a new GHG program or standard, the applicable GHG program shall monitor for the Reversals and have in place a Reversal management mechanism to compensate for material Reversals for at least until 15 years following the end of Carbon Fund in 2025 (i.e. 31 December 2040)
- Additionality: Additionality primarily is addressed through conservative approaches to setting Reference Levels (e.g., including existing and clearly funded programs or activities within the Reference Level), rather than through additionality tests often utilized by project-level initiatives, which have proven difficult to operationalize.
- Leakage: Potential sources of domestic and international displacement of emissions (Displacement) are identified by assessment of all drivers of land-use change relevant for the ER Program; and measures to minimize and/or mitigate the risk of displacement of domestic emissions are incorporated into ER Program design and the estimation and monitoring of ERs. ER Programs should seek to minimize and mitigate Displacement outside the Accounting Area (domestic and international) to the extent possible via design of the ER Program. However, due to accounting and attribution challenges and following UNFCCC guidance on REDD+, potential international Displacement should not have to be accounted for or deducted from the ERs credited to ER Programs.
- Reversals: ER Program are deposited in an ER Program CF Buffer, managed by the Carbon Fund, based on a Reversal risk assessment Leakage; amount of emissions reductions contributed are based on total aggregate uncertainty of emission reductions ranging from 0 – 15%. If forest degradation is measured through a separate approach using proxy-based approaches, a general conservativeness factor of 15% is applied.
- Uncertainty: includes an 'Uncertainty Buffer' to create incentives for improving (reducing) uncertainty associated with the estimation of ERs and manage the risk that the emission reductions were overestimated for prior reporting periods Equal to the Reversal buffer. Each program is required to conduct an uncertainty analysis which consists of a three-step process laid-out in three different criteria: identification (Criterion 7); reduction (Criterion 8) and quantification (Criterion 9). The final objective of the Uncertainty Analysis is to provide an estimate of uncertainty of Emission Reductions in the form of the relative half-width confidence interval at the 90% confidence level.

Verra Jurisdictional and Nested REDD+ Framework

- Eligible Activities: REDD+
- Permanence: Requirement of 100 years, with risk of non-permanence calculated using the VCS JNR Non-Permanence Risk Tool
- Additionality: The project must use the most recent version of the Clean Development Mechanism (CDM) additionality tool to identify the baseline scenario and demonstrate additionality

- Leakage: Accounts for GHG emissions from activity shifting, market leakage and ecological leakage. Determined either directly from monitoring, or indirectly using sound scientific knowledge or research, providing credible estimates of likely impacts through JNR Leakage Tool
- Reversals: A percentage of credits go to buffer pool. Buffer credits are applied via the JNR Non-Permanence Risk Tool; Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification
- Uncertainty: Jurisdictional programs shall undertake an analysis of uncertainty in estimating GHG emissions and GHG emission reductions. Before allocating project baselines and lower-level jurisdictional forest reference emission levels (FRELs), the higher level jurisdictional FREL is required to be conservatively discounted, in order to reduce the risk of overestimation. Nested projects and lower-level jurisdictional programs shall undertake an analysis of uncertainty in estimating GHG emissions.

Project-based Protocols/Methodologies

Verra VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects v2.2

- **Permanence:** 30 years. In the VCS Program all AFOLU projects have a longevity of 30 years as established in the AFOLU Non-Permanence Risk Tool. The project crediting period for AFOLU projects must be between 20 and 100 years. Non-permanence risk in jurisdictional REDD+ programs and nested projects is assessed through the use of a risk analysis.
- **Additionality**: Demonstrated by using the VC VT0001 tool developed by Verra for AFOLU projects. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice).
- **Leakage:** Monitored and quantified using a leakage belt approach for geographically constrained drivers, and a factor approach for geographically unconstrained drivers. If leakage occurs, it is subtracted from the the total GHG emission reductions and removals achieved during the monitoring period. The minimum leakage belt area (defined to address activity-displacement leakage) must equal at least 90% of the area of the project. Market leakage emissions must be quantified by multiplying the net change in C stock with an appropriate leakage discount factor of either 0, 0.1,0.2,0.4 or 0.7. Accounts for GHG emissions due to market effects resulting from any increase in greenhouse gas emissions that occurs outside a project's boundary (but within the same country), that is measurable and attributable to the project activity.
- **Reversals**: Use of pooled buffer account composed of non-tradable credits. This account serves as a shared insurance pool for all VCS AFOLU projects against unpredictable events (drought, fire, flood). Credits from the buffer pool may be released back over time to projects where risks have been successfully mitigated. 15% of project's buffer is released every 5 years at re-verification
- **Uncertainty**: The level of uncertainty is assessed at every step of GHG emission quantification. Uncertainty refers to measurement errors in the sample collection, inventory and laboratory processing. Not explicitly stated but methodology uses whenever possible the proven methods from the GPG-LULUCF, GPG-2000, and the IPCC's Revised 2006 Guidelines. As well, tools and guidance from the CDM Executive Board on conservative estimation of emissions and removals are also used. If uncertainty is significant, project proponents should choose data such that it indisputably tends to under-estimate, rather than over-estimate, net GHG removals by sink.

Verra VM0007 REDD+ Methodology Framework (REDD+MF) v.1

- **Permanence**: 30 years. In the VCS Program all AFOLU projects have a longevity of 30 years as established in the AFOLU Non-Permanence Risk Tool. The project crediting period for AFOLU projects must be between 20 and 100 years. Risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool (T-Bar).

- **Additionality:** Use of tool (T-ADD) to determine additionality of a project**.** Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice).
- **Leakage:** The significance of leakage and the significance of C pools may be determined using T-SIG tool. Leakage is monitored and quantified using a leakage belt approach for geographically constrained drivers, and a factor approach for geographically unconstrained drivers. The minimum leakage belt area (defined to address activity-displacement leakage) must equal at least 90% of the area of the project). Market leakage emissions must be quantified by multiplying the net change in C stock with a appropriate leakage discount factor of either 0; 0.1;0.2;0.4 or 0.7. Leakage must be considered for all activities.
- **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS AFOLU Non-Permanence Risk Tool. Buffer withholding percentages are based on the project's overall risk classification. The percentage of C credits generated by the approved project activity that must be deposited into the AFOLU pooled buffer account to cover non-permanence related project risks.
- **Uncertainty:** The allowable uncertainty under this methodology is +/- 15% of Total net GHG emission reductions of the REDD project activity at the 95% confidence level. Use this VCS module to determine uncertainty (VMD0017 Estimation of uncertainty for REDD+ project activities (X-UNC)

Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1

- **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using methodological equation
- **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities noting that the earliest start date of the proposed AUD project activity is January 1st, 2002. However, the start date can be earlier than January 1st, 2002, provided the requirements for projects with a start date prior to 2002, as set out in the most recent version of the VCS Standard, are met.
- **Leakage:** Accounts for emissions from increased grazing activities, increased emission from displaced forest fires, decrease in carbon stocks due to displaced deforestation; see leakage calculation section of methodology which details the calculation process. If the project area is located within a jurisdictional program the most recent VCS JNR Requirements must be applied to determine whether a leakage belt is required. In all other cases, a leakage belt is required.
- **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification
- **Uncertainty:** If the uncertainty of the total average carbon stock of a class is less than 10% of the average value, the average carbon stock value can be used. If the uncertainty is higher than 10%, the lower boundary of the 90% confidence interval must be considered in the calculations if the class is an initial forest class in the project area or a final non-forest class in the leakage belt, and the higher boundary of the 90% confidence interval if the class is an initial forest class in the leakage belt or a final non-forest class in the project area.

Verra VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation v1.0

- **Permanence: 30** years. In the VCS Program all AFOLU projects have a longevity of 30 years as established in the AFOLU Non-Permanence Risk Tool. Project crediting period of between 20 and 100 years. Risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool. Buffer credits are set aside to address risks of non-permanence and are determined using the net change in C stocks.
- **Additionality**: 2-step procedure: Step 1 -Regulatory Surplus (The project shall not be mandated by any law, statute or other regulatory framework): Step 2 : Use of the VC VT0001 tool developed by Verra for AFOLU projects. Procedure is composed of 4 step (Identification of alternative land use scenarios,

Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice).

- **Leakage:** Leakage management zones (LMZ) are created to manage potential leakage. Accounts for use of fuel wood/fossil fuels from non-renewable sources, shifting of grazing and livestock production, shifting of agriculture activities, increased use of fertilizer, unplanned timber harvesting and biomass collection (the minimum leakage belt area, defined to address activity-displacement leakage) must equal at least 90% of the area of the project). Leakage could be determined using the CDM A/R methodological tool for testing significance of GHG Emissions in A/R CDM Project Activities. Market leakage emissions must be quantified by multiplying the net change in C stock with an appropriate leakage discount factor of either 0; 0.1;0.2;0.4 or 0.7.
- **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS AFOLU Non-Permanence Risk Tool. Use of pooled buffer account composed of non-tradable credits. This account serves as a shared insurance pool for all VCS AFOLU projects against unpredictable events (drought, fire, flood). Credits from the buffer pool may be released back over time to projects where risks have been successfully mitigated
- **Uncertainty:** The level of uncertainty is assessed at every step of GHG emission quantification. Uncertainty refers to measurement errors in the sample collection, inventory and laboratory processing. Uncertainty factor is calculated using the 2006 IPCC Guideline for national GHG inventories. The allowable uncertainty under this methodology is +/- 15% of Total net GHG emission reductions of the REDD project activity at the 95% confidence level.

Verra VM0017 Adoption of Sustainable Agricultural Land Management v.1

- Permanence: 30 years. In the VCS Program all AFOLU projects have a longevity of 30 years as established in the AFOLU Non-Permanence Risk Tool. Risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool. Buffer credits are set aside to address risks of non-permanence and are determined using the net change in C stocks.
- Additionality: The project must use the most recent version of the Clean Development Mechanism (CDM) additionality tool to identify the baseline scenario and demonstrate additionality
- Leakage: Accounts for use of fuel wood/fossil fuels from non-renewable sources due to decrease in use of manure and/or residuals that may be transferred to fields through the project.
- Reversals: A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS AFOLU Non-Permanence Risk Tool. Use of pooled buffer account composed of non-tradable credits. This account serves as a shared insurance pool for all VCS AFOLU projects against unpredictable events (drought, fire, flood). Credits from the buffer pool may be released back over time to projects where risks have been successfully mitigated
- Uncertainty: Has a 15% uncertainty deduction: If the uncertainty of soil models is less than or equal to 15% of the mean value calculated at the 95% confidence interval, then the project proponent may use the estimated value without any deduction for conservativeness or increase in sampling

Verra VM0042 Methodology for Improved Agricultural Land Management v1.0

- Permanence: Requirement of 30 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool
- Additionality: Requires identifying barriers that prevent project activities and demonstrating that the adoption of the proposed project activities is not common practice
- Leakage: Accounts for application of manure from outside project area, sustained reductions in crop yields and livestock displacement
- Reversals: A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS AFOLU Non-Permanence Risk Tool
- Uncertainty: Uncertainty deduction is the extent to which the half width of the 95% confidence interval, as a percentage of the mean, exceeds the threshold of 15%

American Carbon Registry: REDD Methodology Modules (REDD-MF)

- **Permanence:** The project crediting period for AFOLU projects must be between 20 and 100 years. Risk of non-permanence calculated using the ACR AFOLU Non-Permanence Risk Tool (T-Bar). Buffer withholding percentages are based on the project's overall risk classification. The percentage of C credits generated by the approved project activity must be deposited into the AFOLU pooled buffer account to cover non-permanence related project risks
- **Additionality: Use of tool (T-ADD) to determine additionality of a project (Must use the latest version).** Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice).
- **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the ACR AFOLU approved- Risk assessment Tool
- **Leakage:** The significance of leakage and the significance of C pools may be determined using T-SIG tool. Leakage is monitored and quantified using a leakage belt. The minimum leakage belt area (defined to address activity-displacement leakage) must equal at least 90% of the area of the project)
    - Source of leakage: Leakage due to displacement of planned deforestation (LK-ASP tool), Leakage due to displacement of unplanned deforestation (LK-ASU tool), Leakage due to displacement of fuelwood/charcoal collection (LK-DFW tool). Where leakage prevention leads to a significant increase in the use of fertilizers, CPES.H shall be used. T-SIG can be used to determine significance. Market leakage can be assessed when applicable using the LK-ME modules
- **Uncertainty:** The allowable uncertainty under this methodology is ±10% of of total net GHG emission reductions of the REDD project activity at the 90% confidence level. Where this precision level is met then no deduction should result for uncertainty. Use this ACR module to determine uncertainty (Estimation of uncertainty for REDD+ project activities (X-UNC)

Plan Vivo Climate Benefit Quantification Methodology- Small-holder Agriculture Mitigation Benefit Assessment (SHAMBA) Afforestation/Reforestation/Agroforestry

- **Permanence:** The project crediting period for AFOLU projects must be between 10 and 100 years with 10 years increment. Must define a non-permanence risk buffer whose size is based on an analysis of the risks associated with C credits generated by the project.
- **Additionality**: 2 steps procedure: Step 1- Regulatory surplus (activities are not required by enforced legislation or conducted to fulfil the official policies, regulations, or industry standards or any organization or institution), Step 2- Barrier Analysis: Identify barriers that prevent project activities (AA1 document).
- **Leakage:** Cannot find an approach to evaluate leakage. Leakage sources should be identified and mitigated.
- **Reversals:** Each project maintains an unsold reserve of C credits called a risk buffer. The level of the risk buffer is set by the Plan Vivo Foundation according to its risk assessment of the project (normally 10 – 20%)
- **Uncertainty:** Projects must identify and describe where uncertainty exists in quantifications of ecosystem services and estimate the approximate level or range of uncertainty. The level of uncertainty must be factored into the level of conservativeness applied in the accounting method for quantifying ecosystem services

Gold Standard Afforestation/Reforestation GHG Emissions Reduction & Sequestration Methodology v.1

- **Permanence:** Does not specifically require permanence of its projects. It only requires projects maintain C stocks during the crediting period. If the C stocks are not maintained during the crediting period, a shortfall is declared, and projects must demonstrate to the Gold Standard how the project will realistically address the performance shortfall and recover appropriate levels of C stocks. Performance risks is assessed following the "Risk and Capacities" guideline. A risk scoring system assesses pre-defined risk categories and determines whether the risks of a project are acceptable to Gold Standard or whether

mitigation measures shall be adopted. Uses high/medium/low scoring system based on defined thresholds. Risk categories are: 1. Natural Disturbance risks 2. Political risks 3. Project Management risks 4. Financial risks 5. Market risks.

- **Additionality:** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice).
- **Leakage:** Accounting for activity shifting required. Leakage shall be determined on a Modelling Unit (MU) level using the following formula: Leakage MU,t [tCO_2 ha^{-1}] = Leakage Project area [tCO_2] / Eligible planting area [ha]. Leakage is deducted in the first year. Four categories of leakage resulting from collection of wood (for firewood, charcoal), timber harvesting, agriculture (crop cultivation, shrimp cultivation) and livestock. All potential Leakage caused by a project within its crediting period is accounted for in year 1. Parameter is not subject to monitoring. Market leakage not accounted for under this methodology. Projects must submit a Leakage Template which includes information and calculations of potential leakage from different project activities. Provides default values when exact data is not available.
- **Reversals:** A percentage of credits go to a buffer pool; projects must contribute to a risk of reversals buffer (20%). Pooled compliance buffer remains untouched even after the crediting period of the project, further reducing the risk of reversal and non-permanence.
- **Uncertainty:** +/-20% at a 90% confidence interval. Where the error is above 20%, the additional difference shall be deducted. Gold Standard provides 3 approaches to uncertainty: Approach 1: Data is measured within each stratum and shall follow accepted sampling and analysis protocols, Approach 2: Data is derived from peer reviewed published literature, Approach 3: Project owners may use published default factors such as IPCCs.

Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)

- **Permanence**: Minimum project term varies with the type of project; Project generating net C sequestration (or GHG removals) have a minimum project term of 30 years; Project generating net emission reductions have a minimum project term of 20 years; Project generating net irreversible net GHG emission reductions have a minimum project term of 5 years. Project Proponents must conduct **a** risk assessment using the Panda Standard Risk Analysis Tool. The result of the Risk Assessment is an overall risk category for the Project, translating into a percentage or number of PS Credits that must be deposited into the Panda Buffer Pool.
- **Additionality**: Additionality can be demonstrated using 2 approaches:
    - **Three-prong approach**: The project activity must meet the following criteria: a. Complies with regulatory requirements b. Exceeds common practice c. Faces investment, technological or institutional barriers);
    - **Performance standard approach** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice)).
- **Leakage:** Accounting for activity shifting required. Any leakage identified must be quantified and subtracted from the net emission reduction/removal benefits except when leakage arises from the creation of poles and fencing to implement Project Activities • Fossil fuel combustion resulting from ground transportation. Leakage accounting might also be omitted if the following criteria are met: Displacement of baseline activities occurs on less than an average of 5% of the land area for a given project activity during the crediting period • Total quantity of a given good/commodity (e.g. lumber, crop, fuelwood, grazing animal) supplied to market in the project scenario for a given project activity is reduced by less than 20% of in comparison to the Baseline during the crediting period • All Leakage emissions are estimated to be below the de minimis threshold on average during the crediting period
- **Reversals:** A percentage of credits go to a buffer pool (Panda buffer pool). 2 options to mitigate risk:

- **Option 1**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, this percentage of offsets from the Project itself for deposit to the Panda Buffer Pool";
- **Option 2**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, the number of PS credits of any type and vintage that equates to the percentage drawn from the risk assessment". Percentage of contribution to buffer pool is not explicitly stated.
- Accounting for market leakage is not required if the following conditions are satisfied:
  - Average quantity of a given good/commodity supplied to market in the with-Project Scenario for a given Project Activity is reduced by less than 20% in comparison to the Baseline.
  - Average quantity of a given good/commodity in the Baseline per year supplied to market is less than 5% of total commodity produced per year within the PRC Prefecture (s) where the Project is taking place.

- **Uncertainty:** If the 90% confidence interval is greater than 10% of the mean the reportable amount must include an uncertainty deduction. The uncertainty deduction shall be equal to the calculated % of the mean represented by the confidence interval minus the allowable 10%

Climate Action Reserve Mexico Forest Protocol v2.0

- **Permanence**: (100-year permanence) Projects may commit to maintaining C sequestered due to project activities for any length of time. However, credits will be issued in an amount proportional to the length of the commitment relative to 100 years. A project will be eligible to receive C credits for GHG removals quantified using this protocol, and verified by Reserve-approved verification bodies, for a period of 30 years following the project's start date.
- **Additionality:** Projects must satisfy 2 tests to be qualified as additional; Legal requirement test (project activities must be required by law) and Performance Standard Test (agroforestry, and silvopastoral activities automatically satisfy the performance standard test)
- **Leakage:** Accounting for activity shifting required (grazing displacement or harvesting outside of activity area). Landowners must determine the leakage risks percentage using the Risk Assessment chart for reforestation, restoration, agroforestry and silvopastoral activity areas provided in the protocol. Risk adjustment ranges from 10 – 50%.
- **Reversals:** A percentage of credits go to a buffer pool (Reserve Buffer Pool). Contribution to Buffer pool is mandatory. Contribution percentage is a 8% Contribution= 0.08* Net CRTs)
- **Uncertainty:** Activity Area data are accepted with sampling errors up to +/- 20% of the mean at the 90% confidence interval, deductions for uncertainty are applied to an Activity Area's inventory if the sampling error exceeds the Target Sampling Error (TSE). TSE information included in protocol based on number of activity areas.

CDM AR-AMS0007: Afforestation and reforestation project activities implemented on lands other than wetlands v3.1

- **Permanence:** CDM projects produce temporary emissions credits. Specifically, these are either termed "temporary CERs" (tCERs) or "long-term CERs" (lCERs). Both types of CERs have expiration dates, after which they must be replaced by another tradable emissions unit under the Kyoto Protocol. If an Annex 1 country uses a tCER for compliance it must replace it with a permanent Kyoto unit or an unexpired tCER in the next commitment period. If the project is still performing as expected, the new tCERs will just replace the expired ones. Have either a single 30-year crediting period, or 20-year crediting periods that are renewable up to two times.
- **Additionality:** Demonstrated by conducting a barrier analysis (Appendix 1 AR-AMS0007 Methodology) or an approved standardized baseline**.**
- **Leakage:** Accounting for activity shifting required. Landowners must determine the Leakage using the AR-TOOL 15.
- **Reversals:** not mentioned in method or standard
- **Uncertainty:** not mentioned in method or standard

	FAO GSOC MRV Protocol • **Permanence:** Projects are planned for a 4-year duration and can be renewed for another 4 years. • **Additionality:** The project must show improvement over baseline by performing a 20-year SOC simulation • **Leakage:** Potential sources of leakage are outlined during the initial project assessment • **Reversals:** A 5% risk of reversal discount is applied to all projects • **Uncertainty:** Not explicitly addressed. When determining the number of samples to take, the protocol calls for performing a power analysis at an acceptable level of uncertainty

If there are protocols, have there been any registered projects or credits generated? If so, where?	*Jurisdictional*
	ART TREES
	• No projects yet registered (ART operates on a jurisdictional scale)
	• Five jurisdictional concept notes already submitted to ART Directory, more proposals (~20) are going to LEAF for review in 2021 to be listed on registry
	
	ACR Nested REDD+ Standard
	• No credits yet generated
	
	CARB Tropical Forest Standard
	• No credits yet generated
	• CARB will still need to approve usage of any generated credits in the California compliance market
	
	FCPF Carbon Fund
	• No credits generated yet
	• Forty-seven developing countries have been selected to join the FCPF (18 in Africa, 18 in Latin America, and 11 in the Asia-Pacific region)
	
	Verra Jurisdictional Nested REDD+
	• No credits issued yet
	
	Project-based
	Verra VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.2
	• 3 projects under development (2 Colombia, 1 Tanzania)
	  ○ Consejor comunitarios del pacific valle del Cauca (CCPVC) programa REDD+ valle del Cauca (Colombia)
	  ▪ Estimated Annual Emission Reductions: 796,394 Mg CO_2e
	  ○ Cocomacia community REDD+ program Choco/Antioquia (Colombia)
	  ▪ Estimated Annual Emission Reductions: 3,073,861 Mg CO_2e
	  ○ HIMA REDD+ Program (Tanzania)
	  ▪ Estimated Annual Emission Reductions: 244,000 Mg CO_2e
	• 12 projects registered (8 Colombia, 1 Congo, 1 Malawi, 1 Cambodia, 1 Peru)

- Bajo Calima y Bahía Málaga (BCBM) REDD+ Project (Colombia)
  - Estimated Annual Emission Reductions: 498,719 Mg CO_2e
  - Total credits issued: 1,620,202
- Carmen del Darién (CDD) REDD+ Project (Colombia)
  - Estimated Annual Emission Reductions: 462,190 Mg CO_2e
  - Total credits issued: 681,565
- Rio Pepe y ACABA REDD+ Project (Colombia)
  - Estimated Annual Emission Reductions: 224,060 Mg CO_2e
  - Total credits issued: 567,286
- Acapa - Bajo Mira Y Frontera REDD+ Project (Colombia)
  - Estimated Annual Emission Reductions: 404,786 Mg CO_2e
  - Total credits issued: 783,133
- SIVIRÚ-USARAGÁ-PIZARRO-PILIZÁ (SUPP) REDD+ Project (Colombia)
  - Estimated Annual Emission Reductions: 312,078 Mg CO_2e
  - Total credits issued: 1,021,146
- Concosta REDD+ Project (Colombia)
  - Estimated Annual Emission Reductions: 333,978 Mg CO_2e
  - Total credits issued: 544,278
- Mutatá REDD+ Project (Colombia)
  - Estimated Annual Emission Reductions: 156,476 Mg CO_2e
  - Total credits issued: 443,610
- Cajambre REDD+ Project (Colombia)
  - Estimated Annual Emission Reductions: 297,488 Mg CO_2e
  - Total credits issued: 477,432
- Isangi REDD+ Project (Congo)
  - Estimated Annual Emission Reductions: 324,534 Mg CO_2e
- Kulera Landscape REDD+ Program for Co-Managed Protected Areas (Malawi)
  - Estimated Annual Emission Reductions: 210,421 Mg CO_2e
  - Total credits issued: 3,325,607
- Reduced Emissions from Deforestation and Degradation in Community Forests – Oddar Meanchey, Cambodia (Cambodia)
  - Estimated Annual Emission Reductions: 204,792 Mg CO_2e
  - Total credits issued: 597,210
- The Jaguar Amazon REDD+ Project (Peru)
  - Estimated Annual Emission Reductions: 3,073,861 Mg CO_2e
  - Total credits issued: 0

- 2 projects under validation (1 Peru,1 Myanmar)
  - Tahuamanu Amazon REDD Project (Peru)
    - Estimated Annual Emission Reductions: 2,483,319 Mg CO_2e

- Korea - Myanmar Joint - Bago District REDD+ Program, with North Zamari Wildlife Sanctuary (Myanmar)
  - Estimated Annual Emission Reductions: 238,397 Mg CO_2e

Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6

- 12 projects registered
  - Blue C Project Gulf of Morrosquillo "Vida Manglar" (Colombia)
    - Estimated Annual Emission Reductions: 31,310.
    - It has produced about 60,000 verified C units since 2021.
  - Ntakata Mountains REDD (Tanzania)
    - Estimated Annual Emission Reductions: 420,220 Mg CO_2e
    - Total credits issued: 1,286,070
  - REDD+ Project Resguardo Indigena Unificado Selva de Mataven (RIU SM) (Colombia)
    - Estimated Annual Emission Reductions:3,622,352 Mg CO_2e
    - Has produced 322,770 verified C units since 2020
    - Total credits issued: 17,117,664
  - Evio Kuiñaji Ese´Eja Cuana, To Mitigate Climate Change, Madre de Dios - Perú (Peru)
    - Estimated Annual Emission Reductions: 114,410 Mg CO_2e
    - Total credits issued: 349,372
  - REDD project in Brazil nut concessions in Madre de Dios, Peru (Brazil)
    - Estimated Annual Emission Reductions:2,086,089 Mg CO_2e
    - Total credits issued: 10,252,475
  - Madre de Dios Amazon REDD+ Project (Peru)
    - Estimated Annual Emission Reductions: 659,793 Mg CO_2e
    - Total credits issued: 9,767,115
  - The Makira Forest Protected Area in Madagascar (Madagascar)
    - Estimated Annual Emission Reductions: 1,267,231 Mg CO_2e
    - Total credits issued: 1,330,327
  - The Purus Project (Brazil)
    - Estimated Annual Emission Reductions: 89,868 Mg CO_2e
    - Total credits issued: 578,984
  - Katingan Peatland Restoration and Conservation Project (Indonesia)
    - Estimated Annual Emission Reductions:7,451,846 Mg CO_2e
    - Total credits issued: 28,467,987
  - Cordillera Azul National Park REDD Project (Peru)
    - Estimated Annual Emission Reductions: 1,575,268 Mg CO_2e
    - Total credits issued: 25,240,371
  - Reduction of deforestation and degradation in Tambopata National Reserve and Bahuaja-Sonene National Park within the area of Madre de Dios region – Peru (Peru)

        - Estimated Annual Emission Reductions: 457,750 Mg CO_2e
        - Total credits issued: 3,195,747
    - Gilé National Reserve REDD Project (Mozambique)
        - Estimated Annual Emission Reductions: 68,821 Mg CO_2e
        - Total credits issued: 0
- 2 projects under development
    - NAYA REDD+ (Colombia)
        - Estimated Annual Emission Reductions: 350,000 Mg CO_2e
    - PNG Communities BEST REDD - Tavolo Project (Papua New Guinea)
        - Estimated Annual Emission Reductions: 202,142 Mg CO_2e
- 1 project under validation
    - Riscales REDD+ Project (Colombia)
        - Estimated Annual Emission Reductions: 187,240 Mg CO_2e

Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1

- 18 projects registered (7 Brazil, 2 Guatemala, 2 Madagascar, 2 Colombia, 1 Tanzania, 1 Ethopia, 1 Zambia, 1 Peru, 1 Laos)
    - Rio Anapu-Pacaja REDD Project (Brazil)
        - Estimated Annual Emission Reductions: 938,000 Mg CO_2e
        - Total credits issued: 0
    - The ARC REDD+ Project (Brazil)
        - Estimated Annual Emission Reductions: 340,000 Mg CO_2e
        - Total credits issued: 941,618
    - Jari/Pará REDD+ Project (Brazil)
        - Estimated Annual Emission Reductionms : 525,314 Mg CO_2e
        - Total credits issued: 900,752
    - Reducing Emissions from Deforestation and Carbon Enhancement in Xe Pian National Protected Area (Laos)
        - Estimated Annual Emission Reductions: 64,981 Mg CO_2e
        - Total credits issued: 0
    - Scheme of Compensation for Ecosystem Services for Forest Management and Conservation of Water Sources in the Jurisdiction of CORPOCHIVOR (Colombia)
        - Estimated Annual Emission Reductions: 1,662 Mg CO_2e
        - Total credits issued: 0
    - Carbon Emissions Reduction Project in the Corridor Ankeniheny-Zahamena (CAZ) Protected Area, Madagascar (Madagascar)
        - Estimated Annual Emission Reductions: 1,011,973 Mg CO_2e
        - Total credits issued: 0
    - Suruí Forest Carbon Project (Brazil)
        - Estimated Annual Emission Reductions: 247,460 Mg CO_2e
        - Total credits issued: 251,529

- BIOCORREDOR MARTIN SAGRADO REDD+ PROJECT (Peru)
  - Estimated Annual Emission Reductions: 219,722 Mg CO_2e
  - Total credits issued: 566,843
- Manoa REDD+ Project (Brazil)
  - Estimated Annual Emission Reductions: 279,290 Mg CO_2e
  - Total credits issued: 482,344
- RMDLT Portel - Para REDD Project (Brazil)
  - Estimated Annual Emission Reductions : 553,273 Mg CO_2e
  - Total credits issued: 7,087,396
- Carbon Emissions Reduction Project in the Forest Corridor Ambositra-Vondrozo (COFAV), Madagascar (Madagascar)
  - Estimated Annual Emission Reductions: 220,965 Mg CO_2e
  - Total credits issued: 0
- Bale Mountains Eco-region REDD+ project (Ethiopia)
  - Estimated Annual Emission Reductions: 1,288,821 Mg CO_2e
  - Total credits issued: 4,702,511
- Lacandon – Forest for life REDD+ Project (Guatemala)
  - Estimated Annual Emission Reductions: 238,875 Mg CO_2e
  - Total credits issued: 369,982
- Reduced Emissions from Avoided Deforestation in the Multiple Use Zone of the Maya Biosphere Reserve in Guatemala (GuateCarbon) (Guatemala)
  - Estimated Annual emission Reductions: 1,385,971 Mg CO_2e
  - Total credits issued: 0
- COMACO Landscape Management Project (Zambia)
  - Estimated Annual Emission Reductions: 122,047 Mg CO_2e
  - Total credits issued: 755,031
- Mjumita Community Forest Project (Lindi) (Tanzania)
  - Estimated Annual Emisssion Reductions: 46,263 Mg CO_2e
  - Total credits issued: 36,171
- Pacajai REDD+ Project (Brazil)
  - Estimated Annual Emission Reductions: 264,116 Mg CO_2e
  - Total credits issued: 0
- Forest Management to reduce deforestation and degradation in Shipibo Conibo and Cacataibo Indigenous communities of Ucayali region (Peru)
  - Estimated Annual Emission Reductions: 564,818 Mg CO_2e
  - Total credits issued: 2,275,534

- 1 registration approval requested project (Colombia)
  - Redd project of the indigenous peoples of vaupes yutucu and others (Colombia)
    - Estimated Annual Emission Reductions: 438,730 Mg CO_2e
- 1 project under development (Colombia)
  - Conservation project Redd+ sur del meta bosques de paz, sustento de vida (Colombia)

        - Estimated Annual Emission Reductions: 1,334,829 Mg CO_2e
- 2 projects under validation (1 Colombia, 1 Panama)
    - Conservation of Panama Forests - Reduction of GHG Emissions from Deforestation and forest Degradation. Grouped Project (Panama)
        - Estimated Annual Emission Reductions: 14,126,091 Mg CO_2e
    - Grouped Project REDD+ conservation of the Oak ecological corridor Guantiva – La Rusia – Iguaque, Colombia (Colombia)
        - Estimated Annual Emission Reductions: 110 Mg CO_2e
        - 1 project rejected (Congo)
    - National REDD+ Project in the Democratic Republic of Congo (Congo)
        - Estimated Annual Emission Reductions: 999,999,999 Mg CO_2e

Verra VM0017 Adoption of Sustainable Agricultural Land Management, v.1

- 2 projects under development (2 India)
    - Clean Air and Healthy Soil (India)
        - Estimated Annual Emission Reductions: 178,434 Mg CO_2e
    - Agricultural Land Management Project in Hujgal & Kalari Cluster watershed, India implemented by Godrej Agrovet Ltd. (India)
        - Estimated Annual Emission Reductions: 30,403 Mg CO_2e
- 1 project under validation (Kenya)
    - Livelihoods Mount Elgon Project (Kenya)
        - Estimated Annual Emission Reductions: 53,142 Mg CO_2e
- 2 projects registered (1 India, 1 Kenya)
    - Agricultural Land Management project in Beed District, India implemented by Godrej Properties Ltd (India)
        - Estimated Annual Emission Reductions: 33,764 Mg CO_2e
    - Kenya Agricultural Carbon Project (Kenya)
        - Estimated Annual Emission Reductions: 99,004 Mg CO_2e
        - First credits earned in Kenya in 2016. Has produced >10,000 verified C units

Verra VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0

- No project registered

Verra VM0042 Methodology for Improved Agricultural Land Management v1.0

- 1 project under development (South Africa)
    - CNG Agricarbon Rewards Programme (South Africa)
        - Estimated Annual Emission Reductions: 346,356.25 Mg $CO_2e\ yr^{-1}$

American Carbon Registry: REDD Methodology Modules (REDD-MF, ACR)

- No project registered

Plan Vivo Climate Benefit Quantification Methodology- Small-holder Agriculture Mitigation Benefit Assessment (SHAMBA):
Afforestation/Reforestation/Agroforestry

- 4 projects registered
  - Hiniduma Biolink Project (Sri-Lanka)
    - PVCs issued: 2,767
  - Trees for Global Benefits (Uganda)
    - PVCs issued: 647,915
  - Chalo Verde Timor Community Forest C (Philippines)
    - PVCs issued: 18,015
  - Rehabilitation and sustainable management by AGED of degraded pastures in the Sahel region of Burkina Faso (Burkina Faso)
    - PVCs issued: 6,717

Note: The Plan Vivo registry lists projects that use protocols developed by Plan Vivo standard, in addition to protocols that are recognized by Plan Vivo standard, but not developed by the organization. Plan Vivo standard projects that are listed in this table are only those that use protocols specifically developed by Plan Vivo in order to avoid double listing projects. Additionally, the registry does not list all registered projects but only those that the account holder has requested be publicly available.

Gold Standard's Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0

- 24 projects registered
  - Total credits issued: 4,897,962

Note: This is not the number of projects specific to AFS, but rather the total number of projects listed under the methodology

Climate Action Reserve Mexico_Forest_Protocol_v2.0

- 2 projects listed
  - Carbono, Agua y Biodiversidad Indígena Metaltepec
  - Carbono, Agua y Biodiversidad Indígena San Bartolomé
  - Carbono Otomí La Florida
    - Total Number of Offset Credits Registered: 4,474
  - Proyecto de Captura de Carbono Forestal en Bienes Comunales de Santiago Tlacotepec
    - Total Number of Offset Credits Registered: 2,045
  - San Jerónimo ZacapexCO$_2$ - Ejido
    - Total Number of Offset Credits Registered: 11,417

CDM AR-AMS0007: Afforestation and reforestation project activities implemented on lands other than wetlands (V3.1)

- 10 projects registered
  - Small scale Allahabad JFM A/R CDM Project on degraded lands in Allahabad Forest Division, Uttar Pradesh, India
    - Estimated Annual Emission Reductions: 3,794 Mg CO_2e yr^{-1}
  - Small scale Chitrakoot JFM A/R CDM Project on degraded lands in Chitrakoot Forest Division, Uttar Pradesh, India

	▪ Estimated 3,743 Mg CO_2e yr^{-1} emission reductions. ○ Small scale Mirzapur JFM A/R CDM Project on degraded lands in Mirzapur Forest Division, Uttar Pradesh, India ▪ Estimated 10,667 Mg CO_2e yr^{-1} emission reductions. ○ Small scale Kashi JFM A/R CDM Project on degraded lands in Kashi Forest Division, Uttar Pradesh, India ▪ Estimated 4,694 Mg CO_2e yr^{-1} emission reductions. ○ Small scale Lalitpur JFM A/R CDM Project on degraded lands in Lalitpur Forest Division, Uttar Pradesh, India ▪ Estimated Annual Emission Reductions: 5,375 Mg CO_2e yr^{-1} ○ Small scale Obra JFM A/R CDM Project on degraded lands in Obra Forest Division, Uttar Pradesh, India ▪ Estimated Annual Emission Reductions: 5,571 Mg CO_2e yr^{-1} ○ Small scale Sonbhadra JFM A/R CDM Project on degraded lands in Sonbhadra Forest Division, Uttar Pradesh, India ▪ Estimated Annual Emission Reductions: 8,721 Mg CO_2e yr^{-1} ○ Small scale Renukoot JFM AR CDM Project on degraded lands in Renukoot Forest Division, Uttar Pradesh, India ▪ Estimated Annual Emission Reductions: 7,670 Mg CO_2e yr^{-1} ○ Small scale Mahoba JFM A/R CDM Project on degraded lands in Mahoba Forest Division, Uttar Pradesh, India ▪ Estimated Annual Emission Reductions: 4,356 Mg CO_2e yr^{-1} ○ Small scale Jhansi JFM A/R CDM Project on degraded lands in Jhansi Forest Division, Uttar Pradesh, India ▪ Estimated Annual Emission Reductions: 3,376 Mg CO_2e yr^{-1} **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • Unable to locate the registry. **FAO GSOC MRV Protocol** • 8 agricultural companies in the Pampas and NW Argentina have registered a project, covering about 50,000 hectares. ○ Have not generated credits yet.
Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc. within any existing or proposed market?	*Jurisdictional approaches* **ART TREES** • The Architecture for REDD+ Transactions (ART) has been developed as a mechanism to achieve the environmental integrity needed for REDD+ emission reductions (ERs) at national and jurisdictional scale. It uses the REDD+ Environmental Excellence Standard (TREES). **ACR Nested REDD+ Standard** • Provides technical guidance for registration on ACR of REDD+ projects nested within a jurisdictional accounting framework. **CARB Tropical Forest Standard** • Establishes pathway for national or subnational jurisdictions to link forestry offsets to California's Cap-and-Trade program. **FCPF**

- FCPF is a mechanism for performance-based payments for the successful implementation of jurisdictional emission reductions programs.
- As of August 2021, Mozambique became the first FCPF country to successfully verify emissions reductions, becoming the first-ever accredited verification of JREDD+ ERs.

Verra's Verified Carbon Standard: Jurisdictional Nested REDD+ framework

- Has three possible scenarios through which projects can be "nested" based on differing jurisdictional decisions and/or market structures. "Nesting" refers to a set of provisions aimed at ensuring project-level accounting is aligned with jurisdictional (e.g., national) strategies and methods. It includes criteria and requirements to ensure the alignment of baselines, monitored data, emission reductions and/or removals estimates and C accounting across levels, i.e., projects, subnational programs, and national programs.

Project-based protocols/methodologies:

American Carbon Registry: REDD Methodology Modules (REDD-MF)

- Allows aggregation but does not provide specific guidance on how aggregation is to be accomplished.
- CDM AR-AMS0007: Afforestation and reforestation project activities implemented on lands other than wetlands (V3.1)Currently it does not allow REDD projects.
- Allows stacking of project activities.

Climate Action Reserve Mexico Forest Protocol

- Aggregation allowed—must consist of two or more forest owners. In Aggregates formed by three or more Forest Projects, no single Forest Project may comprise more than 50 percent of the total combined area in an Aggregate, based on the hectares included in the Activity Areas for each Forest Project.

Gold Standard Afforestation/Reforestation GHG Emissions Reduction & Sequestration Methodology, v.1

- Supports a landscape approach but has stated that REDD+ approaches have many challenges.

Verra VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.2

- Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements.

Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6

- Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements.

Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1

- Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements

Verra VM0017 Adoption of Sustainable Land Management (SALM), V 1.0

	• Aggregation of projects into larger units allowed. Projects may contain more than one discrete area of land. **Verra VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements. **Verra VM0042 Methodology for Improved Agricultural Land Management v 1.0** • Aggregation of projects into larger units allowed. **Plan Vivo - Climate Benefit Quantification Methodology- Small-holder Agriculture Mitigation Benefit Assessment (SHAMBA): Afforestation/Reforestation/Agroforestry** • Not specified in the protocol. **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • Not specified in protocol **FAO GSOC MRV Protocol** • Aggregation of projects into larger units allowed.
Is there controversy surrounding the markets or credits for the NCS pathway? Why?	<u>*General Comments*</u> • AFSs might be defined as "forests", but this depends on the definition of forest in the country in which the project is implemented (Minang et al., 2014). The definition of forest varies from country to country. Nevertheless, since each country has its own definition for this type of land cover, not all countries refer to the definition of "forest land" given by the UNFCCC. It states that forest is "'a minimum area of land of 0.05 – 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 – 30 per cent with trees with the potential to reach a minimum height of 2 – 5 meters at maturity in situ*"* (UNFCCC, 2001, p. 6). Most AFSs and especially in the tropics, can reach these criteria and therefore by defined as forests (Minang et al., 2014). The definition of each country will determine whether agroforestry is considered as a REDD activity and at the same time if one of the REDD methodologies listed can be used to quantify emission reductions induced by AFSs. The changing definition of forest could prevent the implementation of agroforestry activities as a mean to combat increasing emissions from deforestation and forest degradation. • While agroforestry is recognized as an afforestation/reforestation practice under the CDM, not all A/R methodologies include agroforestry as an "eligible" activity type. • Agroforestry is considered as an intermediary land use between Forestry and Agriculture and does not have a clear home within the UNFCC (Minang et al., 2014). Carbon accounting protocols specific to AFSs could be developed, which could help clarify the status of agroforestry in the C market and encourage agroforestry C offset projects. Others have proposed that agroforestry must become part of the "agricultural tool box and not viewed as something separate from it" (Schoeneberger, 2009). • AFSs are numerous and very diverse. A one size fits all type of C accounting protocol is not appropriate for agroforestry. Current methodologies don't tend to discriminate among AFS types and estimate their C stocks and fluxes using one methodology for all systems. There is a need for the development of C accounting methodologies for specific AFSs.

Concerns with project-scale forest C methodologies

Accurate estimations

- Gold Standard, CDM-A/R methodology: These protocols do not take into account the soil C pool or consider it as "Optional". As a result, they only sometimes quantify changes in C stocks in this pool as a result of project activities. Even though most of the C sequestered by AFSs resides in the aboveground biomass pool (Schoeneberger, 2009), multiple studies have revealed that soil C stocks greatly increased after the implementation of AFSs (Tumwebaze and Byakagaba, 2016; De Stefano and Jacobson, 2018; Shi et al., 2018; Cardinael et al., 2018). Therefore, omitting this C pool might lead to an underestimation of the C benefits induced by agroforestry activities which could subsequently lead to the issuance of fewer C credits.

Concerns with project-scale soil C methodologies

- Several methodologies such as the Soil Enrichment Protocol (Climate Action Reserve), Nori Croplands Methodology, v 1.2, BCarbon Soil Carbon Credit Systems, Soil Organic Carbon Framework Methodology (Gold Standard) and Verra VM0021 Soil Carbon Quantification Methodology v.1, don't define clearly the type of eligible activities. The terminology used does not allow determination of whether C stock changes induced by agroforestry activities can be quantified using those protocols. There is a need for clarification of the type of project activities that are considered as eligible.

Other concerns with SOC protocols

- Permanence and reversal issues: SOC is very vulnerable (Ranganathan et al., 2020; Bottemiller Evich and McCrimmon, 2021).
- Accurate estimation: Need to account for soil depth and uncertainty in modeled projections. Also, field measurements are necessary to calibrate and validate remote sensing and model estimates, but some protocols don't require field measurements (Tumwebaze and Byakagaba, 2016; Slessarev et al., 2021; Simmons et al., 2021).
- Leakage: C benefits of a particular practice may be negated through leakage (Ranganathan et al., 2020).

*Note: Concerns with project-scale REDD+, jurisdictional-scale REDD+ and general concerns with REDD+ as offsets formulated in the **Tropical Forests** table also apply here since agroforestry activities falls within REDD+ scheme.*

Boreal Forests: *Avoided boreal forest conversion and degradation, Reforestation & Improved Forest Management*

Boreal forests cover an estimated 1.11×10^9 hectares globally (FAO FRA, 2020a). Boreal forests are found only in higher latitudes of the Northern Hemisphere, between 50-55 to 65-70 degrees (FAO, 1999). Globally, boreal forests sequester between 367.3 to 1715.8 Pg C (Bradshaw and Warkentin, 2015). Given this C stock range and the global extent boreal forests, this equates to an average of between 364.8 Mg C ha^{-1} to 1,704 Mg C ha^{-1}. In a different study, Goldstein et al. (2020) estimate that boreal forests store 283 Pg C (264 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 30cm, a much smaller value than Bradshaw and Warkentin's (2015) estimate. Most boreal forests are considered a C sink, but the future of this C sink status depends heavily on regional climate change trajectories.

The direct and indirect effects of climate change on boreal forest carbon pools include effects on vegetation productivity, ecological succession and vegetation type, disturbance regimes, and soil carbon dynamics, and these regionally changing dynamics present a particular challenge for high-latitude ecosystems such as boreal forests and must be considered for any plans involving carbon sequestration in these regions. In boreal forests with relatively dry climates, such as those in western Canada and parts of Siberia, warming is exacerbating moisture stress and increasing the intensity, frequency, and spread of wildfires; as a result, biomass carbon stocks and carbon assimilation are already decreasing in these regions (Gauthier et al., 2015; Dass et al., 2016; Sulla-Menashe et al., 2018; Dieleman et al., 2020; Wang et al., 2021). This increase in temperature and moisture stress, and the resulting change in fire regime, may be putting these dryer boreal forest regions on a rapid ecological trajectory away from forests and towards shrublands, which support substantially less carbon storage (Gauthier et al., 2015; Sulla-Menashe et al., 2018). Warming has also been expanding the range of insects such as the mountain pine beetle northward and increasing severity of outbreaks in dry northern forests such as western North America, posing another threat to the carbon of these regions (Kurz et al., 2008; Safranyik et al., 2010). These regions should not be relied upon to provide continued biomass carbon storage at historical densities.

In contrast, some regions, such as the boreal forest of northeastern Canada, are projected to escape the severe moisture stress and accompanying increases in fire intensity and spread that are already occurring in other boreal forest regions, and appear to be experiencing an increase in productivity through several pathways as climate changes; these regions may prove to be more reliable repositories of carbon (Gauthier et al., 2015; D'Orangeville et al., 2016; Sulla-Menashe et al., 2018). Warming appears to be alleviating temperature limitations on photosynthesis and growing season length in northern ecosystems, absent other limitations. Boreal forests with substantial temperature limitations but without moisture limitations, such as those in northeastern Canada, have experienced increases in vegetation growth in the past several decades over large spatial scales (Sulla-Menashe et al., 2018). Regions without moisture limitations also appear to be shifting to more highly productive deciduous vegetation, and boreal vegetation is expanding into regions that were previously low-productivity tundra; these range shifts are projected to continue (Kurz et al., 2013; Gauthier et al., 2015; Ju and Masek, 2016; D'Orangeville et al., 2016; Sulla-Menashe et al., 2018; Mack et al., 2021). In particular, forests on the boreal-tundra ecotone, where temperature limitation has historically been most severe, are experiencing particularly strong increases in productivity (Berner et al., 2013; Gauthier et al., 2015; Sulla-Menashe et al., 2018; Dieleman et al., 2020; Wang et al., 2021). These dynamics may be contributing to an overall increase in the northern carbon sink indicated by atmospheric data (Graven et al., 2013; Forkel et al., 2016; Ciais et al., 2019).

Soil carbon in boreal forests represents a large but highly uncertain carbon pool. In boreal forests and other northern ecosystems, decomposition of soil organic matter has historically been limited by temperature; for this reason, soil carbon constitutes a majority of the carbon storage in boreal forests, but increasing temperatures appear to be speeding up decomposition rates, leading to widespread carbon losses, particularly in soils that were previously permafrost (Karhu et al., 2010; Pan et al., 2011a; Deluca and Boisvenue, 2012; Carey et al., 2016). In addition, increasing fire intensity and frequency threatens soil carbon stocks in addition to biomass carbon stocks (Deluca and Boisvenue, 2012; Walker et al., 2019). However, site-specific soil geochemistry, as well as indirect effects of warming mediated by changing snow cover and vegetation changes, create complicated soil carbon dynamics that may be difficult to predict (Karhu et al., 2010; Yu et al., 2016). Because boreal soils constitute a majority of boreal carbon, this uncertainty in the fate of soil carbon translates into large uncertainties in overall carbon balance (Deluca and Boisvenue, 2012).

Certain forest management practices may help sequester C in boreal forests and slow losses in forests threatened by changing disturbance regimes. (Carroll et al., 2012)These management strategies, particularly those pertaining to fire management, may differ from management strategies employed in temperate regions because of differences between temperate and boreal forest disturbance regimes. Unlike the fire regimes of many temperate forests, which have historically been documented by high-frequency, low-severity ground fires, the fire regimes of many boreal forests have been dominated by low-frequency, high-severity crown fires (Phillips et al., 2022). Thus, strategies such as controlled understory burns or understory thinning, which prove to be effective and ecologically appropriate to reduce the risk of catastrophic fire and large carbon losses in temperate forests, may not effectively prevent increases in fire risk or emissions the boreal forest, where understory vegetation plays less of a role in fire dynamics and where fires are typically high-emission events (Phillips et al., 2022). Because factors such as forest species composition, time since the last burn, stand age, and canopy characteristics appear to be correlated with fire risk and emissions, management may still play a role in curbing the increased risk of major emissions from fire, but this topic may require further study (Walker et al., 2018; Parisien et al., 2020; Groot et al., 2022). Fire suppression in some regions has proven effective in limiting the increase in fire emissions, but this strategy may become more costly under a continuously changing climate (Wotton et al., 2017; Phillips et al., 2022). Generally, management opportunities vary regionally; a large proportion of boreal forests in many regions, such as Canada and Siberia, are unmanaged, while an overwhelming majority of boreal forests in Finland and Scandinavia are already heavily managed (Kurz et al., 2013; Gauthier et al., 2015). In addition, although afforestation and reforestation typically increase C sequestration, in high latitude boreal forests, the positive forcing induced by decreases in albedo can offset the negative forcing expected from C sequestration through reforestation and afforestation (Betts, 2000; Carroll et al., 2012; Portmann et al., 2022).

Ranges for how much additional C could be sequestered by boreal forests are still rare in the literature . Walker et al (2022) estimate that restoring boreal forests (reforestation, improved plantations, avoided woodfuel) at a global scale could sequester an additional 1.416 $PgCO_2\ yr^{-1}$. They also estimate that maintaining and managing boreal forests (avoided conversion, natural forest management, improved plantations, avoided woodfuel, fire management) has a modelled mitigation potential of 4.79 $PgCO_2\ yr^{-1}$. Nonetheless, there are still uncertainties in the estimates of current and future C balances of boreal forests, due to differences in and issues with the methodologies used to calculate estimates.

Few markets and protocols exist for boreal forest C credits, and all appear to be part of the voluntary market. Verra has two boreal-specific protocols, and four other forest protocols that could potentially include boreal forests. American Climate Registry and Climate Action Reserve have general forest protocols, but no boreal-specific protocols. Of the applicable protocols, only VM0012 Improved Forest Management in Temperate and Boreal Forests (LtPF), v1.2 has an actively registered boreal forest project.

Boreal Forest

Global Areal Extent: ~1.11 × 10^9 ha (FAO FRA ,2020)

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?	• Global stock: Estimates vary widely. Bradshaw & Warkentin (2015) estimate 367.3 to 1,715.8 Pg C, with a midpoint of 1,095 Pg (between 1.3 and 3.8 times larger than any previous mean estimates.) On the lower end, Pan et al. (2011) estimate 272 ± 23 Pg C in boreal, with 20% stored in biomass and 60% in soil (missing 20% not identified). Goldstein et al. (2020) estimate that boreal forests store 283 Pg C (264 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 30cm, globally, falling closer to Pan et al.'s estimate • Average per hectare: Using Bradshaw & Warkentin's (2015) estimate, the average estimate is between 364.8 Mg C ha^{-1} to 1,704 Mg C ha^{-1}, with a midpoint of 1086.9 Mg C ha^{-1}
At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	• Harris et al. (2021) estimate that globally boreal forests are a net sink of −1.6 ± 1.1 Pg CO_2e yr^{-1} • However, projected carbon sinks vary greatly by region, with more arid boreal forests transitioning to net carbon sources as warming increases moisture stress and disturbance intensity, and boreal forests that are less limited by moisture and more limited by temperature increasing their carbon assimilation. For example, Zhao et al. (2021) found that from 1986 to 2016, North American boreal forests were a C source due to wildfires. The observed loss of 209.56 Tg CO_2 yr^{-1} (primarily from the dry forests in the West) overwhelmed the net ecosystem production of 6.97 Tg CO_2 yr^{-1} in the region. However, restricting focus to only the Northeastern portion of this region, forests actually experienced an increase in growth over the same time period (Gauthier et al., 2015; D'Orangeville et al., 2016; Sulla-Menashe et al., 2018). Phillips et al. (2022) projected that wildfires in North America boreal forests will release between 1.33 and 11.93 Pg of CO_2 from 2020 to 2050 if current levels of boreal fire management are maintained through mid-century. • Soil carbon, which constitutes a majority of boreal forest carbon stocks, is threatened by warming-induced increased decomposition rates and fire frequency; these threats are particularly acute in regions with thawing permafrost permafrost (Karhu et al., 2010; Pan et al., 2011a; Deluca and Boisvenue, 2012; Carey et al., 2016).

Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	• Increasing stand-level C density can be done by reducing forest degradation, intensifying silviculture, increasing fertilization, adjusting harvesting practices to reduce impacts on soil C, avoiding slash burning, and improving regeneration. Increasing C density at the landscape level may be done by reducing harvesting frequency, accelerating post-disturbance regeneration, reducing forest degradation, altering peatland management, and changing how natural disturbances are managed (Lemprière et al., 2013).
	• According to Carroll et al. (2012), relatively few forest management practices can demonstrate true C additionality, however:
	  ○ Although resilience treatments, such as fuels reduction thinning and prescribed fire, result in lowered C storage on-site and some C release from decomposition and combustion, they help produce forests that are significantly less susceptible to disturbance and associated C release. Forest managers using these treatments accept less than maximum short-term C storage to ensure long-term, secure storage
	  ○ The addition of harvest residues to the litter and soil layers is an important factor in mitigating initial C loss from harvested forests
	  ○ Research has shown the possibility of creating C additionality (in comparison to business-as-usual managed forests) by increasing rotation length

	○ If old forests already exist, maintaining them as old forests maximizes C storage. Old forests tend to have very large pools of vegetative C in comparison to forests managed on shorter rotations. Soil and litter pools may also be quite large in old-growth forests, and in the boreal, the bryophyte pool as well ○ Afforestation/reforestation usually increases a site's C sequestration, unless it results in a significant release of soil C. However, in many boreal forest areas, the positive forcing induced by decreases in albedo can offset the negative forcing that is expected from C sequestration through reforestation/afforestation (Betts, 2000; Portmann et al., 2022). Some high-latitude forestation may therefore increase climate change, rather than mitigate • Phillips et al. (2022) highlighted that increased fire management via enhanced fire suppression activities in North American boreal forests could increase net C sequestration and prevent C emissions. They explained that unlike in Western US forests where fire suppression activities increased the risk of high-intensity crown fires, fire suppression won't have any effects on the natural fire-regime of North American boreal forests since its fire regime is already characterized high-intensity crown fires. As a result, enhancing fire suppression represents an mitigation opportunity in this region (Phillips et al., 2022).
What is the range of estimates for how much additional C could be sequestered globally?	• Restore land with high suitability for forestry-based NCS (Reforestation, Improved plantations, Avoided woodfuel): 21.286 $PgCO_2$ over the period 2000-2050 (0.425 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain and Manage land with high suitability for forestry-based NCS (Avoided conversion, Natural forest/savanna management, Improved plantations, Avoided woodfuel, Fire management): 130.285 $PgCO_2$ over the period 2000-2050 (2.6057 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain land with high suitability for forestry-based NCS (Avoided conversion, Fire management) : 7.707 $PgCO_2$ over the period 2000-2050 (0.154 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Restore land with low suitability for forestry-based NCS (Avoided woodfuel): 49.545 $PgCO_2$ over the period 2000-2050 (0.991 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain and Manage land with low suitability for forestry-based NCS (Avoided conversion, Avoided woodfuel, Fire management): 108.999 $PgCO_2$ over the period 2000-2050 (2.1798 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain land with low suitability for forestry-based NCS (Avoided conversion, Avoided woodfuel, Fire management): 11.01 $PgCO_2$ over the period 2000-2050 (0.220 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Carroll et al. (2012) argue that providing additional C storage in boreal and temperate forests is primarily a matter of refining silvicultural practices, better quantifying the effects of disturbances, and examining the storage potential of forest products • Lemprière et al. (2013) consider the biophysical potential of reduced deforestation as equal to the avoided emissions, plus any sink that would exist if the forest were allowed to grow rather than being permanently removed. They estimate average GHG emissions of 5.87 Tg CO_2 yr^{-1} from boreal zone deforestation in Canada. However, an *overall* quantitative assessment of the climate change potential of Canada's boreal forests was not possible at the time of the study. • Phillips et al. (2022) estimate that increased fire management through enhanced fire suppression in boreal forests of Alaska could avoid the release of 0.89 to 3.87 $PgCO_2$ between 2021 and 2050. They added that fire suppression activities in boreal forests limit fire and burned area size. They reveal that avoiding 1 metric ton of CO_2 via enhanced fire suppression activities cost $12.63. Using this value, they compute that to keep carbon emissions from wildfires in Alaska boreal forest at historical levels over the next decade would cost about $696 million per year. They emphasize that boreal fire management in Alaska proved to be a notable, cost-effective and previously neglected mitigation pathway. However, in many regions of boreal North America, increasing fire intensity may surpass current containment capabilities under business-as-usual climate scenarios (Wotton et al., 2017). • Fire management strategies other than suppression may require additional research to quantify the potential for additional carbon sequestration.

How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that?	• There are uncertainties in the estimates of current and future C balances of boreal forests, due to differences in and issues with the methodologies used to calculate estimates
	• Bradshaw & Warkentin (2015) identify the following issues with methods used to estimate and predict C sequestration:
	  ○ There are substantial differences among 'bottom-up' forest inventory-based assessments of regional and global C stocks and flux due to the use of different biomass density estimates in combination with different forest area assessments
	  ○ 'Top-down', atmosphere-based models have produced variable estimates attributed to gaps in spatial and temporal sampling effort, as well as measurement, modelling and scaling errors
	  ○ Soil C (accounts for at least 3x more C in boreal forests than vegetation) is often determined using model predictions rather than repeated soil measurements over sufficient time sequences at permanent sample plots
	  ○ Despite these uncertainties, a standardized inventory approach to examine and compare available data can be effective in identifying broader trends in C storage and flux estimates
	• Issues identified by Kurz et al. (2013)
	  ○ Modelling capabilities are improving but cannot yet accurately estimate future forest productivity. For Canada's boreal forests, there is currently no agreement on the direction, magnitude, or cause of changes in future productivity
	  ○ Reducing uncertainty in forest C dynamics models will require improvements in the spatial resolution of modelling approaches down to 1 ha resolution and the availability of spatially-explicit data on forest characteristics, topography, and soils at the increased resolution
	  ○ Spatial and temporal upscaling of ecological processes remains a major challenge in estimating C flux changes

C Markets

Is there a market (or proposed market) for carbon credits from the system?	Yes, voluntary markets exist.
Are there protocols (or proposed protocols) for such credits?	*Voluntary* • Verra Improved Forest Management in Boreal Production Forests (under development); international • Verra VM0012 Improved Forest Management in Temperate and Boreal Forests (LtPF), v1.2 [a]; international • Verra VM0035 Methodology for Improved Forest Management through Reduced Impact Logging [a]; international • Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3 [a]; international • Verra VM0009 Methodology for Avoided Ecosystem Conversion [b]; international • Verra VM0003 Methodology for Improved Forest Management Through Extension of Rotation Age, v1.2 [b]; international • Verra VM0034 Canadian Forest Offset Methodology, v2.0 [a]; Canada • Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1 [a]; international

	• American Carbon Registry Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Improved Forest Management on Canadian Forestlands [a] ; Canada • American Carbon Registry's (ACR) Improved Forest Management on Non-Federal US Forestlands Methodology, v1.3; international. • American Carbon Registry (ACR) Afforestation and Reforestation of Degraded Lands [a]**;** international • American Carbon Registry (ACR) IFM on small non-industrial private forestlands [a,1]; U.S. • Climate Action Reserve Forest Project Protocol V5.0 [a]; U.S. and U.S. territories only • Gold Standard's Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0 [d]; international. • Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU) [c]*;* China *Compliance* • N/A [a] *Protocol applies to multiple forest systems* [b] *Protocol applies to grassland, shrubland, and forest systems* [c] *Protocol applies to grassland, cropland, agroforestry and multiple forest systems* [d] *Protocol applies to agroforestry, coastal blue carbon and multiple forest systems* [1] *May be minimally applicable to boreal forest systems* *Note: The Panda Standard Sectoral Specifications applies to boreal forests, however, we have not been able to verify that the protocols have been approved by the Chinese government, and/or have generated boreal forest credits to date. Additional protocols that cover the boreal forest pathways in China may exist, but we have not been able to review all of them due to limited publicly available information.*

If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	*Voluntary market* **Verra Improved Forest Management in Boreal Production Forests (under development)** • **Permanence:** For Improved Forest Management (IFM) projects, the crediting period must include a complete harvest/cutting cycle and must be a minimum of 20 years up to a maximum of 100 years • **Additionality:** Must use the latest version of VCS Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities" OR CDM Tool for the demonstration and assessment of additionality • **Leakage:** Must account for market leakage, activity shifting leakage, and ecological leakage • **Reversals:** Credits are issued to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Uncertainty factor is calculated and used for correction of the model estimated GHG removals for both Baseline and Project activity, as well as for the number of credits, available for issue during the years until next verification. **Verra VM0012 Improved Forest Management in Temperate and Boreal Forests (LtPF), v1.2** • **Permanence:** For Improved Forest Management (IFM) projects, the crediting period must include a complete harvest/cutting cycle and must be a minimum of 20 years up to a maximum of 100 which may be renewed at most four times • **Additionality:** Project proponents must use the newest version of the VCS tool: "Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities". • **Leakage:** All leakage must be assessed and accounted for in GHG calculations. Positive leakage effects must be discounted. Leakage within this methodology is assessed against a national leakage area. • **Reversals:** Credits are issued to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Must calculate and apply an uncertainty factor to net GHG emission reductions at each verification and apply it annually until next verification. To be conservative, this methodology employs an over-riding project confidence deduction as a proxy for collective project uncertainty by assessing statistical uncertainty in the forest C inventory and associated modeling **Verra VM0035 Methodology for Improved Forest Management through Reduced Impact Logging** • **Permanence:** For Improved Forest Management (IFM) projects the crediting period must include a complete harvest/cutting cycle and must be a minimum of 20 years up to a maximum of 100 years • **Additionality:** Uses a performance method for additionality, whereby emission reductions are assigned as a function of the difference between a set crediting baseline for each emission source category (ie, felling, skidding and hauling) and the measured impact of those parameters in the project scenario. Projects may only be credited for emission reductions from one or more impact parameters if they are deemed additional. A project is deemed additional for one or more impact parameters if the impact parameter is below the additionality benchmark assigned for that impact parameter. • **Leakage:** Leakage assumed to be zero because the applicability conditions do not allow for changes in harvest levels; there should be no difference in harvest levels between the baseline and project scenarios • **Reversals:** Credits are issued to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** No uncertainty deduction deemed necessary **Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3** • **Permanence:** For Improved Forest Management (IFM) projects the crediting period must include a complete harvest/cutting cycle and must be a minimum of 20 years up to a maximum of 100

	• **Additionality:** Must demonstrate the additionality of the project using the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage:** There may be no leakage due to activity shifting. If the project proponent controls multiple parcels of land within the country, the proponent must demonstrate that their other lands have not materially changes as a result of the planned project. Market leakage is accounted for through a leakage factor. • **Reversals:** Credits are issued to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Uncertainty is defined at the 95% confidence interval where the estimated variance exceeds +/- 15 percent from the mean. If uncertainty is less than 15%, then no deductions are made **Verra VM0009 Methodology for Avoided Ecosystem Conversion** • **Permanence:** Crediting period is a minimum of 20 years, maximum of 100 years • **Additionality:** Must demonstrate additionality using the latest version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities. The common practice test must demonstrate that project activities will address at least one driver of conversion in such a way that the driver would not have been addressed had the project not been undertaken • **Leakage:** Emissions from activity-shifting leakage are calculated using the Leakage Emissions Model and an activity-shifting leakage area. Emissions from market leakage are estimated using a market leakage area and default values specified in the AFOLU Requirements • **Reversals:** Project proponent must estimate the final level of cumulative baseline emissions at the end of a crediting period. If this estimate is greater than the number of credits issued during the project crediting period, then this difference must be addressed through the AFOLU Pooled Buffer Account. Credits are issued to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Deductions for uncertainty are determined by a linear combination of weighted standard errors of estimates from baseline emissions models and C stock measurement **Verra VM0003 Methodology for Improved Forest Management Through Extension of Rotation Age** • **Permanence:** Crediting period is a minimum of 20 years, maximum of 100 years • **Additionality:** The project proponent must test the additionality of the project using the current CDM Tool for the demonstration and assessment of additionality • **Leakage:** Leakage emissions due to market effects resulting from a shift in harvest must be accounted • **Reversals:** Credits are issues to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Uncertainty deduction must be calculated. Uncertainty at all times is defined as the 90% confidence interval as a percentage of the mean **Verra VM0034 Canadian Forest Offset Methodology, v2.0** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** Must be demonstrated by completing the following steps a) Identification of alternative scenarios, b) Barrier analysis, c) Investment analysis, and d) Common practice analysis. This procedure is based on CDM Tool 02 *Combined tool to identify the baseline scenario and demonstrate additionality* • **Leakage:** Accounts for activity shifting leakage (GHG emissions from areas outside the project area, which is cause by the project activity) and market leakage

	• **Reversals:** Credits are issues to a buffer pool using VCS AFOLU Non-Permanence Risk Tool. Also requires the use of the VCS Non-permanence Risk Report Template, which entails a Risk Mitigation and Contingency Plan that tries to minimize the likelihood that a natural or human-induced reversal event will occur up to 100 years into the future from the time an emission offset is created by the project • **Uncertainty:** Where the width of the 90 percent confidence interval of the sampled data exceeds +/-10% of the estimated value, the amount that the calculated confidence interval is greater than +/- 10% must be added to the average (in the case of the baseline scenario), or subtracted from the average (in the case of the project scenario), and the resulting number used in quantification of carbon in the sampled carbon pool **Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using methodological equation • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities noting that the earliest start date of the proposed AUD project activity is January 1st, 2002. However, the start date can be earlier than January 1st, 2002, provided the requirements for projects with a start date prior to 2002, as set out in the most recent version of the VCS Standard, are met. • **Leakage:** Accounts for emissions from increased grazing activities, increased emission from displaced forest fires, decrease in carbon stocks due to displaced deforestation; see leakage calculation section of methodology which details the calculation process. If the project area is located within a jurisdictional program the most recent VCS JNR Requirements must be applied to determine whether a leakage belt is required. In all other cases, a leakage belt is required. • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** If the uncertainty of the total average carbon stock of a class is less than 10% of the average value, the average carbon stock value can be used. If the uncertainty is higher than 10%, the lower boundary of the 90% confidence interval must be considered in the calculations if the class is an initial forest class in the project area or a final non-forest class in the leakage belt, and the higher boundary of the 90% confidence interval if the class is an initial forest class in the leakage belt or a final non-forest class in the project area. **American Carbon Registry Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Improved Forest Management on Canadian Forestlands** • **Permanence:** A minimum commitment of 40 years is needed for Improved Forest Management practices and any potential loss of sequestered C must be first addressed by means of either a buffer pool or insurance. • **Additionality:** Projects must apply a three-prong additionality test to demonstrate that they exceed currently effective and enforced laws and regulations; exceed common practice in the forestry sector and geographic region; and face a financial implementation barrier. • **Leakage:** Project Proponents must demonstrate there is no activity-shifting leakage above the de minimis threshold. Market leakage must be assessed and accounted for in the quantification of net project benefits. • **Reversals:** Projects must have effective risk mitigation measures in place to compensate fully for any loss of sequestered C. Such mitigation measures can include contributions to the buffer pool, insurance, or other risk mitigation measures approved by ACR • **Uncertainty:** The ACR Standard sets a statistical precision requirement of ±10% of the mean with 90% confidence. When total project uncertainty is beyond this threshold, an uncertainty deduction affects the calculation of Emission Reduction Tons (ERTs.) **American Carbon Registry Improved Forest Management on Non-Federal U.S. Forestlands Methodology, v1.3**

	• **Permanence:** Permanence must be maintained for 40 years. • **Additionality:** The project proponent shall demonstrate that the proposed project activity exceeds the common practice of similar landowners managing similar forests in the region. • **Leakage:** ACR excludes activity-shifting leakage but includes market-shifting leakage. Market leakage is quantified as 0%, 10%, or 40%, based on the total decrease in wood products produced. • **Reversals:** A percentage of credits goes to buffer pool. Unavoidable reversals are compensated with credits in a shared buffer pool; every project contributes to the buffer pool at rates based on risk level. Avoidable reversals or computational reversals must be compensated for by the forest owner or project operator. • **Uncertainty:** Defines uncertainty as the square root of the summed errors in each of the measurement pools. The errors in each pool shall be weighted by the size of the pool so that projects may reasonably target a lower precision level in pools that only form a small proportion of the total stock. **American Carbon Registry Forest Carbon Standard: Improved Forest Management (IFM) on Small Non-Industrial Private Forestlands v1.0** • **Permanence:** 40 years • **Additionality:** ACR three prong additionality test (regulatory surplus, common practice, implementation barriers) and the CDM's "Combined tool to identify the baseline scenario and demonstrate additionality" • **Leakage:** Market leakage deduction of 20% where project activities decrease total wood products produced by the project relative to the baseline by more than 5% over the crediting period **Reversals:** Calculates risk of non-permanence using the ACR Tool for Risk Analysis and Buffer Determination – project proponents may contribute to a buffer pool OR purchase insurance for their credits. **Uncertainty**: +/- 10% of the mean at 90% confidence interval. If calculated uncertainty exceeds 10% then the estimated amount of the combined carbon stock at the project area level cannot be verified without additional sampling or stratification to improve statistical confidence. **American Carbon Registry, Forest Carbon Standard: Afforestation/Reforestation on Degraded Lands v1.2** • **Permanence:** 40 years • **Additionality:** ACR three prong additionality test (regulatory surplus, common practice, implementation barriers) and the CDM's "Combined tool to identify the baseline scenario and demonstrate additionality" • **Leakage:** leakage estimated based on CDM method: Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity • **Reversals:** calculates risk of non-permanence using the ACR Tool for Risk Analysis and Buffer Determination – project proponents may contribute to a buffer pool OR purchase insurance for their credits • **Uncertainty:** +/- 10% of the mean at 90% confidence interval applied to final calculation of emission reduction/removal enhancements **Climate Action Reserve Forest Project Protocol V5.0 (not boreal specific)** • **Permanence:** Carbon sequestered by a project must remain stored in the forest or in wood products for 100 years • **Additionality:** Must undergo a legal requirement test (No federal, state or local laws, statutes, rules, regulations or ordinances, court orders or other legally binding mandates require the project activity) and a performance test (must achieve greenhouse gas reductions or removals above and beyond "business as usual" activities)

	• **Leakage:** The GHG Assessment Boundary accounts for a "leakage" effect (harvesting increase on other lands to compensate for lost production) • **Reversals:** Unavoidable reversals (fires, insects, hurricanes, etc.) are compensated with credits in a shared buffer pool; Avoidable reversals (harvesting trees) or computational reversals (due to confidence deductions or leakage) must be compensated for by the forest owner or project operator • **Uncertainty:** Projects must include an uncertainty adjustment. Discounts for uncertainty are applied to project estimates when confidence standards are below +/- 5 percent at the 90 percent confidence interval. **Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0** ● **Permanence:** Does not specifically require permanence of its projects. It only requires projects maintain C stocks during the crediting period. If the C stocks are not maintained during the crediting period, a shortfall is declared, and projects must demonstrate to the Gold Standard how the project will realistically address the performance shortfall and recover appropriate levels of C stocks. Performance risks is assessed following the "Risk and Capacities" guideline. A risk scoring system assesses pre-defined risk categories and determines whether the risks of a project are acceptable to Gold Standard or whether mitigation measures shall be adopted. Uses high/medium/low scoring system based on defined thresholds. Risk categories are: 1. Natural Disturbance risks 2. Political risks 3. Project Management risks 4. Financial risks 5. Market risks. ● **Additionality:** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice). ● **Leakage:** Accounting for activity shifting required. Leakage shall be determined on a Modelling Unit (MU) level using the following formula: Leakage MU,t [tCO_2 ha^{-1}] = Leakage Project area [tCO_2] / Eligible planting area [ha]. Leakage is deducted in the first year. Four categories of leakage resulting from collection of wood (for firewood, charcoal), timber harvesting, agriculture (crop cultivation, shrimp cultivation) and livestock. All potential Leakage caused by a project within its crediting period is accounted for in year 1. Parameter is not subject to monitoring. Market leakage not accounted for under this methodology. Projects must submit a Leakage Template which includes information and calculations of potential leakage from different project activities. Provides default values when exact data is not available. ● **Reversals:** A percentage of credits go to a buffer pool; projects must contribute to a risk of reversals buffer (20%). Pooled compliance buffer remains untouched even after the crediting period of the project, further reducing the risk of reversal and non-permanence. ● **Uncertainty:** +/-20% at a 90% confidence interval. Where the error is above 20%, the additional difference shall be deducted. Gold Standard provides 3 approaches to uncertainty: Approach 1: Data is measured within each stratum and shall follow accepted sampling and analysis protocols, Approach 2: Data is derived from peer reviewed published literature, Approach 3: Project owners may use published default factors such as IPCCs. **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • **Permanence**: Minimum project term varies with the type of project; Project generating net C sequestration (or GHG removals) have a minimum project term of 30 years; Project generating net emission reductions have a minimum project term of 20 years; Project generating net irreversible net GHG emission reductions have a minimum project term of 5 years. Project Proponents must conduct **a** risk assessment using the Panda Standard Risk Analysis Tool. The result of the Risk Assessment is an overall risk category for the Project, translating into a percentage or number of PS Credits that must be deposited into the Panda Buffer Pool. • **Additionality**: Additionality can be demonstrated using 2 approaches: o **Three-prong approach**: The project activity must meet the following criteria: ▪ Complies with regulatory requirements

	▪ Exceeds common practice ▪ Faces investment, technological or institutional barriers); o **Performance standard approach:** CDM A/R Additionality Tool is required. Procedure is composed of 4 steps: 1) Identification of alternative land use scenarios, 2) Investment analysis (to show that the project activity is not the most attractive financially speaking), 3) Barrier Analysis (identify barriers that prevent project activities) and 4) Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice)). • **Leakage:** Accounting for activity shifting required. Any leakage identified must be quantified and subtracted from the net emission reduction/removal benefits except when leakage arises from the creation of poles and fencing to implement Project Activities • Fossil fuel combustion resulting from ground transportation. Leakage accounting might also be omitted if the following criteria are met: Displacement of baseline activities occurs on less than an average of 5% of the land area for a given project activity during the crediting period • Total quantity of a given good/commodity (e.g. lumber, crop, fuelwood, grazing animal) supplied to market in the project scenario for a given project activity is reduced by less than 20% of in comparison to the Baseline during the crediting period • All Leakage emissions are estimated to be below the de minimis threshold on average during the crediting period o Accounting for market leakage is not required if the following conditions are satisfied: ▪ Average quantity of a given good/commodity supplied to market in the with-Project Scenario for a given Project Activity is reduced by less than 20% in comparison to the Baseline. ▪ Average quantity of a given good/commodity in the Baseline per year supplied to market is less than 5% of total commodity produced per year within the PRC Prefecture (s) where the Project is taking place. • **Reversals:** A percentage of credits go to a buffer pool (Panda buffer pool). 2 options to mitigate risk: o **Option 1**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, this percentage of offsets from the Project itself for deposit to the Panda Buffer Pool"; o **Option 2**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, the number of PS credits of any type and vintage that equates to the percentage drawn from the risk assessment". Percentage of contribution to buffer pool is not explicitly stated. • **Uncertainty:** If the 90% confidence interval is greater than 10% of the mean the reportable amount must include an uncertainty deduction. The uncertainty deduction shall be equal to the calculated % of the mean represented by the confidence interval minus the allowable 10%

If there are protocols, have there been any registered projects or credits generated? If so, where?	*Voluntary* **Verra Improved Forest Management in Boreal Production Forests (under development)** • None yet, methodology is under development **Verra VM0012 Improved Forest Management in Temperate and Boreal Forests (LtPF), v1.2** • Carbon fixation project associated with LtPF conservation scenario of riparian strip enlargement (Registration and verification approval requested) o Estimated annual emission reduction: 7,223 Mg CO_2e • Afognak Forest Carbon Project (Registered) on the North coast (Perenosa Bay/Delphin Bay area) of Afognak Island, Alaska. Covers 3,326.5 ha of adjacent or proximal parcels located. Has an estimated annual emissions reductions of 40,451 and total buffer pool credits of 120,761 o Total credits issued: 970,478 **Verra VM0035 Methodology for Improved Forest Management through Reduced Impact Logging** • None for boreal forests **Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3** • None for boreal forests **Verra VM0009 Methodology for Avoided Ecosystem Conversion** • None for boreal forests **Verra VM0003 Methodology for Improved Forest Management Through Extension of Rotation Age** • None for boreal forests **Verra VM0034 Canadian Forest Offset Methodology, v2.0** • 1 project registered o Quebec Forestry Sector Carbon Sequestration Grouped Project Pivot ▪ Involves multiple activity types such as Afforestation, Reforestation and Revegetation (ARR) • Improved Forest Management – Logged to Protected Forests (IFM – LtPF)• Improved Forest Management – Extended Rotation Age (IFM-ERA). ▪ Estimated Annual Emission Reductions: 115,408 Mg CO_2e ▪ No credits issued yet **Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1** • No projects for boreal forests. While this protocol applies to all forest types, the protocol is based off a draft REDD+ project description in Brazil, and all current projects appear to be in tropical forests **American Carbon Registry** • 4 Improved Forest Management projects registered (4 Alaska)

	○ Total credits issued: 1,293,191 • ACR's Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Improved Forest Management on Canadian Forestlands has registered no credits yet since it was approved in September 2021 *Note: Fewer details provided for American Carbon Registry due to the inability to search the registry by methodology. The registry can be searched for "forest carbon" and methodologies are not distinguished in the results.* **Climate Action Reserve Forest Project Protocol V5.0** • 3 Improved Forest Management projects registered (3 Alaska) ○ Total credits issued: 8,934,489 **Gold Standard's Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0** • None for boreal forests **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • Unable to locate registry *Compliance* **N/A**
Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc. within any existing or proposed market?	*Voluntary market* **Verra Improved Forest Management in Boreal Production Forests (under development)** • The project activity will contain more than one discrete area of land aggregated into a cluster of forest stands. Aggregation of forests with multiple landowners is treated as a single project area **Verra VM0012 Improved Forest Management in Temperate and Boreal Forests (LtPF), v1.2** • Allows combination of multiple projects into a single project **Verra VM0035 Methodology for Improved Forest Management through Reduced Impact Logging (not boreal specific)** • Not explicitly addressed in methodology **Verra VM0010 Methodology for Improved Forest Management: Conversion from L**ogged to Protected Forest, v1.3 (not boreal specific) • Not explicitly addressed in methodology **Verra VM0009 Methodology for Avoided Ecosystem Conversion (not boreal specific)** • Grouped projects are allowed

	Verra VM0003 Methodology for Improved Forest Management Through Extension of Rotation Age (not boreal specific) • Aggregation is allowed **Verra VM0034 Canadian Forest Offset Methodology, v2.0** • Not explicitly addressed in methodology **VM0015 Methodology for Avoided Unplanned Deforestation, v1.1** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements **American Carbon Registry Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Improved Forest Management on Canadian Forestlands** • Aggregation is allowed, but projects are advised against aggregating multiple forest types or attempting a geographic region that is too large **American Carbon Registry's (ACR) Improved Forest Management on Non-Federal US Forestlands Methodology, v1.3** • Aggregation is allowed under this methodology. Chapter 6 of the ACR standard, version 5 provides guidelines for aggregating multiple landholdings into a single forest carbon project **Climate Action Reserve Forest Project Protocol V5.0** • Aggregation of projects is allowed. Only projects of less than 5,000 acres may enroll in an aggregate **American Carbon Registry Forest Carbon Standard: Improved Forest Management (IFM) on Small Non-Industrial Private Forestlands v1.0** • Aggregation of projects is allowed under this protocol **American Carbon Registry, Forest Carbon Standard: Afforestation/Reforestation on Degraded Lands v1.2** • Not specified in protocol **Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0** • Supports a landscape approach but has stated that REDD+ approaches have many challenges. **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • Not specified in protocol *Compliance* **N/A**

Is there controversy surrounding the markets or credits for the NCS pathway? Why?	*Same controversy applies in boreal forests as temperate forests (see below).* • **Permanence:** Another issue among stakeholders is the idea of C offsets being permanent. Permanence is essential to the legitimacy of a C credit because it guarantees that C will be stored, out of the atmosphere, for a long time, typically 100 years. Monitoring is necessary to ensure permanence, but it is costly (Catanoso, 2020). However, the majority of this criticism is aimed at rainforests, especially in South America. Natural disasters, especially wildfires, have the potential to reverse C savings. As intended, thus far, the buffer pools have covered any C lost to wildfires. As climate change progresses and wildfires become more frequent, this becomes a significant problem (Kahn, 2021). • **Additionality:** Many critics agree that there is a problem with the way that additionality is addressed in the protocols. Some argue that, as they currently stand, some forest offset projects are not actually additional. Projects are supposed to be credited for C sequestration in excess of what would have happened without the credit. However, critics claim that some projects are located on land that was never at risk of being logged or clear cut and is under the same management regime as before the credits were registered and awarded (Irfan, 2020; Elgin, 2020, 2021; Elgin and Mider, 2020) • **Leakage:** Leakage is an area that some stakeholders in the media and academia dispute. While forest protocols do account for some leakage, researchers argue that they are not accounting for enough. According to one study, 80% leakage should be deducted from some projects, based on the reduction in wood product production. However, a 20 – 40% deduction is typical for forest projects (Haya, 2019; Temple, 2021) • **Baseline**: The method of determining the baseline for a forest project is debated among stakeholders. Critics, published by CarbonPlan, argue that low baselines, based on unrealistic alternative scenarios, lead to over-crediting of forest projects (Badgley et al., 2021). When baselines are based on common practice, this can lead to inaccurate comparisons to logged forests or dissimilar tree species, which naturally store less C. Forest projects are then credited for more C than they are actually sequestering (Elgin, 2020) • **Low Price:** Most stakeholders agree that the current price of C offsets is too low. While it currently averages around USD 10 MgC^{-1}, the price fails to account for co-benefits that forest projects provide and is a barrier to achieving higher quality credits. Quality C credits require careful sampling and monitoring, which requires more time and money. Microsoft is paying USD 15 MgC^{-1} for forest offset projects, which more accurately accounts for the costs associated with generating high quality credits (Catanoso, 2020; Roberts, 2020; Donofrio et al., 2020; Bangkok Post, 2020) *Note: Carbon losses from fires are of particular concern for boreal forest carbon markets* (Zhao et al., 2021). *Protocols will likely need to distinguish regions most threatened by fires*

Coastal Blue Carbon: *Avoided conversion and degradation of mangrove, Mangrove restoration, Avoided seagrass conversion and degradation, Seagrass restoration, Avoided coral reef conversion and degradation, Coral reef restoration, Avoided emergent marsh conversion and degradation & Emergent marsh restoration*

Traditional definitions of coastal blue carbon ecosystems include mangroves, seagrasses and tidal salt marshes (Macreadie et al. 2021). However, some definitions also include coral reefs (IUCN, 2021) even though reef themselves are generally believed to represent net sources of CO_2 to the atmosphere. Including coral reefs, these blue carbon ecosystems occupy somewhere between 709,000-856,000 km^2 (0.15% of Earth surface, or 0.2% of ocean surface area) [2]. Although the coastal blue carbon ecosystems are presented here in a single table, we consider each system separately within the table because each has different characteristics.

While there is no exact estimate for the global areal extent of seagrasses, their potential extent based on suitable environmental conditions to support seagrass growth is around 345,000 km^2 (UNEP-WCMC, 2016) however the actual extent of seagrass beds is difficult to determine from satellite data and is likely much smaller. Total seagrass C storage ranges from 4.2 – 8.4 Pg C (180 – 210 Mg C ha^{-1}) (Fourqurean et al., 2012). A study by Goldstein et al. (2020) estimates that seagrasses store 5 Pg C (111 Mg C ha-1) in combined aboveground, belowground, and soil organic C depths of 1m, globally

The global areal extent of coral reefs is estimated to be between 154,000-301,110 km^2 (Li et al., 2020) [3]. Reefs do not store large quantities of organic carbon but do comprise a substantial global reservoir of inorganic carbon, found as $CaCO_3$ in both coral framework and underlying/adjacent permeable sediments (Perry, 2011). However, because the calcification produces CO_2 (Frankignoulle et al., 1995), this $CaCO_3$ does not represent C sequestered from the atmosphere over any climatically relevant timescale (Gaffin and Fujita, 1992). As a result, unlike the other blue carbon systems, there are no estimates of global C storage by coral reefs.. Despite not serving directly as sinks for atmospheric CO2, the role of coral reef ecosystems in supporting C sequestration as components of broader seascapes that connect different kinds of blue carbon ecosystems — such as through the export of carbonates to adjacent mangroves and seagrasses (Saderne et al., 2019) or by supporting biodiversity that facilities the provision of ecosystem services elsewhere in the ocean (Mumby, 2006; Guannel et al., 2016) — demands further research.

Mangroves cover an area of 137,600 km^2 (Bunting et al., 2018) to 150,000 km^2 (Slobodian and Badoz, 2019). Estimates of total mangrove C storage largely depend on the depth to which underlying sediments are integrated. When only the top 1 m of soil is included, storage is

[2] Based on extent estimates of Slobodian & Badoz (2019) for mangroves, UNEP-WCMC (2016) for seagrasses, (Li et al., 2020) for coral reefs (upper and lower bounds of probable extent) and Mcowen et al. (2017) for emergent marshes, and the ocean surface area of Eakins & Sharman (2007). The calculation we present here agrees generally with that of Duarte et al. (2013), though the Duarte et al. estimate of 0.2% global extent also included some macroalgae. In all instances, the estimate for seagrasses is particularly uncertain due to ineffectiveness of remote sensing approaches in delineating seagrass habitat.

[3] These estimates (lower and upper probability thresholds from modern remote sensing analysis performed in support of the Allen Coral Atlas mapping project) agree generally with an earlier estimate of 284,300 km^2 (Spalding et al., 2001) but are substantially lower than the 600,000 km^2 estimate of Crossland et al. (1991), which was not based on direct observations.

estimated at 6.4 Pg C (86 – 729 Mg C ha^{-1}, average of 136 Mg C ha^{-1}) (Sanderman et al., 2018). When considering the top 2 m of soil, C storage is estimated at 12.6 Pg C. Goldstein et al. (2020) estimate that mangroves store 7.3 Pg C (502 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C to a depth of 1 m, globally.

Finally, tidal salt marshes have an estimated global areal extent of 54,950 km^2 (Mcowen et al., 2017), though this is a conservative estimate that does not include salt marshes that may exist in high latitude regions. Total C storage of tidal salt marshes is likely between 0.4 – 6.5 Pg C (Duarte et al., 2013), with a per hectare estimate of approximately 250 to 297 Mg C ha^{-1} (Bridgham et al., 2006; IPCC, 2013). Goldstein et al. (2020) estimate that marshes store 5.6 Pg C (265 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 1m, globally. Goldstein et al. (2020), however, estimate the global extent of marshes to be 210,000 km^2.

All blue carbon systems combined likely serve as a net sink, with annual sequestration estimated in two separate, recent assessments to be between 110.1 – 256.9 Tg CO_2 yr^{-1} (Lovelock and Reef, 2020) and 304 (141–466) Tg CO_2e yr^{-1} (Macreadie et al., 2021); importantly, neither of these estimates accounts for CH_4 or N_2O emissions. Recent research indicates that emissions of GHGs other than CO_2 may vary widely from system to system and thus represent a persistent source of uncertainty surrounding carbon accounting in blue carbon ecosystems, particularly in mangroves and salt marshes (Rosentreter et al., 2018; Oreska et al., 2020; Rosentreter et al., 2021a). These findings suggest existing rates of C sequestration determined for these ecosystems may represent substantial overestimates, and that location-specific measurements for individual systems may be required to achieve the level of accuracy and precision necessary to support high-quality carbon credits.

The future ability of these systems to serve as a sink largely depends on the combined effects of habitat loss, natural landward migration, restoration, ocean acidification and sea level rise, among other factors, particularly for mangroves and salt marshes. Mangroves and salt marshes currently serve as net sinks, storing 90-121 Tg CO_2 yr^{-1} (Alongi, 2014; Lovelock and Reef, 2020) and 55.05 Tg CO_2 yr^{-1} (Lovelock and Reef, 2020), respectively. It is not clear whether seagrasses serve as a net global sink for C. For example, z, with substantial rates of *in situ* calcification being one possible driver of net CO_2 production (Van Dam et al., 2021b).(Macreadie et al., 2014) Loss of seagrass extent in the future will likely cause emissions, ranging from 0.37 – 2.20 Pg CO_2 (Lovelock and Reef, 2020). As indicated above, coral reefs do not serve as a sink for CO_2 from the atmosphere over decadal to centennial timescales, due to the net effect of calcification on ocean chemistry (Macreadie et al., 2019).
(Eyre, 2014)
Avoided degradation of mangroves, tidal marshes, and seagrasses could avert 0.15 – 1.02 Pg CO_2e yr^{-1} in new emissions (Pendleton et al., 2012). This does not account for additional new sequestration from restoration, particularly in the case of mangroves. More specifically, further avoided mangrove degradation could prevent 0.09 – 0.45 Pg CO_2 yr^{-1} of emissions and further avoided emergent marsh degradation could prevent 0.02 – 0.24 Pg CO_2 yr^{-1} of emissions (Pendleton et al., 2012). Avoided seagrass degradation could prevent 0.05 – 0.33 Pg CO_2 yr^{-1} (Pendleton et al., 2012). Since coral reefs are not a sink for atmospheric C, there are no global estimates for how much additional C could be stored in the system or avoided.

Generally, mangrove carbon dynamics are most thoroughly understood out of all the blue carbon systems (Alongi, 2014; Lovelock and Reef, 2020; Macreadie et al., 2021). Most mangrove systems are substantial net C sinks (Yiwen et al., 2021), but there is substantial uncertainty regarding net GHG balance. For example, CH_4 emissions may be high in polluted mangrove systems (Kristensen, 2007; Alongi, 2014)and vary heterogeneously from one system to the next (Rosentreter et al., 2018, 2021a). Similarly, deforested mangroves converted to aquaculture ponds, whether abandoned or in operation, are net GHG sources (Cameron et al., 2019); there is increasing evidence that a wide range of aquatic ecosystems are net sources of CH4, in particular (Rosentreter et al., 2021b). While monitoring technology is improving, implementation is not cost-effective for all projects (Yiwen et al., 2021). Thus, current confidence in detecting net changes in C sequestration in mangroves varies from system to system.

Salt marshes may be readily sampled and monitored with current technology, but their areal extent is poorly mapped. For seagrasses, we find there is low confidence in our ability to provide global estimates of sequestration due to a lack of sufficient measurements of air-water CO_2 fluxes (Macreadie et al., 2019). In addition, it is difficult to differentiate between allochthonous and autochthonous sources of organic C in these systems (Macreadie et al., 2019); notably, voluntary C standards (e.g., VM0033) (Emmer et al., 2015) require project developers to discount allochthonous C from carbon budgets.

Both voluntary and compliance markets exist for coastal blue carbon. Verra, Gold Standard, and the Clean Development Mechanism (CDM) have all developed protocols that could apply to blue carbon systems or have been created specifically for blue carbon systems. These protocols account for leakage, permanence, reversals, additionality, uncertainty, and aggregation in different ways. This is described in the table in further detail. It is notable that most of the active blue carbon projects have been focused exclusively on mangrove restoration.

Coastal Blue Carbon (Mangroves, Seagrasses, Coral Reefs and Salt Marshes)

Global Areal Extent: 709,000-856,000 km^2 (0.15% of Earth surface, or 0.2% of ocean surface area)[4]

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?

Possible total C storage in mangroves, seagrasses and salt marshes: 10 – 24 Pg C (36.7 – 88.08 Pg CO_2e) (Lovelock and Reef, 2020). The range estimated by Lovelock and Reef agrees generally with a range of 11 – 21.3 Pg C calculated from different literature values for the individual ecosystem types.

Note: Both of these ranges exclude current storage by coral reefs, which has not been estimated globally.

Mangroves

- Global Areal Extent: 137,600 km^2 (Bunting et al., 2018) to 150,000 km^2 (Slobodian and Badoz, 2019).
- Estimate of total C storage: Depends heavily on depth to which one integrates within underlying sediments. Including only top 1 m of soil: 6.4 Pg C (86 – 729 Mg C ha^{-1}, average of 136 Mg C ha^{-1}). Integrating top 2 m of soil: 12.6 Pg C. Both values from (Sanderman et al., 2018). Goldstein et al. (2020) estimate that mangroves stor Pg C (502 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 1m, globally.

Seagrasses

- Global Areal Extent: Poorly constrained due to limitations associated with remote sensing techniques. Most recent estimate of *possible* extent based on suitable environmental conditions to support seagrass growth: 345,000 km^2 (UNEP-WCMC, 2016). Actual extent of seagrass beds is likely much smaller.
- Estimate of total C storage: 4.2 – 8.4 Pg C (180 – 210 Mg C ha^{-1}) (Fourqurean et al., 2012). Goldstein et al. (2020) estimate that seagrasses store 5 Pg C (111 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 1m, globally
- Estimates of C storage within temperate seagrass beds range from 21-223 Mg C ha^{-1} (sediment carbon integrated to 1m; (IUCN, 2021)

Coral Reefs

[4] Based on extent estimates of Slobodian & Badoz (2019) for mangroves, UNEP-WCMC (2016) for seagrasses, Li et al. (2020) for coral reefs (upper and lower bounds of probable extent) and Mcowen et al. (2017) for emergent marshes, and the ocean surface area of Eakins & Sharman (2007). The calculation we present here agrees generally with that of Duarte et al. (2013), though the Duarte et al. estimate of 0.2% global extent also included some macroalgae. In all instances, the estimate for seagrasses is particularly uncertain due to ineffectiveness of remote sensing approaches in delineating seagrass habitat.

	• Global Areal Extent: 154,000-301,110 km^2 (Li et al., 2020).[5] • There are no estimates of global C storage by coral reefs. Reefs do not store large quantities of organic carbon but do comprise a substantial global reservoir of inorganic carbon, found as $CaCO_3$ in both coral framework and underlying/adjacent permeable sediments (Perry, 2011). However, because calcification produces CO_2 (Frankignoulle et al., 1995), this $CaCO_3$ does not represent C sequestered from the atmosphere over any climatically relevant timescale (Gaffin and Fujita, 1992). *Salt Marshes* • Global Areal Extent: 54,950 km^2 (Mcowen et al., 2017); this is a conservative estimate that does not include salt marshes that may exist in high latitude regions). • Estimate of total C storage: 0.4 – 6.5 Pg C (Duarte et al., 2013). Per hectare: approx. 250 Mg C ha^{-1} (Bridgham et al., 2006); 254-297 Mg C ha^{-1} (IPCC, 2013). Goldstein et al. (2020) estimate that marshes store 5.6 Pg C (265 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 1m, globally. Goldstein et al. (2020), however, estimate the global extent of marshes to be 210,000 km^2 • Estimates of C storage by temperate marshes range from 46.7 - 731 Mg C ha^{-1} (sediment carbon integrated to 1m; IUCN, 2021)
At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	*Possible total C storage in mangroves, seagrasses and salt marshes:* 10 – 24 Pg C (36.7 – 88.08 Pg CO_2e) (Lovelock and Reef, 2020). The range estimated by Lovelock and Reef agrees generally with a range of 11 – 21.3 Pg C calculated from different literature values for the individual ecosystem types. *Note: Both of these ranges exclude current storage by coral reefs, which has not been estimated globally.* *Mangroves* • Global Areal Extent: 137,600 km^2 (Bunting et al., 2018) to 150,000 km^2 (Slobodian and Badoz, 2019). • Estimate of total C storage: Depends heavily on depth to which one integrates within underlying sediments. Including only top 1 m of soil: 6.4 Pg C (86 – 729 Mg C ha^{-1}, average of 136 Mg C ha^{-1}). Integrating top 2 m of soil: 12.6 Pg C. Both values from (Sanderman et al., 2018). Goldstein et al. (2020) estimate that mangroves stor Pg C (502 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 1m, globally. *Seagrasses*

[5] These estimates (lower and upper probability thresholds from modern remote sensing analysis performed in support of the Allen Coral Atlas mapping project) agree generally with an earlier estimate of 284,300 km^2 (Spalding et al., 2001) but are substantially lower than the 600,000 km^2 estimate of Crossland et al. (1991), which was not based on direct observations.

	• Global Areal Extent: Poorly constrained due to limitations associated with remote sensing techniques. Most recent estimate of *possible* extent based on suitable environmental conditions to support seagrass growth: 345,000 km^2 (UNEP-WCMC, 2016). Actual extent of seagrass beds is likely much smaller. • Estimate of total C storage: 4.2 – 8.4 Pg C (180 – 210 Mg C ha^{-1}) (Fourqurean et al., 2012). Goldstein et al. (2020) estimate that seagrasses store 5 Pg C (111 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 1m, globally • Estimates of C storage within temperate seagrass beds range from 21-223 Mg C ha^{-1} (sediment carbon integrated to 1m; (IUCN, 2021) *Coral Reefs* • Global Areal Extent: 154,000-301,110 km^2 (Li et al., 2020).[6] • There are no estimates of global C storage by coral reefs. Reefs do not store large quantities of organic carbon but do comprise a substantial global reservoir of inorganic carbon, found as $CaCO_3$ in both coral framework and underlying/adjacent permeable sediments (Perry, 2011). However, because calcification produces CO_2 (Frankignoulle et al., 1995), this $CaCO_3$ does not represent C sequestered from the atmosphere over any climatically relevant timescale (Gaffin and Fujita, 1992). *Salt Marshes* • Global Areal Extent: 54,950 km^2 (Mcowen et al., 2017); this is a conservative estimate that does not include salt marshes that may exist in high latitude regions). • Estimate of total C storage: 0.4 – 6.5 Pg C (Duarte et al., 2013). Per hectare: approx. 250 Mg C ha^{-1} (Bridgham et al., 2006); 254-297 Mg C ha^{-1} (IPCC, 2013). Goldstein et al. (2020) estimate that marshes store 5.6 Pg C (265 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 1m, globally. Goldstein et al. (2020), however, estimate the global extent of marshes to be 210,000 km^2 • Estimates of C storage by temperate marshes range from 46.7 - 731 Mg C ha^{-1} (sediment carbon integrated to 1m; IUCN, 2021)
Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	*Total* • Avoided degradation of mangroves, salt marshes, and seagrasses could avert 0.15 – 1.02 Pg CO_2e yr^{-1} in new emissions (Pendleton et al., 2012). This does not account for additional new sequestration from restoration, particularly in the case of mangroves. *Mangroves* • With further avoided degradation: 0.09 – 0.45 Pg CO_2e yr^{-1} (Pendleton et al., 2012). • Mangrove avoided conversion and degradation (technical potential): 0.073 Pg CO_2e yr^{-1} (Roe et al., 2021) • Mangrove avoided conversion and degradation (cost-effective potential): 0.065 Pg CO_2e yr^{-1} (Roe et al., 2021)

[6] These estimates (lower and upper probability thresholds from modern remote sensing analysis performed in support of the Allen Coral Atlas mapping project) agree generally with an earlier estimate of 284,300 km^2 (Spalding et al., 2001) but are substantially lower than the 600,000 km^2 estimate of Crossland et al. (1991), which was not based on direct observations.

- Mangrove avoided conversion and degradation (cost-effective potential): 0.117 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Mangrove avoided conversion and degradation (maximum mitigation potential): 0.130 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Mangrove avoided conversion and degradation (cost-effective potential): 0.08 Pg CO_2e yr^{-1} (Nature4Climate, 2022)
- Mangrove avoided conversion and degradation (maximum mitigation potential): 0.089 Pg CO_2e yr^{-1} (Nature4Climate, 2022)

- Mangrove restoration: Restoration of lost mangroves worldwide could lead to the storage of an extra 0.25 Pg CO_2 in aboveground tissues and 1.08 Pg CO_2 in soils (Donato et al., 2011)
- Mangrove restoration (technical potential): 0.019 Pg CO_2e yr^{-1} (Roe et al., 2021)
- Mangrove restoration (cost-effective potential): 0.0057 Pg CO_2e yr^{-1} (Roe et al., 2021)
- Mangrove restoration (cost-effective potential): 0.179 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Mangrove restoration (maximum mitigation potential): 0.596 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Mangrove restoration (cost-effective potential: <$100 USD/ton): 0.008 Pg CO_2e yr^{-1} (Nature4Climate, 2022)
- Mangrove restoration (maximum mitigation potential): 0.002 Pg CO_2e yr^{-1} (Nature4Climate, 2022)

Seagrass

- With further avoided degradation: 0.05 – 0.33 Pg CO_2 yr^{-1} (Pendleton et al., 2012).
- Seagrass avoided conversion and degradation (maximum mitigation potential): 0.132 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Seagrass avoided conversion and degradation (cost-effective mitigation potential):0.119 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Seagrass restoration (maximum mitigation potential): 0.209 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Seagrass restoration (cost-effective mitigation potential): 0 Pg CO_2e yr^{-1} (Griscom et al., 2017)

Coral Reefs

- Not applicable.

Salt Marshes

- With further avoided degradation: 0.02 – 0.24 Pg CO_2e yr^{-1} (Pendleton et al., 2012).
- Emergent marsh avoided conversion and degradation (maximum mitigation potential): 0.042 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Emergent marsh avoided conversion and degradation (cost-effective mitigation potential): 0.038 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Emergent marsh restoration (maximum mitigation potential): 0.036 Pg CO_2e yr^{-1} (Griscom et al., 2017)
- Emergent marsh restoration (cost-effective mitigation potential): 0.022 Pg CO_2e yr^{-1} (Griscom et al., 2017)

Note: For the following reasons, we believe there to be high uncertainty associated with the mitigation potentials of restoration pathways for mangrove, seagrass and salt marsh ecosystems reported by Griscom et al. (2017), Roe et al. (2021), and others:

	• *Griscom et al. (2017) and Roe et al (2021) did not take climate change or its effects into account when estimating the potential restoration area, with direct implications for the permanence of any possible future C storage.* • *Neither the Griscom et al. (2017) nor Roe et al. (2021) studies accounted for possible destruction or degradation from increased frequency or severity of tropical cyclones, or for "coastal squeeze" (the interactive effect of sea level rise and a human failure to create the necessary accommodation space for the systems' landward or latitudinal migration), despite the impact both of these phenomena could have on the climate mitigation potential of coastal blue carbon systems.* • *Neither the Griscom et al. (2017) nor Roe et al. (2021) studies accounted for emissions of GHGs other than CO_2, which could substantially reduce estimates of current and potential sequestration.* • *The Griscom et al. (2017) and Roe et al. (2021) projections for the sequestration potential associated with the restoration of mangroves and salt marshes may represent overestimates due to the studies' failure to account for current land use: Because roughly half of the world's coastal wetlands have been converted to agricultural use* (Pendleton et al., 2012), Reise et al., (2022) *conclude in a recent assessment of nature-based solutions that much of this land should not be included in estimates of the area available for restoration because restoring such systems could compromise food security or lead to emissions leakage.*
What is the range of estimates for how much additional C could be sequestered globally?	*Total* • With sufficient accommodations for the landward movement of mangroves and salt marshes (i.e., minimization of the "costal squeeze" effect) and no further habitat destruction, 5.51 Pg CO_2 in additional sequestration is possible. Failure to accommodate coastal squeeze could result in emissions of 12.48 Pg CO_2 (Lovelock and Reef, 2020). *Mangroves* • With sufficient accommodations for coastal squeeze, up to 5.87 Pg CO_2 additional sequestration possible by 2100 (Lovelock and Reef, 2020). *Seagrass* • Losses largely assessed as unavoidable. 0.37 Pg CO_2 in additional emissions by 2100 (Lovelock and Reef, 2020). *Coral Reefs* • Not applicable. *Salt Marshes* • With sufficient accommodations for coastal squeeze, up to 0.73 Pg CO_2 additional sequestration possible by 2100 (Lovelock and Reef, 2020).

How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that system?	*Mangroves* • Current confidence in detecting net changes in C sequestration in mangroves varies from system to system. • Out of all the coastal blue C systems, highest confidence. Monitoring technology is improving, but implementation costs can be high (Yiwen et al., 2021) • Mangrove carbon dynamics are most thoroughly understood out of all the blue carbon systems (Alongi, 2014; Lovelock and Reef, 2020) Largest source of uncertainty is the effect of GHG emissions other than CO_2. Traditionally, mangrove systems have been universally assumed to be substantial net CO_2 sinks (Yiwen et al., 2021). However, several recent studies indicate CH_4 and N_2O emissions from mangroves may be substantial, suggesting existing assessments of sequestration by these systems may be overestimates (Rosentreter et al., 2018, 2021a). CH_4 emissions may be particularly high in polluted or previously disturbed mangrove systems (Kristensen, 2007; Alongi, 2014). *Seagrass* • Low confidence because lack of constraint on air-water CO_2 fluxes in many instances (Macreadie et al., 2019) and indications there is heterogeneity in these systems' ability to serve as sources or sinks . System-by-system measurements are generally required (Van Dam et al., 2021a; b). In addition, it is difficult to differentiate between allochthonous and autochthonous sources of organic C in these systems (Macreadie et al., 2019); voluntary C standards (e.g., VM0033) (Emmer et al., 2015) don't allow allochthonous carbon. *Coral Reefs* • Not applicable. *Salt Marshes* • Marshes may be readily sampled and monitored with current technology. However, the areal extent of marshes is poorly mapped.

C Markets

Is there a market (or proposed market) for carbon credits from the system?	Yes, voluntary and compliance markets exist. Mangroves: Yes Seagrass: Yes, but speculative (Oreska et al., 2020). Coral Reefs: Yes Salt Marshes: Yes

Are there protocols (or proposed protocols) for such credits?	*Voluntary* • Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6[c]; international • Verra VM0024 Methodology for Coastal Wetland Creation, v1.0; U.S. only • Verra VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v1.0; international • Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0[a]; international *Compliance* • CDM AR-AM0014: Afforestation and reforestation of degraded mangrove habitats, v3.0; international • CDM AR-AMS0003: Afforestation and reforestation project activities implemented on wetlands, v3.0 [b]; international [a] *Protocol applies to coastal blue carbon, agroforestry and multiple forest systems* [b] *Protocol applies to coastal blue carbon and tropical forests* [c] *Protocol applies to coastal blue carbon, agroforestry, peatlands, freshwater wetlands and tropical forests* *Note: We acknowledge the existence of the methodology "Methodology for Coastal Resilience Benefits from Restoration and Protection of Tidal Wetlands". This methodology is developed by the SD Vista program managed by Verra, which sets out rules and criteria for the design, implementation and assessment of projects that aim to deliver high-impact sustainable development benefits. Since the SD Vista program delivers SD vista assets instead of C credits, we did not include it in the above protocol list.*
If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	*Voluntary* **VM0007 REDD+ Methodology Framework (REDD+MF), v1.6** • Permanence: Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • Additionality: The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • Leakage: Leakage must be considered for all activities, calculated using leakage modules which are defined in the methodology based on project activities • Reversals: A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Different percentages will likely be calculated for each of the baseline types as relevant. 15% of project's buffer is released every 5 years at re-verification • Uncertainty: allowable uncertainty under this methodology is +/- 15% of Total net GHG emission reductions of the REDD+ project activity (NERRED+) at the 95% confidence level. Where this precision level is met then no deduction should result for uncertainty. Where uncertainty exceeds 15% of NERREDD+ at the 95% confidence level then the deduction must be equal to the amount that the uncertainty exceeds the allowable level.

Verra VM0024 Methodology for Coastal Wetland Creation, v1.0

- **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool
- **Additionality**: Demonstrated using an activity method which consists in 2 steps**:**
    - **1-Regulatory surplus:** The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the VCS Standard.
    - **2- Positive list:** The applicability conditions of this methodology represent the positive list. The positive list was established using the activity penetration option (Option A in the VCS Standard). Projects located in the United States, and which meet all of the applicability conditions of this methodology, are deemed additional).
- **Leakage**: Account for activity-shifting leakage, market-effects leakage as well as ecological leakage. Leakage must be considered for all activities, calculated using leakage modules which are defined in the methodology based on project activities.
- **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Different percentages will likely be calculated for each of the baseline types as relevant. Periodically (every 5 years), project may be eligible for a release of credits from the AFOLU pooled buffer account.
- **Uncertainty:** allowable uncertainty under this methodology is +/- 15% of Total net GHG emission reductions at the 95% confidence level. Where this precision level is met then no deduction should result for uncertainty. Where uncertainty exceeds 15% at the 95% confidence level then the deduction must be equal to the amount that the uncertainty exceeds the allowable level.

Verra VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v1.0

- **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool.
- **Additionality:**
    - **For projects located in the U.S.,** additionality is demonstrated using an activity method which consists in 2 steps: 1-Regulatory surplus (The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the VCS Standard.), 2- Positive list (The applicability conditions of this methodology represent the positive list. The positive list was established using the activity penetration option (Option A in the VCS Standard). Projects located in the United States, and which meet all of the applicability conditions of this methodology, are deemed additional).
    - **For projects located outside of the U.S.,** additionality is demonstrated using the latest version of the CDM Combined tool to identify the baseline scenario and demonstrate additionality for A/R CDM project activities.
- **Leakage:** Activity-shifting and market leakage are assumed to be zero. Ecological is also assumed to not occur if project design meets the applicability conditions of this methodology. If project activity impact GHG emissions outside the project area, project design must be modified and validated by experts**.**

	• **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Different percentages will likely be calculated for each of the baseline types as relevant. Periodically (every 5 years), project may be eligible for a release of credits from the AFOLU pooled buffer account. • **Uncertainty:** allowable uncertainty under this methodology is +/- 20% or 30% of Total net GHG emission reductions at the 90% or 95% confidence level, respectively. Where this precision level is met then no deduction should result for uncertainty. Where uncertainty exceeds 15% at the 95% confidence level then the deduction must be equal to the amount that the uncertainty exceeds the allowable level. **Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0** • **Permanence**: Does not specifically require permanence of its projects. It only requires projects maintain C stocks during the crediting period. If the C stocks are not maintained during the crediting period, a shortfall is declared, and projects must demonstrate to the Gold Standard how the project will realistically address the performance shortfall and recover appropriate levels of C stocks. Performance risks is assessed following the "Risk and Capacities" guideline. A risk scoring system assesses pre-defined risk categories and determines whether the risks of a project are acceptable to Gold Standard or whether mitigation measures shall be adopted. Uses high/medium/low scoring system based on defined thresholds. Risk categories are: 1. Natural Disturbance risks 2. Political risks 3. Project Management risks 4. Financial risks 5. Market risks. • **Additionality**: CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice). • **Leakage**: Accounting for activity shifting required. Leakage shall be determined on a Modelling Unit (MU) level using the following formula: Leakage MU,t [tCO_2 ha-1] = Leakage Project area [tCO_2] / Eligible planting area [ha]. Leakage is deducted in the first year. Four categories of leakage resulting from collection of wood (for firewood, charcoal), timber harvesting, agriculture (crop cultivation, shrimp cultivation) and livestock. All potential Leakage caused by a project within its crediting period is accounted for in year 1. Parameter is not subject to monitoring. Market leakage not accounted for under this methodology. Projects must submit a Leakage Template which includes information and calculations of potential leakage from different project activities. Provides default values when exact data is not available. • **Reversals**: A percentage of credits go to a buffer pool; projects must contribute to a risk of reversals buffer (20%). Pooled compliance buffer remains untouched even after the crediting period of the project, further reducing the risk of reversal and non-permanence. • **Uncertainty**: +/-20% at a 90% confidence interval. Where the error is above 20%, the additional difference shall be deducted. Gold Standard provides 3 approaches to uncertainty: Approach 1: Data is measured within each stratum and shall follow accepted sampling and analysis protocols, Approach 2: Data is derived from peer reviewed published literature, Approach 3: Project owners may use published default factors such as IPCCs.

	Compliance **CDM AR-AM0014: Afforestation and reforestation of degraded mangrove habitats, v3.0** • Permanence: CDM projects produce temporary emissions credits. Specifically, these are either termed "temporary CERs" (tCERs) or "long-term CERs" (lCERs). Both types of CERs have expiration dates, after which they must be replaced by another tradable emissions unit under the Kyoto Protocol. If an Annex 1 country uses a tCER for compliance it must replace it with a permanent Kyoto unit or an unexpired tCER in the next commitment period. If the project is still performing as expected, the new tCERs will just replace the expired ones. Have either a single 30-year crediting period, or 20-year crediting periods that are renewable up to two times • Additionality: Project participants (PPs) shall identify the baseline demonstrate that the project activity is additional by selecting one of the following options: (a) Applying the "Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities"; (b) Applying an approved standardized baseline appropriate to their project • Leakage: leakage estimated based on CDM method: Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity • **Reversals:** Not specified in the protocol • **Uncertainty:** Not specified in protocol **CDM AR-AMS0003: Afforestation and reforestation project activities implemented on wetlands, v3.0** • Permanence: CDM projects produce temporary emissions credits. Specifically, these are either termed "temporary CERs" (tCERs) or "long-term CERs" (lCERs). Both types of CERs have expiration dates, after which they must be replaced by another tradable emissions unit under the Kyoto Protocol. If an Annex 1 country uses a tCER for compliance it must replace it with a permanent Kyoto unit or an unexpired tCER in the next commitment period. If the project is still performing as expected, the new tCERs will just replace the expired ones. Have either a single 30-year crediting period, or 20-year crediting periods that are renewable up to two times • Additionality: Project participants (PPs) shall demonstrate that the project activity is additional by selecting one of the following options: (a) Using the barrier (Investment, Institutional, Traditional, Ecological, Social, Prevailing practice) analysis outline contained in appendix 1 of this methodology; or (b) Using an approved standardized baseline applicable to their project. • Leakage: leakage estimated based on CDM method: Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity • **Reversals:** Not specified in the protocol • **Uncertainty:** Not specified in protocol

If there are protocols, have there been any registered projects or credits generated? If so, where?	*Voluntary*
	Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6
	• **2 projects registered**
	  ○ Blue Carbon Project Gulf of Morrosquillo "Vida Manglar" (Colombia)
	  ▪ Estimated Annual Emission Reductions: 31,310 Mg CO_2e yr^{-1}.
	  ▪ Total credits issued 59,363.
	  ▪ The Blue Carbon Project Gulf of Morrosquillo is a grouped project whose expansion region includes all the mangrove forests present in the Gulf of Morrosquillo, in the Colombian Caribbean. The main objective of the project is the reduction of greenhouse gas emissions through activities that allow the identification, prioritization and execution of actions for the adequate management of mangroves, the promotion of sustainable development, the strengthening of local governance and the promotion of alternative productive activities, while contributing to the protection of high values of community conservation and biodiversity.
	  ○ Community based avoided deforestation project in Guinea-Bissau- REDD (Guinea-Bissau)
	  ▪ Estimated Annual Emission Reductions: 920,436 Mg CO_2e yr^{-1}.
	• **9 projects under development (2 Indonesia, 1 Gambia, 4 Mexico, 1 Mozambique, 1 Senegal).**
	  ○ Carbon sequestration in mangroves of the south – central coastal zone of the state of Sinaloa, México (Mexico)
	  ▪ Estimated Annual Emission Reductions: 3,123,836 Mg CO_2e yr^{-1}.
	  ▪ The project consists of the reforestation and conservation of the mangrove swamp located in the south-central zone of the state of Sinaloa, Mexico.
	  ○ Senegal and West Africa Mangrove Programme (SWAMP) (Senegal)
	  ▪ Estimated Annual Emission Reductions: 2,547 Mg CO_2e yr^{-1}.
	  ▪ The proposed project activity is a plan for the restoration and conservation (afforestation, reforestation and/or revegetation-ARR and reducing emissions from deforestation and forest degradation-REDD+) of the degraded lands in the mangrove patches of Sine Saloum, Senegal. The stated goal of the project activity is to restore degraded wetlands and protect the areas currently facing a risk of deforestation.
	  ○ Uh lu'umil Zazil-ha Blue Carbon Mangrove Conservation Project, Conserving Coastal Ecosystems in Quintana Roo to Support Life (Mexico)
	  ▪ Estimated Annual Emission Reductions: 1.718 Mg CO_2e yr^{-1}.
	  ○ Conservation and restoration of the mangrove ecoystem in the Gambia through the REDD+ mechanism (Gambia)
	  ▪ Estimated Annual Emission Reductions: 300,000 Mg CO_2e yr^{-1}.
	  ○ Blue Forest & Mozambique: Building Africa's Largest Mangrove Restoration Project (Mozambique)
	  ▪ Estimated Annual Emission Reductions: 2,965,555 Mg CO_2e yr^{-1}.

- Tlawan kiwi nak chuchit Blue Carbon Mangrove Conservation Project, Conserving Coastal Ecosystems in Veracruz to Support Life (Mexico)
  - Estimated Annual Emission Reductions: 65,946 Mg CO_2e yr^{-1}.
- U' Balam'moo A'kalché ó Blue Carbon Mangrove Conservation Project, Conserving Coastal Ecosystems in Campeche to Support Life (Mexico)
  - Estimated Annual Emission Reductions: 667,276 Mg CO_2e yr^{-1}.
- Aztlan Blue Carbon Mangrove CONSERVATION project - Conserving the Marismas NACIONALES of Nayarit (Mexico)
  - Estimated Annual Emission Reductions: 65,946 Mg CO_2e yr^{-1}.
- Riau Ecosystem Restoration Carbon Project (Indonesia)
  - Estimated Annual Emission Reductions: 6,870,411 Mg CO_2e yr^{-1}.
- OKI REDD+ Project (Indonesia)
  - Estimated Annual Emission Reductions: 181,986 Mg CO_2e yr^{-1}.

- **2 projects under validation (1 Honduras, 1 Colombia)**
  - MUSKITIA PÂSA KLÎN NÂKA
    - This projects involves multiple activities including the conservation of seagrass beds
    - Estimated Annual Emission Reductions: 39929 Mg CO_2e yr^{-1}.
  - Riscales REDD+ Project (Colombia)
    - Estimated Annual Emission Reductions: 187,240 Mg CO_2e yr^{-1}.

Verra VM0024 Methodology for Coastal Wetland Creation, v1.0

- No project registered

Verra VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v1.0

- 1 project registered (Pakistan)
  - Delta Blue Carbon – 1
    - Estimated Annual Emission Reductions: 2,407,629 Mg CO_2e yr^{-1}
- 1 project under validation (China)
  - Mangrove restoration project in Wenchang and Changjiang, Hainan
    - Estimated Annual Emission Reductions: 4,672 Mg CO_2e yr^{-1}.
- 4 projects under development (2 Mexico, 1 Saudi Arabia, 1 US)
  - Virginia Coast Reserve Seagrass Restoration Project
    - Estimated Annual Emission Reductions: 1,349Mg CO_2e yr^{-1}.

	○ Abu Ali Island Mangrove Planting Project - Eastern Province Saudi Arabia ▪ Estimated Annual Emission Reductions: 1,627 Mg CO_2e yr^{-1}. ○ Restoring Mangroves in Mexico's Blue Carbon Ecosystems ▪ Estimated Annual Emission Reductions: 868,302 Mg CO_2e yr^{-1}. ○ Bonos Del Jaguar Azul (Mexico) ▪ Estimated Annual Emission Reductions: 48,518 Mg CO_2e yr^{-1}. ▪ The Blue Carbon Project Bonos del Jaguar Azul is the first project in México to be developed for mangroves under VCS program. It is a project which includes in its expansion region all the mangrove and tropical dry forests located in the Yucatan Peninsula,in the Mexican Caribbean. **Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v.1** • No project registered *Compliance* **CDM AR-AM0014: Afforestation and reforestation of degraded mangrove habitats, v. 3.** • No project registered **CDM AR-AMS0003: Afforestation and reforestation project activities implemented on wetlands, v. 3.0** • 1 project registered (Senegal) ○ Oceanium Mangrove Restoration Project (Senegal) ▪ Estimated emission reductions: 2,704 Mg CO_2e yr^{-1}. ▪ The proposed small-scale A/R CDM project activity plans to establish over the period 2008 – 2009 1,700 ha of mangrove plantations on currently degraded wetlands in the Sine Saloum and Casamance deltas, Senegal
Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage,	*Voluntary* **Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements **Verra VM0024 Methodology for Coastal Wetland Creation, v1.0** • Grouped projects are permitted under this protocol. If grouped project are developed, the following items must be provided by the project proponent: A list and descriptions of all enrolled project activity instances in the group at the time of validation; A map of the designated

additionality, etc. within any existing or proposed market?	geographic area within which all project activity instances in the group may be located, indicating that all instances are in the same region; a list of eligibility criteria for project activity instances. **Verra VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v1.0** • Aggregation permitted under this protocol **Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v.1** • Supports a landscape approach but has stated that REDD+ approaches have many challenges *Compliance* **CDM AR-AM0014: Afforestation and reforestation of degraded mangrove habitats, v.3** • Allows aggregation of projects. Refers as "Programme of Activities (PoA)." Once PoA is registered, an unlimited number of component project activities (CPAs) can be added without undergoing the complete CDM project cycle. **CDM AR-AMS0003: Afforestation and reforestation project activities implemented on wetlands, v.3** • Allows aggregation of projects. Refers as "Programme of Activities (PoA)." Once PoA is registered, an unlimited number of component project activities (CPAs) can be added without undergoing the complete CDM project cycle.
Is there controversy surrounding the markets or credits for the pathway/practice? Why?	General comment: Yes, there is controversy surrounding coastal blue C markets, but they vary by system. In a general sense, monitoring and verification is the largest technical hurdle. This is probably followed by complex regulatory or governance mechanisms, including but not limited to property rights. Effects from climate change such as sea level rise, changes in precipitation patterns, and runoff cast doubt on the longevity of sequestered C and further whether systems can maintain relative height or recolonize to higher elevations. Accommodation for coastal squeeze will largely determine whether these systems increase or decrease in overall extent. Concerns about equity and distribution of benefits are common themes and concerns. Additionality must be addressed with the establishment of in situ baselines that consider CO_2 as well as other greenhouse gases. Finally, allochthonous (from outside) C accounting is still a major concern for mangroves, seagrass beds, and marshes as much of the stored C comes from outside sources. Specific concerns and sources of uncertainty for each the systems include: *Mangroves* • Social/equity considerations, durability of C storage in face of climate change and human development patterns, unaccounted-for methane and N_2O emissions, system-to-system heterogeneity surrounding both storage and sequestration.

	Seagrass • Poor understanding of the heterogeneity of air-sea CO_2 exchange above seagrass beds, extreme heterogeneity in system trophic status, poor performance of restoration efforts, allochthonous C, monitoring accuracy. *Coral Reefs* • Reefs do not fundamentally sequester C on climactically relevant timescales, longevity/resilience. *Salt Marshes* • Allochthonous C accounting, monitoring, durability of C storage in face of climate change and human development patterns, unaccounted-for methane and N_2O emissions, system-to-system heterogeneity surrounding both storage and sequestration.

Croplands: *Enhanced mineral weathering (EMW), Microbial amendments, Biochar amendments, Compost amendments, Cover cropping, Reduced/no till and crop rotations & Conversion/restoration of annual crops to perennial vegetation or crops*

Croplands, here defined as land used for cultivation of crops, cover 15.6×10^6 km^2 globally, as of 2019 (FAOSTAT, 2020). The global carbon (C) stock stored in cropland soils is estimated to be ~130-140 Pg C in the top 30 cm of soil (Sanderman et al., 2017; Zomer et al., 2017). Given a stock of 140 Pg C, Zomer et al.(2017) estimate a global average of 81.6 Mg C ha^{-1}.[7] However, this per hectare estimate is highly variable across landscapes and depends on soil type, climate, topography and previous and current land use and management.

Cropland soils have been a net source of C to the atmosphere, with rates of C loss increasing dramatically over the past 200 years (Sanderman et al., 2017). The global C debt due to agriculture (focusing only cropland) is 9.6 Pg C for the top 30 cm soil (Sanderman et al., 2017). This degradation means that cropland soils are thought to have C sequestration maximum theoretical potential up to the amount of SOC lost from human activity (Lal, 2018). When determining C storage potential for soils, it is important to identify soils that have lost more SOC from cultivation (these are likely to be farther from C saturation).

Certain management practices can mitigate SOC losses and store new soil C on croplands, and/or mitigate other GHG (such as nitrous oxide, N_2O) losses. These practices may include reduced and no-tillage, retaining crop residues, cover cropping, diverse crop rotations, and fertilizer management, among others (Smith et al., 2008; Paustian et al., 2016). The most productive mitigation options include conversion of croplands to perennial vegetation or avoided conversion of wetlands, peatlands, grasslands, and forests. Sanderman et al., (2017) estimate that 1.47 to 5.14 Pg CO_2 yr^{-1} can be recaptured in agricultural soil, though realistically it may be less due to the social, economic, and technical constraints of adopting Best Management Practices (BMPs). Other sources estimate that cropland soils, specifically, could sequester between 1.84 – 6.79 Pg CO_2 yr^{-1} (Zomer et al., 2017; Lal, 2018).

However, there are critical knowledge gaps, such as a lack of data on the spatial and temporal patterns of SOC across agricultural landscapes, that have contributed to high uncertainty in our ability to understand the carbon storage potential of cropland soils (Smith et al., 2020). There are ongoing efforts to increase standardization of soil metrics and improve our understanding of carbon sequestration potential on working agricultural landscapes. Despite these knowledge gaps, markets for cropland soil carbon credits have grown. This growth has led to the creation of different protocols for cropland soil carbon credits, all varying in methodology and rigor. Organizations such as Verra, Gold Standard, Climate Action Reserve, FAO, and various countries, have all created different carbon crediting protocols for cropland soil carbon credits, further detailed below.

[7] Zomer et al. (2017) use a different but comparable estimate for cropland area (15.9×10^6 km^2) than FAOSTAT (15.6×10^6 km^2). Zomer et al.'s estimate comes from the Global Land Cover SHARE Beta-Release v1.0 (GLC_SHARE) fractional landcover geospatial database, while FAOSTAT uses Land Use, Irrigation and Agricultural Practices FAO Questionnaire, http://www.fao.org/food-agriculture-statistics/data-collection/en/, sent annually to 204 countries and territories.

Cropland Soils

Global Areal Extent: 15.6×10^6 km^2 in 2019 (1.56×10^9 ha) (FAOSTAT, 2020)
Note: This estimate is comprised of arable land (1.39×10^9 ha) and permanent crops (nearly 1.7×10^8 ha).

C Sequestration Potential	
How much C is currently stored (globally) in the system (total and on average per hectare)?	Global stock: ~ 130 - 140 Pg C in top 30 cm (Sanderman et al., 2017; Zomer et al., 2017) Average per hectare: ~ 81.6 Mg C ha^{-1} (Zomer et al., 2017), however this number is highly variable across landscapes as it and depends on soil type, climate, topography, and previous and current land use and management
At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	• Cropland has been C source. The top 30 cm of the world's cropland soils have lost an estimated 9.6 Pg C (6.8% of the current stock) due to agriculture (Sanderman et al., 2017). Rate of loss has increased dramatically over the past 200 years. • While continuing conversions of forests, wetlands and grasslands to cropland are C sources, most cropland soils that stay cropland are C sinks (at least for the U.S.). The EPA GHG inventory estimates that cropland soils that remained cropland in the U.S. experienced net drawdown of 16.6 Tg CO_2 yr^{-1} as of 2018. This number is a modelled estimate from the process biogeochemical model Daycent.

Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	• Best management practices (BMPs), such as reduced and no-tillage*****, retaining crop residues, cover cropping, diverse crop rotations, can show improvement in SOC levels, compared to conventional practices (Paustian et al., 2016). While mitigation potential of these practices is somewhat controversial, the adoption of BMPs have been shown to reduce emissions compared to a business-as-usual approach (Sanderman and Baldock, 2010). **Note: No- and reduced-till can be a somewhat controversial carbon sequestration practice, as the effects of no-till on SOC are primarily found in the topsoil. SOC gains found under reduced and no-till for the whole soil profile are typically much smaller than the SOC gains found at more shallow soil depths (0 – 30 cm)* (Franzluebbers and Stuedemann, 2013; Ogle et al., 2019; Xiao et al., 2020; Slessarev et al., 2021). • When considering BMPs, it is important to identify soils that are farther from C saturation. Cropland soils have high SOC potential because they have typically been affected by various degradation processes (Lal, 2018). • The most productive mitigation options are conversion to perennial vegetation either left unmanaged or sustainably harvested and avoided conversion of wetlands, peatlands, grasslands, and forests to cropland (Paustian et al., 2016). • Practices that increase C inputs to the soil include planting species with greater root mass to deposit C in deeper layers where turnover is slower, adopting crop rotations that provide greater C inputs, growing cover crops during fallow periods to provide increased C inputs, and adding carbon-rich amendments, such as compost and biochar, to soil (Paustian et al., 2016). o Biochar amendments may be an effective natural climate solution. The main mechanism is via reduced decomposition rates of biochar C relative to unpyrolyzed feedstocks, but other reductions in GHGs are also possible depending on the full biochar system. Current estimates of global mitigation potential range from 0.3 – 10.3 $PgCO_2e\ yr^{-1}$, depending on the source and availability of biochar feedstocks, the amount and type of land allocated to biochar production, and whether carbon capture and storage (CCS) is employed during biochar production (Griscom et al., 2017; Fuss et al., 2018; Lehmann et al., 2021; Roe et al., 2021) (Fuss et al., 2018; Lehmann et al., 2021). Furthermore, most of these estimates are not limited to cropland (Blanco-Canqui et al., 2020) Griscom et al. (2017) find that biochar additions to soil offer the largest maximum mitigation potential among the agricultural pathways they examined, but this approach has not been well demonstrated beyond research settings. Biochar is also currently too expensive for the average farmer to apply; economic returns to the farmer are currently not enough to justify its application (Vochozka et al., 2016; Latawiec et al., 2019). o Compost and manure amendments can increase soil C through the amendment itself and by improving soil physical attributes and nutrient availability. However, it can be difficult to quantify the impact of these amendments because they typically come from off-site locations and therefore do not directly reflect on-farm CO_2 uptake from the atmosphere (Paustian et al., 2019). Furthermore, the mitigation potential of compost may lie primarily in avoided C losses from anaerobic respiration in landfills, rather than direct enhancement of soil C pools (DeLonge et al., 2013; Paustian et al., 2019). • Although enhanced mineral weathering (EMW) on croplands is at early stages of research and development, there is evidence that adding rock dust to croplands can remove CO_2 from the atmosphere. Beerling et al. (2018) state that EMW could potentially extract 0.5–4 Pg CO_2 yr^{-1} by 2100 depending on climate, soil and crop type., although this estimate does not account for a full life cycle assessment. A more recent

	study by Beerling et al., (2020) finds that EMW on croplands in China, India, U.S., and Brazil has the potential to extract 0.5 – 2 Pg CO_2 yr^{-1}, costing approximately USD 80 – 180 Mg^{-1} CO_2. However, EMW amendments are controversial as emissions associated with the production and transportation of EMW products may exceed their carbon uptake abilities (Schlesinger and Amundson, 2019). As such, the mitigation potential of EMW is highly uncertain. • Presently, there is limited literature on microbial soil amendments and their effect on carbon sequestration. However, research has shown that soil organisms play an important role in nutrient cycling and carbon uptake, particularly following restoration of abandoned agricultural fields (Morriën et al., 2017). Active microbial communities are important for SOC stabilization, so manipulations that enhance microbial communities may promote C sequestration in soils (Jastrow et al., 2007).
What is the range of estimates for how much additional C could be sequestered globally?	• The global sink potential is estimated at ~116 Pg C, or 425.72 Pg CO_2, assuming the maximum global sink potential is the amount lost. However, sequestration below 30 cm (a typical root depth) is challenging and soil C changes slowly. Using bottom-up estimates of the maximum biophysical potential per unit area, extending to all global crop and grazing land, *and* assuming SOC reaches a new steady state in 20 years, only 29.36 to 102.76 Pg CO_2 can be recaptured. Realistically, even this is an over-estimation due to social, economic, and technical constraint on adoption of BMPs (Sanderman et al., 2017). • Zomer et al. (2017) estimate that croplands worldwide could sequester between 3.30 and 6.79 Pg CO_2 yr^{-1} (0.56 to 1.15 Mg C ha^{-1} yr^{-1}) for at least 20 years if the SOC content in the 0–30 cm depth layer if SOC in all available cropland increased by 0.27% to 0.54% (or 0.012 to 0.027% annual increase, a medium to high scenario). Zomer et al.'s estimate is higher than those from other studies, listed below. • A systematic review by Fuss et al. (2018) assessed the technical potential of soil carbon sequestration to be 1.5-3 Pg CO_2 yr^{-1} for croplands • Lal (2018) estimates that the global potential of SOC sequestration on cropland is 1.84 – 4.40 Pg CO_2 yr^{-1} at a rate of 0.92 – 3.67 Mg CO_2 ha^{-1} yr^{-1} • Other studies have estimated lower rates closer to 1.17 Mg CO_2 ha^{-1} yr^{-1} with implementation of cover cropping (Poeplau and Don, 2015; Bossio et al., 2020). The global mitigation potential of cover crops may be between 0.37 – 0.44 Pg CO_2e yr^{-1} (Poeplau and Don, 2015; Griscom et al., 2017; Bossio et al., 2020). • Although reduced and no-till practices are controversial for the reasons stated above, there have been several attempts to quantify the mitigation potential of no-till. Roe et al.(2021) estimate the technical potential of no-till at 1.02 Pg CO_2 yr^{-1} (over 30 years, 2020-2050), however, this estimate assumes that all cropland is under conventional till and shifts to no-till with an input scenario consistent with cover cropping. Powlson et al. (2014) present a more realistic estimate of 0.4 - 0.6 Pg CO_2 yr^{-1}, however they still identify major limitations and uncertainties regarding the impact and degree of adoption of no-till, and conclude that the true impact of no-till will likely only be a fraction of their reported estimate. • A synthesis by Conant et al. (2017) found that conversion of annual cropland to permanent vegetation resulted in a 39% increase in C stocks, with an average rate of 3.30 Mg CO_2 ha^{-1} yr^{-1}

	• Most of the studies cited in this section employ bottom-up calculations, in which the sequestration rates of C promoting practices are multiplied by the potential area over which the practices can be applied, or estimate potential soil C gains based on partial recovery of soil C that has been lost due to human activity. However, a new study by Janzen et al. (2022) proposes that management induced gains in soil C can be estimated from amounts of photosynthetically-derived C available to replenish soil organic matter as an alternative to the aforementioned approaches. Their results suggest a maximum C input rate into the lingering SOC *pool* (C pool that remains in the soil long enough to "serve as a lasting repository of C derived from atmospheric CO_2") of 0.44 Pg C yr^{-1}, and a maximum net sequestration rate of 0.51 Pg CO_2 yr^{-1} (0.14 Pg C yr^{-1}), which is much less than estimates derived from previous studies. • Maximum carbon sequestration potential biochar: 1.034 Pg CO_2 yr^{-1} (Nature4Climate, 2022) • Cost-effective ($100 USD/ton CO_2e) carbon sequestration potential biochar: 0.287 Pg CO_2 yr^{-1} (Nature4Climate, 2022)
How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that?	• Lack of confidence and uncertainty in our ability to detect changes in cropland soil C sequestration (Oldfield et al., 2021): o Although the methodology for relatively accurate and precise measurement of SOC is understood, it is intensive and expensive to do so and change detection is only likely over multiple years. We currently have a lack of data on the spatial and temporal patterns of SOC across agricultural landscapes o Long-term datasets often lack a baseline measurement of SOC and bulk density value, which is critical to determining the trajectory of change in SOC o Changes in SOC are small in comparison to the existing stock; it can take a long time before enough SOC has been accrued to be detected o High spatial variability of SOC across a field further hampers detection of SOC changes o Quantifying tradeoffs or unintended consequences (e.g., increasing emissions of GHGs other than CO_2) that result from shifting management practices on agricultural land is difficult. In particular, N_2O emissions constitute an uncertain component of agricultural GHG budgets. Capturing GHG emissions over a landscape and over time is difficult

C Markets	
Is there a market (or proposed market) for carbon credits from the system?	Yes. Mostly voluntary markets exist, and some compliance markets.
Are there protocols (or proposed protocols) for such credits?	*Voluntary* • Climate Action Reserve (CAR) Soil Enrichment Protocol v1.0; non-federal lands in the U.S., U.S. territories, and U.S. tribal lands • Verra VM0042 Methodology for Improved Agricultural Land Management v1.0[b]; international • Verra VM0021 Soil Carbon Quantification Methodology, v1.0[1]; international • Verra VM0017 Adoption of Sustainable Land Management (SALM), v1.0[b,1]; international • Gold Standard Soil Organic Carbon Framework Methodology v1.0; international • FAO GSOC MRV Protocol [b]; international • Carbon Credits (Carbon Farming Initiative— Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination (Australia's Department of Industry, Science, Energy and Resources); Australia • Carbon Credits (Carbon Farming Initiative— Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination (Australia's Department of Industry, Science, Energy and Resources); Australia • Nori Croplands Methodology, v1.2; Continental U.S. • BCarbon Soil Carbon Credit Systems; U.S. private and tribal lands, other countries • Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)[c]; China • CAR is developing a brand-new Biochar Protocol , and Verra is developing a new Methodology for Biochar Utilization in Soil and non-Soil Applications *Compliance* • Quantification Protocol for Conservation Cropping, v1.0 (Government of Alberta, Canada); Alberta, Canada in the Dry Prairie and Parkland ecozones [b] *Protocol applies to cropland soils and agroforestry* [c] *Protocol applies to grassland, cropland, agroforestry, and multiple forest systems*

	[1] *The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) accepts carbon offset projects that use this protocol* *Note: The Panda protocol includes cropland soils, however, we have not been able to verify that the protocol has been approved by the Chinese government, and/or has generated cropland soil credits to date. Additional protocols that cover cropland soils pathways in China may exist, but we have not been able to review all of them due to limited publicly available information.* *Note: Verra has established the Enhanced Weathering and Mineralisation Advisory Group (AG) as a resource to support development of an EWM initiative under VCS*
If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	<u>*Voluntary*</u> **Climate Action Reserve Soil Enrichment Protocol v1.0** • **Permanence:** Commitment of 100 years. If a project does not commit to the 100-year permanence requirement, it will receive fewer credits based on the length of commitment. Credits can be issued as a proportion of the 100-year permanence timeframe achieved. • **Additionality**: Determined by a performance standard test (adopting or stopping practices that impact SOC storage; no additionality for single-practice adoption if practices performed on >50% of cropland/pasture area within a county) and a legal requirement test (practices not required by law) • **Leakage:** Accounts for leakage related to displacement of livestock outside the project area and sustained decline in yields for crops grow in the project area. • **Reversals**: A percentage of credits goes to buffer pool to mitigate risks of unavoidable reversals (e.g., drought, fire, flood) • **Uncertainty**: Uncertainty deduction is the extent to which the margin of error of the average emissions reduction exceeds 15% of the estimated average emissions reduction (considers uncertainty related to modeling and sampling/analysis) **Verra VM0042 Methodology for Improved Agricultural Land Management v1.0** • **Permanence:** Requirement of 30 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** Requires identifying barriers that prevent project activities and demonstrating that the adoption of the of proposed project activities is not common practice • **Leakage:** Accounts for application of manure from outside project area, sustained reductions in crop yields and livestock displacement • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Uncertainty deduction is the extent to which the half width of the 95% confidence interval, as a percentage of the mean, exceeds the threshold of 15%

Verra VM0017 Adoption of Sustainable Land Management (SALM), v1.0

- **Permanence:** Requirement of 30 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool.
- **Additionality:** The project must use the most recent version of the Clean Development Mechanism (CDM) additionality tool to identify the baseline scenario and demonstrate additionality.
- **Leakage**: Accounts for use of fuel wood/fossil fuels from non-renewable sources due to decrease in use of manure and/or residuals that may be transferred to fields through the project.
- **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS AFOLU Non-Permanence Risk Tool.
- **Uncertainty**: Has a 15% uncertainty deduction: If the uncertainty of soil models is less than or equal to 15% of the mean value calculated at the 95% confidence interval, then the project proponent may use the estimated value without any deduction for conservativeness or increase in sampling.

Verra VM0021 Soil Carbon Quantification Methodology, v1.0

- **Permanence:** Requirement of 30 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool.
- **Additionality:** The project must use the most recent version of the Clean Development Mechanism (CDM) additionality tool to identify the baseline scenario and demonstrate additionality.
- **Leakage:** Accounts for livestock displacement and sustained reductions in crop yields.
- **Reversals:** A percentage of credits go to buffer pool. Buffer credits are applied via the VCS AFOLU Non-Permanence Risk Tool.
- **Uncertainty:** The confidence interval for SOC in each stratum cannot exceed +/- 10% with a 90% confidence. Projects must calculate the standard deviation and CI for total carbon for each stratum. Where CI exceeds +/- 10% with 90% confidence, projects can re-stratify and install new monitoring plots and increase the number of plots.

Gold Standard Soil Organic Carbon Framework Methodology v 1.0

- **Permanence:** Permanence required within crediting period (depending on SOC Activity Module, 5 – 20 years).
- **Additionality:** Projects need to demonstrate that they would not have been implemented without the benefits of carbon certification (performance standard test and legal requirement test).

- **Leakage:** Accounts for leakage from shifting crop production to compensate for yield reductions or emissions from increased C runoff.
- **Reversals:** A percentage of credits must be transferred to the Gold Standard Compliance Buffer.
- **Uncertainty:** 20% of the mean at 90% confidence - if >20%, then project will receive an uncertainty deduction (calculated uncertainty - 20%).

FAO GSOC MRV Protocol

- **Permanence:** Projects are planned for a 4-year duration and can be renewed for another 4 years.
- **Additionality:** The project must show improvement over baseline by performing a 20-year SOC simulation.
- **Leakage:** Potential sources of leakage are outlined during the initial project assessment.
- **Reversals:** A 5% risk of reversal discount is applied to all projects.
- **Uncertainty:** Not explicitly addressed. When determining the number of samples to take, the protocol calls for performing a power analysis at an acceptable level of uncertainty.

Carbon Credits (Carbon Farming Initiative— Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination (Australia's Department of Industry, Science, Energy and Resources)

- **Permanence:** 100 years or 25 years; if projects elect for 25 years, then 20% of the carbon credits will be deducted over the crediting period.
- **Additionality**: Requires a "newness" test. Activities must be new or different from practices undertaken in the 10 years prior to registration.
- **Leakage**: Applied amendments must come from within a carbon estimation area (CEA) that is part of the project.
- **Reversals:** A percentage of credits go to a buffer pool; projects must contribute to a risk of reversals buffer (5%).
- **Uncertainty:** Statistical approaches are used to define the level of carbon sequestration associated with a probability of exceedance equal to 60% for a reporting period. The change in soil carbon stock at time 1 is discounted to 50% of the calculated change. Once three or more temporal measurements of equivalent mass soil carbon stocks are completed, a regression approach is used to define the rate of equivalent soil mass carbon stock is changing.

Carbon Credits (Carbon Farming Initiative— Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination (Australia's Department of Industry, Science, Energy and Resources)

- **Permanence:** 100 years or 25 years; if projects elect for 25-year permanence, then 20% of the carbon credits will be deducted over the 25-year project crediting period.
- **Additionality:** Requires a "newness" test. Activities must be new or different from practices undertaken in the 10 years prior to registration; must prove that additional atmospheric emissions will be sequestered.

- **Leakage:** Leakage discount factors are applied for project management activity that involves new irrigation from a water access entitlement or an irrigation right (0.75 of the sequestration value).
- **Reversals:** If a practice is stopped within a carbon estimation area (CEA), a "depletion event" has taken place. If a project activity has stopped, estimated SOC stocks are taken to reverse at an annual rate of 1/7 of the total sequestration achieved for the relevant CEA.
- **Uncertainty:** Uncertainty associated with activity data and the model was determined using a Monte Carlo analysis, in conjunction with the IPCC Approach 1 propagation of error method outlined in the IPCC inventory guidelines.

Nori Croplands Methodology, v1.2

- **Permanence:** 10 years. Suppliers are required to report operating data to prove C retention for 10 years from the date of Nori Carbon Removal Tonnes (NRT) issuance.
- **Additionality:** Project activities must show improvement in carbon sequestration over baseline scenario.
- **Leakage:** The carbon removal claim verification process will establish whether the incremental SOC stock gains realized within the project boundaries directly result in SOC stock losses outside the boundaries.
- **Reversals:** Restricted tokens are used to account for any deliberate reversals.
- **Uncertainty:** Restricted tokens are currently being issued to the supplier to account for any uncertainty or intentional release of carbon. This will eventually change so that the price of NRTs depends on levels of uncertainty and risk of reversal within 10 years -- each NRT will receive a score that reflects a combination of estimation error, risk the recovered C will not be retained in the soil for at least 10 years, and other factors that contribute to uncertainty that the NRT truly represents 1 Mg CO_2e removed from the atmosphere and that the recovered C is retained in U.S. cropland soils for at least 10 years.

BCarbon Soil Carbon Credit Systems

- **Permanence:** 10 years required, which is renewable each subsequent year when new credits are issued.
- **Additionality:** Credits are only awarded for carbon dioxide removed from the atmosphere and stored in the soil. Therefore, it is additional to the year prior to initiation of testing.
- **Leakage:** Leakage is addressed by a life cycle assessment principle that is under development. Principle says that any increase in the life cycle emissions must be deducted.
- **Reversals:** 10% of credits go to the buffer pool for land conversion or subsurface soil disturbance.
- **Uncertainty:** No deduction of credits if 90% or greater statistical accuracy; deduction for greater variability based upon "difference between the means" statistical approach.

Panda Standard Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)

- **Permanence**: Minimum project term varies with the type of project; Project generating net C sequestration (or GHG removals) have a minimum project term of 30 years; Project generating net emission reductions have a minimum project term of 20 years; Project generating net irreversible net GHG emission reductions have a minimum project term of 5 years. Project Proponents must conduct a risk assessment using the Panda Standard Risk Analysis Tool. The result of the Risk Assessment is an overall risk category for the Project, translating into a percentage or number of PS Credits that must be deposited into the Panda Buffer Pool.
- **Reversals:** A percentage of credits go to a buffer pool (Panda buffer pool). 2 options to mitigate risk:
    - **Option 1**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, this percentage of offsets from the Project itself for deposit to the Panda Buffer Pool";
    - **Option 2**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, the number of PS credits of any type and vintage that equates to the percentage drawn from the risk assessment". Percentage of contribution to buffer pool is not explicitly stated.
- **Leakage:** Accounting for activity shifting required. Any leakage identified must be quantified and subtracted from the net emission reduction/removal benefits except when leakage arises from the creation of poles and fencing to implement Project Activities • Fossil fuel combustion resulting from ground transportation. Leakage accounting might also be omitted if the following criteria are met: Displacement of baseline activities occurs on less than an average of 5% of the land area for a given project activity during the crediting period • Total quantity of a given good/commodity (e.g. lumber, crop, fuelwood, grazing animal) supplied to market in the project scenario for a given project activity is reduced by less than 20% of in comparison to the Baseline during the crediting period • All Leakage emissions are estimated to be below the de minimis threshold on average during the crediting period. Accounting for market leakage is not required if the following conditions are satisfied:
    - 1) Average quantity of a given good/commodity supplied to market in the with-Project Scenario for a given Project Activity is reduced by less than 20% in comparison to the Baseline.
    - 2) Average quantity of a given good/commodity in the Baseline per year supplied to market is less than 5% of total commodity produced per year within the PRC Prefecture (s) where the Project is taking place.
- **Additionality**: Additionality can be demonstrated using 2 approaches:
    - **Three-prong approach**: The project activity must meet the following criteria: a. Complies with regulatory requirements b. Exceeds common practice c. Faces investment, technological or institutional barriers);
    - **Performance standard approach** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice)).
- **Uncertainty:** If the 90% confidence interval is greater than 10% of the mean the reportable amount must include an uncertainty deduction. The uncertainty deduction shall be equal to the calculated % of the mean represented by the confidence interval minus the allowable 10%

	Compliance **Quantification Protocol for Conservation Cropping, v1.0 (Government of Alberta, Canada)** • **Permanence:** Requirement of 20 years • **Additionality:** Uses Western Climate Initiative (WCI) proportional additionality approach for sequestration projects. Eligible project must be new and additional to business as usual. Sequestration coefficient discounted according to observed rate of increase in adoption of no-till. • **Leakage:** Based on ISO 14064:2 - activity shifts deemed minimal. • **Reversals:** Each offset is discounted by a percentage specific to the region containing project in Alberta. This fraction is set aside in a reserve to protect against soil carbon lost to the atmosphere. • **Uncertainty:** Not explicitly addressed, but uncertainty is accounted for in the estimation of sequestration coefficients

If there are protocols, have there been any registered projects or credits generated? If so, where?	*Voluntary*
	Climate Action Reserve Soil Enrichment Protocol v 1.0
	• 2 projects registered (2 US)
	  ○ Total credits issued: 18,966
	
	Verra VM0042 Methodology for Improved Agricultural Land Management v 1.0
	• 6 projects registered (1 Argentina, 3 China, 1 UK, 1, India)
	  ○ Total credits issued: 0
	• 18 projects under development (South Africa)
	• 3 projects registration and verification approval requested (1 India, 1 Mexico, 1 South-Africa)
	• 1 project, involving cropland to perennial conversion,under validation in Italy
	
	Verra VM0017 Adoption of Sustainable Land Management (SALM), v 1.0
	• 2 projects registered (1 Kenya, 1 India)
	  ○ Total credits issued: 325,825
	• 15 projects under development (13 India, 1 Brazil, 1 Zambia)
	• 2 projects under validation (1 Kenya, 1 Zambia)
	• 2 projects rejected (2 New Zealand)
	• 4 projects registration requested (2 India, 1 Kenya, 1 Mozambique)
	
	Verra VM0021 Soil Carbon Quantification Methodology, v 1.0
	• Earth Partners and Shepherds Grain have piloted the methodology on 7×10^6 acres in the Palouse and Columbia Plateau region (Washington).
	• 1 project under validation (Brazil)
	
	Gold Standard Soil Organic Carbon Framework Methodology v 1.0
	• No, just published in 2020
	
	FAO GSOC MRV Protocol
	• 8 agricultural companies in the Pampas and NW Argentina have registered a project, covering about 50,000 hectares.
	• Have not generated credits yet

	Carbon Credits (Carbon Farming Initiative— Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination (Australia's Department of Industry, Science, Energy and Resources) • 125 projects registered in Australia only. • 1 project has generated and sold credits (note: this is for improved grassland management). **Carbon Credits (Carbon Farming Initiative— Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination (Australia's Department of Industry, Science, Energy and Resources)** • Limited likely because it is restricted to more specific activities and conservative sequestration rates **Nori Croplands Methodology, v 1.2** • Pilot project currently underway for Iowa crop and cattle farmer – project still requires verification but projected 19,000 NRTs. • Maryland corn, wheat, and soybean farmer: 14,010.6 NRTs issued and sold. • Enrolled projects in Kansas, Illinois, Indiana, Iowa, Maryland, Nebraska, Wisconsin. **BCarbon Soil Carbon Credit Systems** • No credits issued yet – have guaranteed they can sell 70,000 Mg - 60,000 in U.S., 10,000 in United Kingdom with 20,000 more under discussion **Panda Standard Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • Unable to locate the registry *Compliance* **Quantification Protocol for Conservation Cropping, version 1.0** (Government of Alberta, Canada) • Conservation tillage offsets through adoption of this protocol have delivered over 17×10^6 Mg of offsets since 2007. *Note: Despite the absence of MRV methodologies/protocols for the Cropland enhanced mineral weathering amendments pathway, carbon credits have been sold for that pathway.*

Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc. within any existing or proposed market?	*Voluntary* **Climate Action Reserve Soil Enrichment Protocol v 1.0** • Aggregation of projects into larger units allowed **Verra VM0042 Methodology for Improved Agricultural Land Management v 1.0** • Aggregation of projects into larger units allowed **Verra VM0017 Adoption of Sustainable Land Management (SALM), v 1.0** • Aggregation of projects into larger units allowed. Projects may contain more than one discrete area of land. **Verra VM0021 Soil Carbon Quantification Methodology, v 1.0** • Aggregation of projects into larger units allowed. Projects may contain more than one discrete area of land. **Gold Standard Soil Organic Carbon Framework Methodology v 1.0** • Yes, aggregation of projects into larger units allowed. **FAO GSOC MRV Protocol** • Aggregation of projects into larger units allowed **Carbon Credits (Carbon Farming Initiative— Measurement of Soil Carbon Sequestration in Agricultural Systems) Methodology Determination (Australia's Department of Industry, Science, Energy and Resources)** • Yes, projects can contain one more carbon estimation area (CEA) **Carbon Credits (Carbon Farming Initiative— Estimating Sequestration of Carbon in Soil Using Default Values) Methodology Determination (Australia's Department of Industry, Science, Energy and Resources)** • Aggregation of projects into larger units allowed **Nori Croplands Methodology, v 1.2** • Projects may encompass fields or the whole farm and multiple fields and/or farms can join together to aggregate into a larger project. **BCarbon Soil Carbon Credit Systems** • Aggregation of projects into larger units allowed only if tracts are similar and testing is accomplished in a manner that is representative of all tracts.

	Panda Standard Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU) • Not specified in protocol *Compliance* **Quantification Protocol for Conservation Cropping, version 1.0 (Government of Alberta, Canada)** • The market relies on aggregator companies, which aggregate credits from different sources (groups of farmers or land holders) to assemble projects large enough to attract buyers *Note: Aggregation is allowed in most protocols, but typically not required. Aggregation of projects (as currently allowed) is more focused on achieving an economy of scale for project developers rather than enabling better accounting of additionality and leakage. The bounds of aggregation are not defined and whether it makes sense to do so will likely be up to the crediting organization*
Is there controversy surrounding the markets or credits for the NCS pathway? Why?	*Yes, concerns related to:* • Additionality: Farmers may be getting paid for carbon they would've been storing without payments, which is not considered additional (Johnson and Kempe, 2021). • Accurate estimation: Need to account for soil depth and uncertainty in modeled projections. Also, field measurements should support remote sensing and model estimations, but some protocols don't require field measurements (Slessarev et al., 2021; Simmons et al., 2021). • Leakage: Carbon benefits of a particular practice may be negated through leakage (Ranganathan et al., 2020). • Permanence and reversal issues: SOC is very vulnerable (Ranganathan et al., 2020; Bottemiller Evich and McCrimmon, 2021). *Additional market-side concerns* • The price of carbon needs to increase encourage participation and momentum in markets. However, it's unclear how much the price of carbon can go up if the market relies primarily on demand from corporations that make voluntary emissions reductions pledges. C markets will need regulation (Bottemiller Evich and McCrimmon, 2021).

Freshwater Wetlands: *Restoration & Avoided conversion and degradation*

Freshwater wetlands[8] cover around 5.7×10^6 km^2 globally (includes bogs, fens, swamps, marshes, floodplains, and shallow lakes), though estimates vary (Matthews and Fung, 1987; Aselmann and Crutzen, 1989). Several efforts have been made to map global and regional wetland area, however, there is currently no consensus on wetland extent and estimates vary by an order of magnitude (Hu et al., 2017; Davidson et al., 2018; Pickens et al., 2020). Freshwater wetlands typically have a dissolved salt concentration measuring less than 0.5 ppt (Cowardin and U. S. Fish and Wildlife Service, 1979).Though peatlands (pg. XX) are technically under the umbrella of freshwater wetlands, they are considered in a separate section here because they are an especially large C sink and have different C dynamics than non-peatland freshwater wetlands (Charman, 2009; Villa and Bernal, 2018). Freshwater wetlands are also considered separately from saltwater/tidal wetlands, as these wetlands fall under the commonly used term "coastal blue carbon" and their biogeochemistry is controlled by salinity and tides.

Estimates of global C stocks for freshwater wetlands are difficult to find since most estimates include peatland carbon, which comprises a significant portion of total wetland carbon stocks. Estimates of soil C in global wetlands (all wetlands, not just freshwater) range from 202 to 535 Pg C (Mitra et al., 2005). This wide range of estimates is impacted by diverging definitions of wetlands and the use of global averages that have high variability. In the U.S., mineral-soil freshwater inland wetlands are estimated to store 2.45 ± 0.14 Pg C in the 0-100 cm depth (Nahlik and Fennessy, 2016). Villa & Bernal, (2018) estimate that the combined above- and below-ground C pools in all temperate and tropical freshwater wetlands are somewhere around 750 Mg C ha^{-1} (this estimate also includes tropical peatlands and most of this pool is belowground soil carbon not including roots).[9]

Freshwater wetlands have the potential to act as both a C sink and source. Although they are often highly productive systems and tend to be substantial sinks of CO2, they can exhibit positive radiative forcing (a warming effect), because of their production of methane (CH4) and other greenhouse gases such as nitrous oxide (N2O) (Mitsch & Mander, 2018; Moomaw et al., 2018; Taillardat et al., 2020). Research has shown that their ability to act as sources or sinks depends on the timescale being considered. Over long time periods (centuries to millennia), freshwater wetlands are thought to have a net cooling effect, acting as a sink. Over shorter time periods, they may act as a source of positive radiative forcing, especially under pressures from climate change and land-use conversion (e.g., draining wetlands for agriculture and forestry) (Moomaw et al., 2018; Neubauer & Megonigal, 2015).

Restoration, often of hydrology and vegetation, and avoided conversion are the two major NCS pathways for freshwater wetlands. For freshwater wetland restoration, studies have generally found that wetlands are net sources at first, but then become net C sinks after some time. The

[8] We recognize that wetlands and peatlands are typically studied together; however, at the time of this writing, existing protocols separate them, so they are analyzed separately in this paper.

[9] *This number is not exact and should not be referenced as such. It is an estimate from a graph that does not provide exact numbers. Authors calculated this this C stock by subtracting coastal wetland and northern peatland carbon stock and area from global estimates of wetland C stock and area found in* (Gorham, 1991; Mitra et al., 2005; Zedler and Kercher, 2005).

amount of time it takes for restored wetlands to become a sink varies widely and is explored in the associated table (Whiting and Chanton, 2001; Petrescu et al., 2015; Valach et al., 2021). This "lag" in becoming a source to sink brings into question the "creditable" sequestration benefit of freshwater wetlands, since carbon crediting usually occurs on shorter time frames (generally 100 years or less) (Petrescu et al., 2015). Conversion of freshwater wetlands results in loss of soil organic matter, resulting in increased CO_2 emissions. Resulting methane emissions from conversion depend on the new land use and legacy emissions from wetland degradation. Thus, the radiative forcing from wetland conversion ultimately depends on relative changes in the direction and magnitude of CO_2 and CH_4 (Moomaw et al., 2018). However, Petrescu et al. (2015) found that most converted wetlands have a positive radiative forcing.

Global estimates for how much additional C could be sequestered by freshwater wetlands through restoration and/or avoided degradation/conversion, specifically, are lacking. Griscom et al. (2017) included only peatlands (here treated separately, see pg. XX) in their freshwater wetland assessment. The associated table presents a few regional estimates. Confidence in methods to detect changes in net C sequestration in freshwater wetlands is impacted by the way in which methane emissions are accounted for in net C sequestration calculations. These issues are described in detail below. Furthermore, short term observations of C fluxes may not provide an accurate picture of long-term C dynamics. As a result of these methodological uncertainties, freshwater wetlands have not been extensively considered in C markets and climate mitigation policies (Villa and Bernal, 2018). Our research has only elucidated two C market protocols that include freshwater wetlands, to date (note: there are a number of methodologies for peatlands which are covered in the Peatlands Table): American Carbon Registry's (ACR) Restoration of California Deltaic and Coastal Wetlands Methodology and Verra VM0007 REDD+ Methodology Framework (REDD+MF). There have been no registered projects for freshwater wetlands with Verra' protocol. ACR's protocol has one project with 59,552 registered credits in the Western Sacramento San-Joaquin Delta.

Freshwater Wetlands Summary

Global Areal Extent: Between 5.3 and 5.7 × 10^6 km^2 (Matthews and Fung, 1987; Aselmann and Crutzen, 1989; Zedler and Kercher, 2005); this estimate includes peatlands

Note: these are old estimates; it is difficult to find more current estimates for areal extent of freshwater wetlands. Furthermore, there is currently there is no commonly accepted figure available for areal extent of currently extant global wetlands due to the difference in datasets used to make estimations (e.g., remote sensing, aggregating inventories and individual observations, and simulated datasets based on hydrological models (Huff et al., 2017; Hu et al., 2017)

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?	• Global estimates for C stocks of freshwater wetlands are difficult to find. Most of the literature on wetlands as climate solutions focuses on coastal wetlands and estimates for freshwater wetlands often include peatlands • Estimates of soil C in *global wetlands* (all wetlands, not just freshwater) range from 202 to 535 Pg C (Mitra et al., 2005). This wide range of estimates is impacted by the high variability between wetland types. In the U.S., mineral-soil freshwater inland wetlands are estimated to store 2.45 ± 0.14 Pg C in the 0-100 cm depth (Nahlik and Fennessy, 2016). • Villa & Bernal (2018) estimate that the combined above- and below-ground C pools in all temperate and tropical freshwater wetlands are somewhere around 750Mg C ha^{-1} *** (**most of this pool is belowground and includes peatlands, which constitutes a significant portion of overall stock). The authors note that while this is a large C pool, "there are no accurate global estimates per wetland class within this category that can be compared to global C pool estimates of mangroves, saltmarshes, and boreal peatlands." ***** *This number is not exact and should not be referenced as such. It is an estimate from a graph that does not provide exact numbers. Authors calculated this this C stock by subtracting coastal wetland and northern peatland carbon stock and area from global estimates of wetland C stock and area found in Gorham, 1991; Mitra et al., 2005; Zedler & Kercher, 2005*

At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	• Overall, wetlands are key C sinks (Villa and Bernal, 2018). Mitsch et al. (2013) calculated that all wetlands globally have the potential to sequester 4,697 Tg CO_2 yr^{-1} • However, the C balance in freshwater inland wetlands is poorly understood (Mitsch and Mander, 2018), as freshwater wetlands can act as both a sink and source of radiative forcing (Villa and Bernal, 2018). For example, although freshwater tree-dominated wetlands have, on average, very high C sequestration rates, they also have high methane emissions (Villa and Bernal, 2018).Taillardat et al. (2020) find that although freshwater marshes were the strongest C sink in terms of C unit and the most productive wetland types, they had net positive radiative forcing over a 100 year timeframe. These complexities make it difficult to determine whether freshwater wetlands can act as a *net* C sink, particularly at shorter time scales. • In the long term (century-millennia), research suggests that C sequestration in wetlands has a net cooling effect, acting as a sink (Neubauer and Megonigal, 2015; Moomaw et al., 2018). • Villa & Bernal (2018) estimated mean C sequestration rates in different wetland types based on data from 110 different studies. C sequestration rate is determined as the product of bulk density, soil C concentration, and accretion rate. In permanent freshwater marshes the sequestration rate is 447.74 g CO_2 m^{-2} yr^{-1} and in freshwater, tree dominated wetlands, the rate is 645.92 g CO_2 m^{-2} yr^{-1}. However, as mentioned above, the actual freshwater wetland sink capacity depends on the net balance of its C fluxes • A meta-analysis by Lu et al. (2017) that used data from 143 eddy covariance sites around the globe found that inland wetlands were small CO_2 sinks or nearly CO_2 neutral, while coastal wetlands provided large CO_2 sinks • Increased atmospheric CO_2 is projected to almost double current freshwater wetland CH_4 emissions (Shindell et al., 2004). Land use and climate mediated changes in CH_4 emissions from freshwater wetlands can produce a large increase in radiative forcing for decades to several centuries, and may even potentially negate their ability to act as a long-term sink (Moomaw et al., 2018)
Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	Two major pathways for wetlands as a natural climate solution are restoration and avoided conversion. *Restoration* • Limpert et al. (2020) found that total C emissions (CO_2 & CH_4) were reduced within a semi-arid freshwater floodplain wetland during and after rewetting due to increasing vegetative growth and increased anoxic levels • Valach et al. (2021) found that the magnitude of C sequestration in California deltaic wetlands representing a range of restoration stages (3 to 23 years) depended on restoration methods and site conditions, such as bathymetry-determined water levels, planting methods, and soil nutrients. Most sites became a net sink after 2 years of restoration. However, sites with rapidly expanding vegetation were consistent C sinks, while those with slower expanding vegetation had C source years or had greater interannual variability, with some years being close to C neutral. Overall, a minimum of 55% vegetation cover was needed for the wetlands to become a net C sink. • Petrescu et al. (2015) found that methane emissions in rewetted former agricultural areas or restored wetlands in temperate climates are *not* offset by the CO_2 sink in the short term. Similarly, Neubauer (2014) modeling study found that newly created wetlands will contribute to global

	radiative forcing for the first portion of their lifetime unless the projects can be designed to maximize CO_2 sequestration and/or minimize CH_4 and N_2O emissions. This is an important consideration in the discussion of the *creditable* sequestration benefit of freshwater wetlands, since crediting usually occurs on shorter time frames • Whiting & Chanton (2001) found that newly created wetlands may have to establish themselves for over 100 years to be considered C sinks • Recreating properly the signature hydrology of freshwater wetland types may reduce CH_4 emissions. (Altor and Mitsch, 2006) found that pulsing hydrology, as opposed to continuous inundated conditions, led to reduction in methane emissions *Avoided conversion and degradation* • Drainage of wetlands generally results in loss of C because soil organic matter previously stored under anaerobic conditions is aerated and exposed to atmospheric oxygen (Mitra et al., 2005; Moomaw et al., 2018) For example, in North American prairie wetlands, wetland conversion to agriculture has resulted in an estimated loss of 10.1 Mg ha^{-1} of SOC (Euliss et al., 2006). While methane emissions usually decrease with drainage, it is unclear how this balances out with CO_2 emissions from increased aerobic decomposition in freshwater wetlands (Mitra et al., 2005) Although wetland conversion results in loss of soil C, the radiative forcing from wetland conversion depends on relative changes in the direction and magnitude of CO_2 and CH_4 (Moomaw et al., 2018) • Petrescu et al. (2015) found that draining temperate wetlands for agricultural use enhances CO_2 efflux due to decomposition, C export, and exploitation through grazing. Nearly all of the converted wetlands they assessed had a positive radiative forcing, which depended on management intensity after conversion • Nitrogen inputs from agricultural activities increase CO_2, CH_4, and N_2O emissions in freshwater wetlands (Chen et al., 2020).
What is the range of estimates for how much additional C could be sequestered globally?	• Global estimates specifically for freshwater wetlands are lacking. Furthermore, estimates for freshwater wetlands are often considered together with peatlands • Total C emissions from the conversion of wetlands to agricultural lands is estimated to range between 0.18 and 0.40 Pg CO_2 yr^{-1} (Mitra et al., 2005). This is the amount of emissions that would be avoided if wetland conversion to agriculture were prevented • Euliss et al. (2006) estimate that wetland restoration in the prairie wetlands of North America (around 1.6×10^7 ha of wetlands) has the potential to sequester 1387.26 Tg CO_2 over a 10-year period if all cropland wetlands were *restored* • Drever et al. (2021) estimate an annual mitigation potential for *avoided conversion* of freshwater mineral wetlands of 3.1 Tg CO_2e yr^{-1} in 2030. By 2030 and 2050, cumulative avoided emissions were estimated at an average 17 Tg CO_2e and 61.5 Tg CO_2e, respectively.
How much confidence do we have in current methods to detect	• It is essential to account for methane emissions when calculating the net C sequestration of freshwater wetlands. However, there are various issues with the way in which current methods account for methane, which Villa & Bernal (2018) outline below: ○ Global warming potential (GWP) is the metric suggested by the IPCC to account for trade-off between different GHGs. GWP can be used to compare discrete emissions, but not those sustained through time, as is the case for methane emissions in wetlands. Neubauer

any net increases in C sequestration in a system or net changes in areal extent of that system?	& Megonigal (2015) propose the sustained-flux global warming potential (for emissions) and the sustained-flux cooling potential (for uptake) as alternative metrics to GWP. o GWPs are time dependent (e.g.,100-year period) and emissions are assumed to remain constant during that time period. However, methane emissions in wetlands change seasonally with temperature and water table shifts. Ocko et al. (2017) emphasize the importance of not only reporting methane's GWP at the 100-year time scale, but also at the 20-year time scale. GWP_{20} ignores climate effects after 20 years, while GWP_{100}, focuses on the climate impact of a pulse emission over 100 years, diluting near-term effects of methane emissions. Presenting these two values together would provide a more accurate picture of the role of wetlands in climate change mitigation. o The GWP value increases as concentration of GHGs in the atmosphere increases. The GWP for methane has progressively increased since it was introduced in 1990 o Methods that aim to calculate the net C sequestration benefits of freshwater wetlands should account for these challenges • Anderson et al. (2016) found strong variability in the exchange of atmospheric CO_2 and CH_4 in freshwater wetlands, despite high productivity. Due to this high, short-term variability, they suggest that extrapolating long-term C dynamics from *short-term observations*, such as theirs, may be inaccurate. As such, the trajectory of C sequestration potential for the wetland in their study is unclear. The authors note that Roulet et al. (2007) similarly point out that "any single year of a 6-year study to assess longer-term wetland C sequestration potential would result in errors as high as 4 times the annual flux" • Differences in models have led to different conclusions regarding the role of freshwater wetlands as net C sinks over the long term. Mitsch et al. (2013) presented a model that estimated the ability of freshwater wetlands to act as net GHG sinks; they suggested that rapid CH_4 oxidation in the atmosphere has the effect of minimizing the importance of CH_4 emissions from wetlands. Neubauer (2014) re-examined methods used by Mitsch et al. (2013) and concluded that issues with their model led them to substantially underestimate the radiative forcing from freshwater wetlands. Issues identified by Neubauer include the absence of an important feedback mechanism and the misuse of GWP to determine the amounts of warming (due to CH_4 emissions) and cooling (due to soil C sequestration) attributable to their study wetlands. Both conclude that freshwater wetlands eventually cause net radiative forcing, but Neubauer (2014) identifies a timescale of 61 to 14,049 years as opposed to <300-year timeframe reported by Mitsch et al. (2013) • Although it is not an issue related to methods, it is worth noting that the biogeochemistry of tropical freshwater wetlands is not well studied. This has resulted in a research gap regarding factors affecting SOM decomposition and mineralization in these systems (Villa and Bernal, 2018).

C Market	
Is there a market (or proposed market) for carbon credits from the system?	Yes, voluntary markets exist, though not many specifically for freshwater wetlands that do not include peatlands.
Are there protocols (or proposed protocols) for such credits?	*Voluntary* • American Carbon Registry (ACR) Restoration of California Deltaic and Coastal Wetlands Methodology, v1.1; California • Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6[a]; applicable to forest lands, **forested wetlands, tidal wetlands** and forested peatlands; international • INACTIVE: ACR's Restoration of Degraded Wetlands of the Mississippi Delta. ACR has determined that the methodology requires updates to measurement, monitoring, reporting and verification requirements to be consistent with the current version of the ACR Standard. *Note: The Government of Alberta began creating a Wetland Restoration Protocol, however this protocol was stopped or withdrawn because "an activity cannot qualify for an offset if there is a legal obligation to perform it."* *Compliance* • N/A [a] *Protocol applies to agroforestry, tropical forest, peatland, coastal blue carbon and freshwater wetland systems*

If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	*Voluntary* **ACR Restoration of California Deltaic and Coastal Wetlands Methodology, v1.1** • **Permanence**: requires a minimum project term of 40 years. Crediting period is 40 years. Uses T-RISK, which is ACR's approved permanence risk tool • **Additionality:** must undergo a legal test and performance standard evaluation. The legal test requires that the activities that result in GHG emission reduction are not required by law, regulation or any legally binding mandate applicable in the offset project's jurisdiction. If there is any legally binding mandate that requires the implementation of the project, only emissions reductions that are in excess of what is required to comply with laws are eligible for crediting. A practice-based performance approach is used, meaning that if the approach used in the project is not common practice, then the project activity is deemed additional • **Leakage:** Project proponents must deduct leakage that reduces the GWP benefit of a project in excess of the 3% threshold. Market effects leakage in this methodology results from replacement of crops currently grown in the Sacramento-San Joaquin Delta by wetlands and rice • **Reversals:** Project proponents must conduct a risk assessment using the most recent ACR risk assessment tool to assess the risk of reversal or termination of the project. Through this risk assessment, a percentage of credits must be allocated to a buffer pool • **Uncertainty:** X-UNC module is used to calculate project uncertainty. If uncertainty is less than or equal to 10% at the 90% confidence level, then no uncertainty adjustment is made **Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6** • **Permanence**: Project crediting period must be between 20 and 100 years. Project uses the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** Uses two methods for determining additionality. For tidal wetlands conservation and restoration project activities, the methodology uses module ADD-AM (Demonstration of Additionality of Tidal Wetland Restoration and Conservation Project Activities. For other activities it uses T-ADD (CDM Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities.) • **Leakage:** Uses a variety of leakage modules to calculate leakage. Wetland specific modules: Module LK-ASP for planned deforestation/degradation and planned wetland degradation; Module LK-ASU for unplanned deforestation and unplanned wetland degradation • **Reversals:** A percentage of credits goes to a buffer pool. Buffer withholding percentage is calculated using VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Allowable uncertainty under this methodology is +/- 15% at the 95% confidence level. Any greater uncertainty results in a credit deduction *Compliance* • N/A

If there are protocols, have there been any registered projects or credits generated? If so, where?	*Voluntary*
	ACR Restoration of California Deltaic and Coastal Wetlands Methodology, v1.1
	• 1 freshwater wetland restoration projects registered
	  ○ Restoring Wetlands on California Department of Water Resources-Owned Areas of Twitchell and Sherman Islands
	  ▪ Total number of credits issued: 59,552 Mg CO_2e
	• 1 project listed
	  ○ Staten Island CA
	  ▪ Total number of credits issued: 0 Mg CO_2e
	
	Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6
	• None for **freshwater** wetlands, though some exist for coastal blue carbon
	
	Compliance
	• N/A

Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc. within any existing or proposed market?	*Voluntary* **ACR Restoration of California Deltaic and Coastal Wetlands Methodology, v1.1** • Allows for aggregation following the ACR standard **Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements *Compliance* • N/A

Is there controversy surrounding the markets or credits for the NCS pathway? Why?	• Main controversy in using freshwater wetlands for C credits is accounting for their methane emissions, which has been described above in more detail. According to Villa & Bernal (2018), the limitations associated with accounting for methane emissions must be addressed in order to design "plausible financing mechanisms targeting freshwater wetlands" • Neubauer & Megonigal (2015) argue that wetlands should be treated as a continuous source of methane. They suggest that the creditable benefit of wetlands would be lower at market-relevant time scales • High short-term variability in wetland net ecosystem exchange of CO_2 versus long-term sequestration creates uncertainty regarding the efficacy and permanence of wetland restoration projects and the ability to document any GWP reduction using verification protocols over the 50 – 100-year period of many C offset trading programs (Anderson et al., 2016). • Voluntary carbon market protocol developers for wetland restoration and conservation have found that methane emissions often do not change significantly between baseline and project scenarios, or are not higher in the project scenario. Therefore, methane emissions are conservatively excluded from the C accounting, depending on the circumstances – the Verra VM0007 BL-PEAT methodology 0and the ACR methodology mentioned in the row directly above provide a more detailed description of why and when methane is excluded from C accounting.

Grasslands: *Reduced livestock stocking rates in overgrazed systems sufficiently to increase lant productivity, Grazing management techniques other than lowering stocking rates (e.g., rotational grazing), Avoided degradation and conversion to cropland, Restoration resulting in increased herbaceous biomass on severely degraded grasslands (excluding woody species removal efforts), Fire management, Pasture management (irrigation, sowing legumes), EMW amendments & Nutrient additions (compost and fertilizer)*

The global grassland area as of 2018 ranged from 1.8×10^7 km^2 (CCI-LC) to 3.0×10^7 km^2 (MODIS-based) (FAOSTAT, 2020). Grasslands are considered a type of land cover, not land use, and they can be managed by humans or unmanaged. A grassland is an area "dominated by natural herbaceous plants (grasslands, prairies, steppes and savannahs) with a cover of 10 per cent or more, irrespective of different human and/or animal activities, such as grazing or selective fire management", and less than 10 per cent cover of woody plants (trees and/or shrubs) (FAOSTAT, 2020).

Grasslands[10] are a significant C pool, containing about 20% of the world's soil C stocks (Conant, 2010). Most of the ecosystem C stored in grasslands is found in the soil (Janowiak et al., 2017). The total C stock of grassland soils is estimated to be 325 Pg C ± 20 Pg C to 1 m depth (Conant, 2010; Sanderman et al., 2017; Lorenz and Lal, 2018). Given this stock estimate and a global areal extent of 1.8×10^7 km^2 to 3.0×10^7 km^2, grassland soils contain somewhere between 108 Mg C ha^{-1} – 180 Mg C ha^{-1}, though this number is highly variable and dependent on climate and soil characteristics. In a different study, Goldstein et al. (2020) split up grasslands into tropical, temperate, and montane categories. They estimate that temperate grasslands store 39 Pg C (77 Mg C ha^{-1}), tropical grasslands store 30 Pg C (43 Mg C ha^{-1}), and montane grasslands store 27 Pg C (104 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C to a depth of 30cm, globally, which is much lower than the 325 Pg C estimate due to the focus on surface soils. This discrepancy in estimates is due in part to the different depths considered, but may also be due to differences in the way that grasslands are defined in Goldstein et al.'s (2020) study. Business-as-usual projections for C dynamics in grasslands under future climate change and management regimes are uncertain. However, years of human management practices on grasslands have caused estimated soil C losses of 14 – 16 Pg C (51.38 – 58.72 Pg CO_2e) (Houghton and Nassikas, 2017; Sanderman et al., 2017) and thus there is potential to restore C with improved management practices.

Since C in grasslands is predominantly stored in soils, most of the discussions around increasing C in grasslands are focused on increasing soil organic carbon (SOC), particularly in managed grasslands such as rangelands and pasturelands. Practices such as improved grazing management (e.g., lowering stocking rates in overgrazed areas); sowing improved grass species mixes and legumes; optimized inputs of water, fertilizer (though tradeoffs with nitrous oxide emissions need to be calculated), and organic amendments; fire management; and restoration of degraded lands can increase overall C storage in grasslands. An estimated 0.2 – 0.8 Pg CO_2 yr^{-1} could be sequestered in grassland soils globally by 2030 with improved management practices, given prices for CO_2 of USD 20 – 50 Mg^{-1} (Conant, 2010). Conant et al. (2017) identify the C storage

[10] Grasslands and shrublands are considered separately in this analysis to align with the classifications from the IUCN (https://global-ecosystems.org/explore/realms/T), NASA earth observatory (https://earthobservatory.nasa.gov/biome) and FAO (https://www.fao.org/faostat/en/#data/LC).

potential of different management practices on managed grasslands and estimate that improved management increased soil C sequestration, by an average of 1.72 CO_2 Mg ha^{-1} yr^{-1}. Importantly, management options on many grasslands such as rugged and/or extensive rangelands are limited in scope due to feasibility. Further, Henderson et al. (2015) found that N_2O emissions resulting from sowing legumes in pastures are likely to offset about 28% of the C sequestration benefits; additional N_2O emissions always exceeded C sequestration in grazing land that received fertilization, and ruminant CH_4 emissions linked to more forage could also offset soil C gains (Henderson et al., 2015). While improved management of grasslands is one pathway to sequester soil C, the most effective way to keep SOC in soil is through avoided conversion of sustainably stocked grasslands and native grasslands to cropland or other land uses, but conversion is taking place at a rapid pace. Estimates of native grassland losses to conversion range between 0.4-0.8 M hectares per year in the US (Lark et al., 2020), which could equate to 9.18×10^6 - 1.84×10^7 Mg C yr Pg C (Sanderman et al., 2017).

Measuring changes in SOC sequestration in grasslands presents similar challenges to measuring changes in cropland SOC. Conant (2010) explains that the main challenge in documenting plot-level changes in grassland soil C stocks is not in measuring C (these methods exist and are accurate, though expensive and time-consuming), but rather in designing an efficient, cost-effective system for measuring, monitoring, and verification (Conant, 2010). Smith (2014) also identify important nuances in the methods used to estimate C sequestration rates in grasslands. These nuances must be considered when drawing conclusions from studies. For example, studies that measure fluxes on grasslands immediately following significant improvement in management regime or land use change may yield results that are not representative of long-term sequestration rates, since carbon accumulation tends to be rapid following changes in land use and management.

Since grasslands have been identified as important potential C sinks, a voluntary market for grassland carbon credits has emerged, primarily focusing on avoided conversion. Organizations like Verra, American Carbon Registry, and Climate Action Reserve have specific protocols for grassland C projects, which all account for permanence, additionality, reversals, leakage, and uncertainty to varying degrees. Certain protocols, such as CAR's grassland protocols, have more registered projects than others. These protocols are described in more detail in the associated table.

Grasslands

Global areal extent: 1.8×10^7 km^2 (CCI-LC) to 3.0×10^7 km^2 (MODIS) as of 2018 (FAOSTAT, 2020).

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?	• Total stock: 325 Pg C (± 20 Pg C) in soil, at 1 m depth (Conant, 2010; Sanderman et al., 2017; Lorenz and Lal, 2018). • Average per hectare: 108 – 180 Mg C ha^{-1} based on stock of 325 Pg C. However, this per ha number is highly variable, depending on climate and soil characteristics. Goldstein et al. (2020) split up grasslands into tropical, temperate, and montane grasslands. They estimate that temperate grasslands store 39 Pg C (77 Mg C ha^{-1}), tropical grasslands store 30 Pg C (43 Mg C ha^{-1}), and montane grasslands store 27 Pg C (104 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 30cm, globally, much lower than the 325 Pg C estimate. This discrepancy in estimates may be due to differences in the way that grasslands are defined in Goldstein et al.'s (2020) study. • Gross Primary Production (GPP) ranges from 31.3 Pg C yr^{-1} for tropical savannas and grasslands to 8.5 Pg C yr^{-1} for temperate grasslands and shrublands (Lorenz and Lal, 2018) • NPP measurements are difficult because of biomass removal through harvest, grazing, fire, and senescence (Janowiak et al., 2017). • Most of the C in grasslands is stored in the soil rather than aboveground vegetation; grassland plants' deep root systems contribute to large soil C stocks (Janowiak et al., 2017).
At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	• Years of human management practices on grasslands have caused estimated soil C losses of 14 – 16 Pg C (51.38 – 58.72 Pg CO_2e) (Houghton and Nassikas, 2017; Sanderman et al., 2017). Thus, there is potential to restore this C with improved management practices. • Pendall et al. (2018) identify contrasting findings regarding C fluxes in grasslands in the U.S. Many studies that have scaled up flux tower observations and biogeochemical modeling indicate that U.S. grasslands have been C sinks in recent years (Zhang et al., 2011; Liu et al., 2012, 2014a; Xiao et al., 2014). However, discrepancies in findings can be attributed to differences between modeling and studies that use empirical data values. This contributes to uncertainties in grassland carbon fluxes and cycling rates (Pendall et al., 2018). • Grassland conversion to arable land continues to occur in many places, accompanied by large soil C losses. When grasslands are converted to croplands, soil C stocks tend to decline by an average of about 60 percent (Conant, 2010).

Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	• Most discussions center around increasing SOC in grasslands; soil C accounts for approximately 81 percent of total ecosystem C found in grasslands (Janowiak et al., 2017). • Practices that can increase overall C storage in grasslands include improved grazing management (specifically lowering stocking rates in overgrazed systems to increase plant productivity), sowing improved species/favorable forage species, increased inputs of water, fertilizer, and organic amendments, restoring degraded lands, and fire management (Conant, 2010; Conant et al., 2017). However, (Henderson et al., 2015) demonstrates trade-offs with emissions of other greenhouse gases that need to be accounted for in net mitigation calculations for some of these practices. • Sustainably stocked and managed grasslands may already be at or near their maximum SOC storage capacity, therefore, protecting them from conversion is one of the most important strategies for keeping C in soil (Martin et al., 2021). • Improving grazing practices, particularly lowering stocking rates in overgrazed systems to increase plant productivity, can sequester C (Soussana et al., 2004; He et al., 2011; McSherry and Ritchie, 2013). • Fertilization and irrigation can have strong impacts on plant production and SOC (Conant et al., 2001), though these practices mostly apply to grasslands managed as pastures. However, net sequestration needs to be determined by accounting for emissions from fertilizer production and transport, irrigation equipment, and N_2O emissions. • Sowing legumes and managing plant mixtures can lead to increased C sequestration (Conant et al., 2017), however N_2O emissions also need to be considered for net C sequestration benefits • The use of prescribed fire can help prevent encroachment of woody shrubs and maintain native grass species composition. This can be important for maintaining soil C pools in certain grasslands, as encroachment of woody shrubs may reduce soil C in wetter grasslands (Janowiak et al., 2017). • Enhanced Mineral Weathering (EMW) may be able to increase SOC sequestration in grasslands since it has positive impacts on productivity and arbuscular mycorrhizal fungi (AMF) proliferation, and can enhance the cation exchange capacity and nutrient availability of soils. However, the impacts of EMW on SOC is currently poorly understood and requires additional research (Gomez-Casanovas et al., 2021). Furthermore, emissions associated with the production and transportation of EMW products may exceed their carbon uptake abilities (Schlesinger and Amundson, 2019). • Changes in ecosystem C from management practices will vary across grassland types, with the greatest C gains expected to occur in cool, humid climates, and the lowest gains in warm, arid climates (Janowiak et al., 2017). • Importantly, other GHG implications of changing grassland management need to be evaluated in order to fully assess grasslands' ability to contribute to climate change mitigation (e.g., emissions from manufacturing and transport, equipment, increased soil N_2O emissions, etc.) For example, while fertilizer additions may increase soil C, increased emissions from N_2O and other GHGs need to be accounted for to assess net climate benefits

What is the range of estimates for how much additional C could be sequestered globally?	• Potential for additional C storage is uncertain because of limited data on grazing land SOC stock responses over time with varied management
	• 0.2 – 0.8 Pg CO_2 yr^{-1} could be sequestered in grassland soils globally by 2030 with improved management practices, given prices for CO_2 of USD 20 – 50 Mg^{-1} (Conant, 2010; Roe et al., 2021)
	• Conant et al. (2017) synthesized information from different studies on management effects on grassland soil carbon stocks. Most of the studies included in this analysis contrasted a standard/common management practice with an 'improved" management practice that differed from the standard, or a "degraded" condition that compared with a standard/common condition:
	  ○ Practices like improved grazing management, fertilization, sowing legumes and improved grass species, irrigation, and conversion from cultivation lead to increased soil C sequestration in managed grasslands, by an average of 1.72 Mg CO_2 ha^{-1} yr^{-1}
	  ○ The largest average increases in C observed in conversion from cultivation to grass (3.19 Mg CO_2 ha^{-1} yr^{-1}) and sowing legumes (2.42 Mg CO_2 ha^{-1} yr^{-1}; Conant et al., 2017). At a global scale, Griscom et al., (2017) estimate that sowing legumes could have a maximum mitigation potential 0.147 Pg CO_2e yr^{-1} of and cost-effective mitigation potential (<100 USD $MgCO_2e^{-1}$) of 0.132 Pg CO_2e yr^{-1} beginning in 2030 and hitting saturation at ~100 years.
	  ○ Improved grazing management led to an average increase of 1.03 Mg CO_2 ha^{-1} yr^{-1}
	  ○ Application of organic fertilizers led to an average increase of 3.00 Mg CO_2 ha^{-1} yr^{-1} and for inorganic fertilizers, an average increase of 1.98 Mg CO_2 ha^{-1} yr^{-1}
	  ○ However, N_2O emissions from sowing legumes in pastures may offset about 28% of the C sequestration benefits, additional N_2O emissions always exceeded C sequestration in grazing land that received fertilization, and ruminant CH_4 emissions linked to more forage could also offset soil C gains (Henderson et al., 2015)
	  ○ The largest average increases in C observed in conversion from cultivation to grass (3.19 Mg CO_2 ha^{-1} yr^{-1}) and sowing legumes (2.42 Mg CO_2 ha^{-1} yr^{-1}; Conant et al., 2017). At a global scale, Griscom et al., (2017) estimate that sowing legumes could have a maximum mitigation potential 0.147 Pg CO_2e yr^{-1} of and cost-effective mitigation potential (<100 USD $MgCO_2e^{-1}$) of 0.132 Pg CO_2e yr^{-1} beginning in 2030 and hitting saturation at ~100 years.
	• Maximum carbon sequestration potential of Optimal Grazing Intensity: 0.106 Pg CO_2e yr^{-1} (Nature4Climate, 2022)
	• Cost-effective (<100 USD $MgCO_2e^{-1}$) carbon sequestration potential of Optimal Grazing Intensity: 0.098 Pg CO_2e yr^{-1} (Nature4Climate, 2022)
	• Maximum carbon sequestration potential of grazing legumes: 0.106 Pg CO_2e yr^{-1} (Nature4Climate, 2022)
	• Cost-effective (<100 USD $MgCO_2e^{-1}$) carbon sequestration potential of grazing legumes: 0.055 Pg CO_2e yr^{-1} (Nature4Climate, 2022)
	• Maximum carbon sequestration potential of avoided grassland conversion: 0.362 Pg CO_2e yr^{-1} (Nature4Climate, 2022)
	• Cost-effective (<100 USD $MgCO_2e^{-1}$) carbon sequestration potential of avoided grassland conversion: 0.209 Pg CO_2e yr^{-1} (Nature4Climate, 2022)

	• Maximum carbon sequestration potential of improved fire management (savannas): 0.107 Pg CO_2e yr^{-1} (forthcoming in Naturebase: https://www.naturebase.org/) • Cost-effective (<100 USD $MgCO_2e^{-1}$) carbon sequestration potential of improved fire management (savannas): 0 Pg CO_2e yr^{-1} (forthcoming in Naturebase: https://www.naturebase.org/) • Schuman et al. (2002) estimate that improved grazing management could increase soil C storage on U.S. rangelands from 0.37 – 1.10 Mg CO_2 ha^{-1} yr^{-1} (Conant et al., 2017) estimate of 1.03 Mg CO_2 ha^{-1} yr^{-1} falls within this range.) They also estimate that newly restored grasslands can store 2.20 Mg CO_2 ha^{-1} yr^{-1}.Using these numbers, the authors estimate that the total potential gain in soil C from improved management of poorly managed rangelands *and* restored grasslands could be as much as 69.73 Tg CO_2 yr^{-1} • In a recent synthesis of C sequestration on grasslands, Bai and Cotrufo (2022) estimate that globally, the mean theoretical, realistic, and achievable potential of SOC sequestration with grassland restoration is 10.2, 6.8, and 3.4 Pg CO_2 ha^{-1} yr^{-1}, respectively. • Globally, Griscom et al. (2017) estimate that "optimal grazing intensity" has a mitigation potential of 0.145 Pg CO_2e yr^{-1}. The authors define optimal grazing intensity as a decrease in stocking rates in areas that are over-grazed and an increase in stocking rates in areas that are under-grazed, but with the net result of increased forage offtake and livestock production. This estimate represents max SOC mitigation potential beginning in 2030 and hitting saturation in ~100 years, constrained by food security, fiber security, and biodiversity conservation. However, the cost-effective mitigation potential (<100 USD $MgCO_2e^{-1}$) necessary to keep global warming below 2°C.is much lower, at 0.089 Pg CO_2e yr^{-1}. • The maximum mitigation potential of avoided grassland conversion (including shrublands and savannas) beginning in 2030 and hitting saturation at ~100 years is 0.116 Pg CO_2e yr^{-1} and the cost-effective mitigation potential (<100 USD $MgCO_2e^{-1}$) is 0.035 Pg CO_2e yr^{-1} (Griscom et al., 2017) • Fargione et al. (2018) estimate that avoided conversion of grassland to cropland in the United States prevents emissions from soils and root biomass, by a *maximum* of 107 Tg CO_2e yr^{-1}; however, at a price of USD 10 Mg CO_2e^{-1}, the authors estimate that avoided grassland conversion could prevent emissions by about 24 Tg CO_2e yr^{-1} • Compost additions can improve grassland productivity and increase SOC; in California grasslands, the net greenhouse gas (GHG) benefits of compost additions were estimated at 0.7 Mg CO_2e ha^{-1} yr^{-1}, assuming that the source compost would otherwise have been buried in a landfill (Ryals et al., 2015). However, compost additions may be a difficult practice to scale up since, for example, potential compost production in California is estimated at 27 – 33 MMT yr^{-1}, which would be enough to apply to 25% of California's rangelands every 17 – 40 years (Silver et al., 2013). • Griscom et al. (2017) estimate the maximum mitigation potential of fire management on savannas to be 0.125 Pg CO_2e yr^{-1}. This estimate represents max SOC mitigation potential beginning in 2030 and hitting saturation in ~100 years, constrained by food security, fiber security, and biodiversity conservation.

	Note: "Improved grazing management" in (Conant et al., 2017) *and other papers evaluate the combined impacts of practices such as lower stocking rates, removal of grazing livestock, several types of rotational or short-duration grazing, seasonal grazing, etc. This can be problematic as these practices have different effects on sequestration. Bundling these practices can confound the effects of practices that are known to increase sequestration, such as lowering the stocking rate in overgrazed systems for the purpose of increasing plant productivity, with those that have not been shown to increase sequestration, such as rotational and short duration systems. However, it is important to note that even decreasing stocking rates can have varying effects on sequestration, depending on climate, soil properties, and vegetation type (C3 vs C4 dominated)* (Potter et al., 2001; McSherry and Ritchie, 2013; Abdalla et al., 2018).

How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that system?	• Smith (2014) identifies some issues with the methods that have been used to estimate grassland C sequestration rates
	  ○ The effects of land use history before C flux experiments begin may influence soil C and measured C flux years later during the C flux measurement period. High C accumulation rates measured by flux towers could be measuring legacy effects of land use or management long before the beginning of the experiment. Therefore, some C flux estimates may not be representing true rates of C sequestration
	  ○ Some studies may be measuring fluxes on grasslands immediately following significant improvement in management regime or land use change, when carbon accumulation is rapid. These sequestration rates are not likely to be representative of long-term sequestration rates. Grassland sinks decrease in strength once soil reaches a new equilibrium level, typically after 20 - 50 years
	• Since most of the C in grasslands is in the soil, some of the same issues for estimating C in cropland soils apply to grasslands
	  ○ The main challenge in documenting plot-level changes in soil C stocks is not in measuring C (these methods exist and are accurate, but are expensive and time-consuming), but rather designing an efficient, cost effective system for measuring, monitoring, and verification (Conant, 2010).
	  ○ In general, there has been less effort to develop process-based soil biogeochemical models to represent grasslands than for croplands or forests, and therefore the uncertainty in model predictions is generally relatively high for grasslands.
	• Limited data on grassland C stocks and the influence of grassland management practices soil C in developing countries. This presents a challenge for creating accounting systems that offer the same utility for quantifying soil C sequestration in both developed and developing countries (Conant, 2010).

C Market	
Is there a market (or proposed market) for carbon credits from the system?	Yes, voluntary markets exist.
Are there protocols (or proposed protocols) for such credits?	*Voluntary* • ACR Avoided Conversion of Grasslands and Shrublands to Crop Production Methodology[a]; U.S. and Canada • ACR Grazing Land and Livestock Management Methodology (Under Development); international • BCarbon Soil Carbon Credit Systems; U.S. private and tribal lands, other countries • CAR Grassland Protocol; conterminous United States and on U.S. tribal land • CAR Canada Grassland Protocol [a]; Canada • Verra VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing, v1.0[1]; geographic scope not specified in protocol • Verra VM0026 Methodology for Sustainable Grassland Management (SGM), v1.1[1]; geographic scope not specified in protocol • Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0[b]; international • Verra Methodology for Agricultural Land Management: Improved Grassland Management (Under Development); geographic scope not specified in protocol • Verra Avoided Planned Conversion of Grasslands and Shrublands to Crop Production [a] (Under Development); United States or Canada • Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU) [c]; China *Compliance* • N/A [a] *Protocol applies to grassland and shrubland systems* [b] *Protocol applies to grassland, shrubland, and forest systems* [c] *Protocol applies to grassland, cropland, agroforestry, and multiple forest systems*

	[1] *The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) accepts carbon offset projects that use this protocol* *Note: The Panda Standard Sectoral Specifications applies to grasslands, however, we have not been able to verify that the protocols have been approved by the Chinese government, and/or have generated grassland credits to date. Additional protocols that cover grassland pathways in China may exist, but we have not been able to review all of them due to limited publicly available information.*
If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	*Voluntary* **ACR Avoided Conversion of Grasslands and Shrublands to Crop Production** • **Permanence**: Minimum project term is 20 years, and may be renewed up to four times, for a total duration of 100 years. • **Additionality**: Additionality must be satisfied using an independent appraisal that satisfies ACR's three prong additionality test through the demonstration of regulatory surplus, a lack of common practice, and a financial implementation barrier • **Leakage:** Project proponents should use a conservative default value of 20% market leakage for avoided conversions of grassland or shrublands to commodity crops in the U.S. Proponents are encouraged to use a leakage decision tree to determine if accounting for activity shifting leakage is necessary. • **Reversal:** use the VCS AFOLU Non-Permanence Risk Tool until the ACR Tool for Risk Analysis and Buffer Determination is available • **Uncertainty:** Must account for uncertainty of avoided conversion using avoided conversion discount factor. Also, estimation of uncertainty is required for each baseline and project carbon pool and GHG sources **ACR Grazing Land and Livestock Management Methodology (Under Development)** *Note: This methodology is in very early stages and as a result there are very few details.* • **Permanence/Reversal**: Uses T-RISK, an ACR-approved risk assessment tool used to calculate the non-permanence buffer deduction for projects claiming credit for increased biotic sequestration. • **Leakage**: Uses L-GLLM, which calculates emissions due to activity-shifting and market effects leakage, where applicable. • **Uncertainty:** Not specified • **Additionality**: Not specified
	CAR Grassland Protocol • **Permanence:** An emission reduction is considered "permanent" if the quantity of carbon associated with that reduction is stored for at least 100 years following the issuance of a credit for that reduction • **Additionality:** Projects must satisfy a performance test and legal requirement test. Also, any type of conservation or ecosystem service payment or credit received for activities on the project area must be disclosed by the Project Owner to the verification body and the Reserve on an ongoing basis • **Leakage:** Conservative approach of assuming 20% leakage effect from grassland projects

	• **Reversal: I**f the Reserve determines that there has been an unavoidable reversal, it reserves a quantity of CRTs from the Reserve Grassland Buffer Pool equal to the size of the reversal in metric tons of CO2 (for each reporting period, project owner must transfer a quantity of credits to the Reserve Grassland Buffer Pool at time of credit issuance.) Avoidable reversals must be communicated to the Reserve and compensated for by the Project Owner by transferring a quantity of CRTs from its reserve account equal to the size of the reversal • **Uncertainty:** discount factors for the uncertainty of conversion and uncertainty of modeling future management practices and climatic conditions. The baseline emissions quantified in this protocol are discounted to account for increasing uncertainty about input assumptions and model outputs into the future. The discount for uncertainty is 1% per 10-year emission factor period. **CAR Canada Grassland Protocol** • **Permanence:** for this protocol, an emission reduction is considered "permanent" if the quantity of carbon associated with that reduction is stored for at least 100 years following the issuance of a credit for that reduction. • **Additionality:** Projects must satisfy a performance test and legal requirement test. Also, any type of conservation or ecosystem service payment or credit received for activities on the project area must be disclosed by the Project Owner to the verification body and the Reserve on an ongoing basis • **Leakage:** Assumes 20% leakage effect, like the U.S. CAR Grassland Protocol • **Reversal:** If the Reserve determines that there has been an unavoidable reversal, it shall retire a quantity of CRTs from the Reserve Grassland Buffer Pool equal to the size of the reversal in metric tons of CO2 (for each reporting period, project owner must transfer a quantity of credits to the Reserve Grassland Buffer Pool at time of credit issuance.) Avoidable reversals must be communicated to the Reserve and compensated for by the Project Owner by transferring a quantity of CRTs from its reserve account equal to the size of the reversal • **Uncertainty:** discount factors for the uncertainty of conversion and uncertainty of modeling future management practices and climatic conditions. The baseline emissions quantified in this protocol are discounted to account for increasing uncertainty about input assumptions and model outputs into the future. Consistent with the U.S. Grassland Project Protocol, the Reserve has set the discount as one percent to start, increasing an additional one percent every five years **Verra VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing** • **Permanence:** Crediting period not specified in protocol, but uses latest version of the VCS AFOLU Non-permanence risk tool • **Additionality:** Additionality must be demonstrated using the latest version of the VCS tool VT0001 Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities • **Leakage**: considers two forms of leakage: displacement leakage from the movement of livestock off the project area where they may reduce soil carbon, and market leakage, where reductions in livestock numbers as a project activity would create market incentives to replace the lost livestock • **Reversal**: not specified beyond use of latest version of the VCS AFOLU non-permanence risk tool

- **Uncertainty**: If total project uncertainty in year t, based on 95% confidence intervals, is less than 30%, then no deduction must result from uncertainty.

Verra VM0026 Methodology for Sustainable Grassland Management (SGM), v1.1

- **Permanence:** Crediting period not specified in protocol, but uses latest version of the VCS AFOLU non-permanence risk tool
- **Additionality:** Must demonstrate additionality using the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities
- **Leakage**: Considers market leakage due to reduction in the production of livestock products within the project boundary using VCS Module VMD0033 Estimation of Emissions from Market Leakage; considers leakage due to displacement of grazing beyond the project boundary using VMD0040 Leakage from Displacement of Grazing Activities
- **Reversal**: not specified beyond use of latest version of the VCS AFOLU non-permanence risk tool and the use of an AFOLU pooled buffer account
- **Uncertainty**: Emissions reductions must be adjusted for uncertainty. when the uncertainty is 15 percent or less than 15 percent there is no deduction and when the uncertainty is between 15 and 30 percent a deduction is calculated

Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0

- **Additionality:** Must demonstrate additionality using the latest version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities. The common practice test must demonstrate that project activities will address at least one driver of conversion in such a way that the driver would not have been addressed had the project not been undertaken
- **Leakage:** Emissions from activity-shifting leakage are calculated using the Leakage Emissions Model and an activity-shifting leakage area. Emissions from market leakage are estimated using a market leakage area and default values specified in the AFOLU Requirements
- **Permanence:** Crediting period is a minimum of 20 years, maximum of 100 years
- **Reversals:** Project proponent must estimate the final level of cumulative baseline emissions at the end of a crediting period. If this estimate is greater than the number of credits issued during the project crediting period, then this difference must be addressed through the AFOLU Pooled Buffer Account
- **Uncertainty:** Deductions for uncertainty are determined by a linear combination of weighted standard errors of estimates from baseline emissions models and carbon stock measurement

Verra Methodology for Agricultural Land Management: Improved Grassland Management (Under Development)

- **Permanence:** Crediting period is not specified in the protocol, but uses VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination
- **Additionality:** Must demonstrate additionality using the current VCS Tool for Demonstration and Assessment of Additionality in AFOLU Project Activities

- **Leakage**: There may be no leakage due to activity shifting; at each verification, project proponent must provide documentation on any other grasslands controlled by the project proponent where leakage could occur, including, at a minimum, their location(s), area and type of existing land use(s), and grazing management plans. Leakage due to market effects is calculated by multiplying net emissions in the baseline scenario by an appropriate leakage factor
- **Reversal**: uses VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination
- **Uncertainty**: Uncertainty at all times is defined as the 95% confidence interval as a percentage of the mean

Verra Avoided Planned Conversion of Grasslands and Shrublands to Crop Production (Under Development)

- **Permanence:** Project crediting period minimum of 20 years, renewable up to four times for a maximum project duration of 100 years. Crediting for avoided conversion may only occur for 20 years following the occurrence of conversion activities in the baseline on each Participant Field
- **Additionality:** Additionality shall be satisfied using a Project Method, demonstrated with the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities
- **Leakage**: An overall leakage factor that accounts for market and activity shifting leakage is calculated. Project Proponents are encouraged to use the Leakage Decision Tree to determine if accounting for Activity Shifting Leakage (ASL) is necessary. A default market leakage factor is used for all projects using this methodology
- **Reversal**: not specified beyond use of VCS AFOLU Non-permanence risk tool
- **Uncertainty**: Where uncertainties exceed 15% at the 95% confidence interval or 10% at the 90% confidence interval, an appropriate confidence deduction shall be applied. Uncertainties should be estimated with default values (such as those by the IPCC), estimates from peer-reviewed literature, or directly estimated with appropriate statistical techniques. Where there are a range of uncertainty values, project proponents must choose the most conservative value, so as to not overestimate project emissions reductions

Panda Standard Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)

- **Permanence**: Minimum project term varies with the type of project; Project generating net C sequestration (or GHG removals) have a minimum project term of 30 years; Project generating net emission reductions have a minimum project term of 20 years; Project generating net irreversible net GHG emission reductions have a minimum project term of 5 years. Project Proponents must conduct **a** risk assessment using the Panda Standard Risk Analysis Tool. The result of the Risk Assessment is an overall risk category for the Project, translating into a percentage or number of PS Credits that must be deposited into the Panda Buffer Pool.
- **Reversals:** A percentage of credits go to a buffer pool (Panda buffer pool). 2 options to mitigate risk:
    - **Option 1**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, this percentage of offsets from the Project itself for deposit to the Panda Buffer Pool";
    - **Option 2**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, the number of PS credits of any type and vintage that equates to the percentage drawn from the risk assessment". Percentage of contribution to buffer pool is not explicitly stated.

	• **Leakage:** Accounting for activity shifting required. Any leakage identified must be quantified and subtracted from the net emission reduction/removal benefits except when leakage arises from the creation of poles and fencing to implement Project Activities • Fossil fuel combustion resulting from ground transportation. Leakage accounting might also be omitted if the following criteria are met: Displacement of baseline activities occurs on less than an average of 5% of the land area for a given project activity during the crediting period • Total quantity of a given good/commodity (e.g. lumber, crop, fuelwood, grazing animal) supplied to market in the project scenario for a given project activity is reduced by less than 20% of in comparison to the Baseline during the crediting period • All Leakage emissions are estimated to be below the de minimis threshold on average during the crediting period o Accounting for market leakage is not required if the following conditions are satisfied: ▪ 1) Average quantity of a given good/commodity supplied to market in the with-Project Scenario for a given Project Activity is reduced by less than 20% in comparison to the Baseline. ▪ 2) Average quantity of a given good/commodity in the Baseline per year supplied to market is less than 5% of total commodity produced per year within the PRC Prefecture(s) where the Project is taking place. • **Additionality**: Additionality can be demonstrated using 2 approaches: o **Three-prong approach**: The project activity must meet the following criteria: a. Complies with regulatory requirements b. Exceeds common practice c. Faces investment, technological or institutional barriers); o **Performance standard approach** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice)). • **Uncertainty:** If the 90% confidence interval is greater than 10% of the mean the reportable amount must include an uncertainty deduction. The uncertainty deduction shall be equal to the calculated % of the mean represented by the confidence interval minus the allowable 10% *Compliance* • N/A
If there are protocols, have there been any registered projects or credits generated? If so, where?	*Voluntary* **ACR Avoided Conversion of Grasslands and Shrublands to Crop Production** o ACR222 "Prairie Pothole Avoided Conversion of Grasslands and Shrublands" in North Dakota. o 2018 Verification report indicates net GHG emission reductions or removals of 37,238 t CO_2e. 81,917 credits registered. **CAR Grassland Protocol** • CAR1460 "54 Ranch" in Mussellshell County, Montana.

	○ 54 Ranch has voluntarily chosen to permanently protect its soil carbon and forever remain in a grassland state by recording a no-till conservation easement. Project is listed but has not yet undergone reporting and verification • CAR1425 “Medford Spring Grassland Conservation” in Bent County, Colorado. ○ The project's boundaries encompass 5,900 acres in Bent County, Colorado that the Southern Plains Land Trust has placed under a conservation easement to permanently protect native grasslands from conversion to croplands. ○ 1,452 registered offset credits. • CAR1238 “Heartland Ranch Phase 1” in Bent County, Colorado. ○ This project is the first phase of a property, Heartland Ranch, that the Southern Plains Land Trust in Colorado plans to purchase and place under a conservation easement to permanently protect grasslands from conversion to croplands. ○ 8,686 registered offset credits. • CAR1299 “Heartland Ranch Phase 2” in Bent County, Colorado. ○ This project is the second phase of a property, Heartland Ranch, that the Southern Plains Land Trust in Colorado has purchased and placed under a conservation easement to permanently protect grasslands from conversion to cropland. ○ 5,810 registered offset credits. • CAR1328 “Heartland Ranch Phase 3” in Bent County, Colorado. ○ This project is the third phase of a property, Heartland Ranch, that the Southern Plains Land Trust in Colorado has placed under a conservation easement to permanently protect grasslands from conversion to croplands. ○ 651 registered offset credits. • CAR1237 “Raven’s Nest Nature Preserve” in Bent County, Colorado. ○ The Raven's Nest property is the first that the Southern Plains Land Trust in Colorado has placed under a conservation easement to permanently protect grasslands from being converted to croplands. ○ 24,881 registered offset credits. • CAR1247 “Bluesource - Carroll Avoided Grassland Conversion Project” in Valley County, Montana. ○ Property of 16,000 acres under a conservation easement prohibiting conversion to agriculture. ○ 48,447 registered offset credits. • CAR1564 “Bluesource - Soda Creek Avoided Grassland Conversion Project”, Montana ○ Appeared as listed • CAR1259 “Lightning Creek Ranch” in Wallowa County, Oregon. ○ Project area is estimated around 4,112 acres. These grassland acres are part of the larger Lightning Creek Ranch, a 12,225 acre working cattle ranch located in eastern Oregon. This property is protected by a permanent no-till conservation easement (the land cannot be converted to cropland) ○ 8,332 registered offset credits.

	• CAR1260 “BNW West” in Wallowa County, Oregon.
	  ○ The project area is estimated to be 1,327.4 acres. These grassland acres are part of a larger 3,269 acre property purchased by The Nature Conservancy. Placed under a no-till conservation easement on the property.
	  ○ 2,696 registered offset credits.
	• CAR1261 “May Ranch Avoided Grassland Conversion” in Prowers County, Colorado.
	  ○ Avoided grassland conversion project on ~14,500 acres.
	  ○ 39,599 registered offset credits.
	• CAR1284 “BNW Ranch” in Wallowa County, Oregon.
	  ○ The BNW Ranch project area is estimated to be 4098 acres. Placed under a no-till conservation easement (the land cannot be converted to cropland)
	  ○ 5,952 registered offset credits
	• CAR1398 “Veseth and Veseth Ranch” in Phillips County, Montana.
	  ○ Veseth and Veseth Ranch has voluntarily chosen to permanently protect its soil carbon and forever remain in a grassland state by recording a no-till conservation easement. Project is listed but has not yet undergone reporting and verification
	• CAR1641 “AgriCapture Grasslands Project 1”, Texas
	  ○ Appeared as listed
	• CAR 1649 “Fauth Ranch”, Montana
	  ○ Appeared as listed
	• CAR1650 “Roen Ranch”, Montana
	  ○ Appeared as listed
	• CAR1651 “Middle Fork I Avoided Grassland Conversion”, Montana
	  ○ Appeared as listed
	• CAR 1652 “Willow Creek Avoided Grassland Conversion”, Montana
	  ○ Appeared as listed
	• CAR1653 “Middle Fork II Avoided Grassland Conversion”, Montana
	  ○ Appeared as listed
	• CAR1580 “Pfister Ranch Avoided Conversion”, Montana
	  ○ Appeared as listed
	
	CAR Canada Grassland Protocol
	  ○ N/A

	Verra VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing • Northern Kenya Grasslands Project: The Northern Rangelands Trust is aiding 11 different conservancies on pastoralist-occupied lands in northern Kenya implement a shift from continuous, unrestricted grazing to planned rotational grazing. Project area spans 1,993,078 ha. The project is expected to restore overgrazed grasslands and remove more than 600,000 tons of greenhouse gas (CO_2e) from the atmosphere. o 1,797,493 estimated annual emissions reductions. • Soil carbon improvement Project through Grassland Management, in South Africa: o 238,813 estimated annual emissions reductions **Verra VM0026 Methodology for Sustainable Grassland Management (SGM), v1.1** • Guoluo Grassland Sustainable Management Project in Guoluo Tibetan Autonomous Prefecture, Qinghai Province, China. (Registered) o The project's aim is to restore the local degraded grassland ecosystem by seeding grass on black soil beach, increase carbon sequestration and contribute to local development by introducing sustainable grazing and management of grassland across 160,549 ha. o 456,953 estimated annual emissions reductions. • Northern Great Plains Regenerative Grazing Project in Montana (Registered) o Project implements sustainable grazing management on multiple ranches in Montana. It is a grouped projected starting with 33,292 acres. o 22,000 estimated annual emissions reductions once practices are fully implemented. • Zhangye Improved Grassland Management Project in China. (Registered) o Rest grazing and rotational grazing are implemented in slightly degraded areas (the total grass yield decreased by 30%-50% compared with that before degradation), and reseeding is implemented in severely degraded areas. o Estimated annual emissions reductions: 736,006 • Xinjiang Burqin Improved Grassland Management Project in China (Registration and verification approval requested) o Grass seeding was implemented in 5,000 ha of the severely degraded grasslands where grass seeds of local high-quality forage was sowed under the condition of fencing enclosure for 2 years & Imposing grazing prohibition measures and building fences on 60,000 hectares of degraded grassland o Estimated annual emissions reductions: 271,847 • NATURE GENERATOR ONE Northern Mexico Sustainable Grazing Carbon Capture Project in Mexico (Under Development) o Implement a project of sustainable grazing practices on private ranch lands in the geographic area located in the state of Coahuila, Mexico. o Estimated annual emissions reductions: 152,864

	• Patagonia Region Improved Grazing Project in Argentina (Under development)
	  o Pastures will be grazed with higher livestock densities followed by longer periods of rest, increasing both plant productivity and soil carbon inputs relative to baseline conditions\
	  o Estimated annual emissions reductions: 24,952
	• Northern Great Plains Regenerative Grazing Project 2 in the US (Under development)
	  o Planned grazing will increase the rest and rotation on pastures above baseline practices and reduce unrestricted grazing by livestock. Pastures will be grazed with higher livestock densities followed by longer periods of rest, increasing both plant productivity and soil carbon inputs relative to baseline conditions.
	  o Estimated annual emissions reductions: 17,000
	• Tibet Ngari Improved Grassland Management Project in China (Under development)
	  o Objective of the project is to restore the 'black soil beach' and degraded grassland ecosystem through reseeding native grasses and grazing management, such as rest grazing and grazing prohibition, increase carbon sequestration, and promote local development.
	  o Estimated annual emissions reductions: 485,038
	• Xinjiang Burqin Improved Grassland Management Project Phase II in China (Under validation)
	  o Estimated annual emissions reductions: 262,318
	• Tibet Nagqu Improved Grassland Management Project in China (Under Validation)
	  o Estimated annual emissions reductions: 373,458
	
	Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0; international
	• Avoided Grassland Conversion Cerrado Project in Brazil. (Registered)
	  o The Cerrado biome is a tropical wet and dry grassland/savanna, and since 1985 has lost 47% of its native vegetation to agriculture. The Avoided Grassland Conversion Cerrado Program was launched as a grouped project to provide an alternative for landholders with surplus native vegetation to receive payments for conservation by leveraging the voluntary carbon market. Under the program, the private landholder foregoes their legal right to convert native vegetation, and in doing so avoids GHG emissions. The project is implemented across 10,841 ha.
	  o 100,000 estimated annual emissions reductions.
	• Pendjari and W-Benin National Parks REDD+ Project in Benin (Registration and verification approval requested)
	  o Estimated annual emission reductions: 269,843
	• Chinko conservation area REDD+ project , central African republic in Central African Republic (Registration and verification approval requested)
	  o Estimated annual emission reductions: 1,248,867

	• Musokotwane REDD+ Project in Zambia (Under Validation)
	  ○ Estimated annual emission reductions: 1,100,000
	
	Verra Methodology for Agricultural Land Management: Improved Grassland Management (Under Development)
	  ○ N/A
	
	Verra Avoided Planned Conversion of Grasslands and Shrublands to Crop Production (Under Development)
	  ○ N/A
	
	Panda Standard Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)
	  ○ Unable locate the registry
	
	Compliance
	  ○ N/A

Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc. within any existing or proposed market?	*Voluntary* **ACR Avoided Conversion of Grasslands and Shrublands to Crop Production** • Not specified in the protocol **CAR Grassland Protocol** • Not specified in the protocol **CAR Canada grassland protocol** • Not specified in the protocol **Verra VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing** • Not specified in the protocol **Verra VM0026 Methodology for Sustainable Grassland Management (SGM), v1.1** • Aggregation of grassland parcels with multiple landowners is permitted under the methodology, with aggregated areas treated as a single project area

	Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0 • Grouped projects permitted **Verra Methodology for Agricultural Land Management: Improved Grassland Management (Under Development**) • Not specified in the protocol **Verra Avoided Planned Conversion of Grasslands and Shrublands to Crop Production (Under Development)** • Aggregation permitted **Panda Standard Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • Not specified in protocol *Compliance* • N/A
Is there controversy surrounding the markets or credits for the NCS pathway? Why?	• Concerns about accurate estimation of SOC across a project area, given the challenges around estimating SOC • **Permanence** and **reversal** issues due to SOC vulnerability • **Additionality**: anticipated low costs of grassland C sequestration are intertwined with issues of additionality. If barriers/costs for adopting practices that sequester C are low, they are more likely to be adopted in the absence of policies to promote them (Conant, 2010) • **Leakage**: grassland conversion could happen elsewhere • Additional social/equity concerns ○ Pastoralists occupy substantial portions of grasslands across the world, but they are often socially marginalized and have insecure land-tenure rights, which makes it difficult to participate in C markets. There may be similar issues for smallholder producers in North America • Controversy around “improved grazing”, and the management practices included in this category

Macroalgae (Aquaculture): *Macroalgae farming*

Macroalgae, or seaweeds, are multicellular marine autotrophs (requiring only CO2, water, light, nitrogen, and other nutrients) that take up C through photosynthesis. Global macroalgae cover (including aquaculture) is estimated to be about 6 million km2, or 1.6% of the ocean's surface (Duarte et al., 2022).

There are generally three groups of seaweeds, largely distinguished by their pigmentation, commonly referred to as reds, greens, and browns. Even within these groups, seaweeds vary widely in their morphology and C concentration, including bottom-anchored species that form the structure for entire ecosystems (e.g., kelp forests) and genera such as Sargassum, which can be found in both free-floating and anchored forms. Benthic macroalgae cover about 1% of the ocean's surface, but the spatial extent of pelagic macroalgae is unknown – they can form very large rafts of up to 600 km2; one study estimates that blooms weighing 20 million tons formed in the tropical Atlantic alone in 2018 (Wang and Hu, 2016). While the vast majority of seaweeds are naturally occurring, more than 32 million metric tons of seaweed are farmed each year (FAO, 2020) for a diverse array of human uses ranging from fertilizers to food products to hydrocolloids (McLachlan, 1985; Sangha et al., 2014).

Seaweeds take up dissolved carbon (C) from seawater and convert it to organic compounds and biomass (Paine et al., 2021) via photosynthesis at rates that are among the highest on the planet (Packer 2009). The dissolved C removed by seaweed is slowly replaced by atmospheric CO2 (NASEM 2021 report and references therein), resulting in a flux of CO2 from the atmosphere into the ocean.

While seaweeds fix C rapidly, and store it for a time in biomass, only a portion of this C is sequestered on a timescale of centuries or millennia. Some of the fixed C is grazed, then remineralized to CO2. In some cases, grazing can remove a large fraction of the seaweed biomass. For example, Krumhansl & Scheibling (2012) estimate that 82% of kelp productivity is removed by grazing. Some of the carbon fixed by seaweeds is exuded as dissolved organic C (DOC), a portion of which is also remineralized to CO2 in surface waters. Natural seaweed stands sequester C via three primary pathways: Some seaweed biomass is buried directly below seaweed beds; some biomass is transported by currents to deep ocean waters and sediments, where it can be buried; and seaweeds also leach C into the water column in a dissolved form that is resistant to degradation (i.e., dissolved organic carbon (DOC)) The total quantity of C sequestered by seaweeds is thus affected by many factors, including the gradient in CO2 concentration between the ocean and the atmosphere, the amount of loss to grazing and DOC remineralized in surface waters, and the amount of seaweed C that is transported to sediments or deep waters as fragments, C adsorbed onto particles, or as DOC (Krause-Jensen and Duarte, 2016).

The fate of seaweed that is harvested from natural stands or farms also affects C sequestration: currently, almost all harvested seaweed is used to produce food and colloids, thus entering the fast carbon cycle and not contributing much to C sequestration. Sinking the seaweed into deep waters has been proposed as a way to increase C sequestration through this pathway, but it is not currently economically feasible, the ecological risks are unknown, and the many other known benefits of seaweeds for people and nature would be lost. Injecting seaweed into stable geological formations has also been proposed but may also be economically infeasible and would result in a substantial loss in benefits.

Converting seaweed into products that result in avoided GHG emissions (e.g., fertilizers, bioplastics, and biofuels) may be the most effective way to make use of seaweeds to reduce atmospheric GHG concentrations. The use of certain seaweed species as cattle feed supplements that reduce methane emissions is under active investigation (Kinley et al., 2020). Converting seaweed into long lasting materials such as building materials or into soil conditioners that result in the incorporation of C fixed by seaweed into soil for longer term storage may represent ways to increase carbon sequestration by seaweeds but these uses are still under development.

The rate of C sequestration by natural seaweeds remains uncertain but is estimated to be approximately 0.173 Pg C yr-1 (Krause-Jensen & Duarte, 2016; equivalent to 0.635 Pg CO2 yr-1), roughly equivalent to that believed to be sequestered by all coastal blue C ecosystems combined (mangroves, tidal marshes and seagrass beds) (Howard et al., 2017). This estimate of C sequestration is limited to that sequestered by wild seaweed (not including aquaculture farms). The sequestered carbon is produced over the 3.5 million km2 occupied by seaweed and is mostly stored in the deep sea (Krause-Jensen and Duarte, 2016). The area occupied by seaweed aquaculture represents about 1,600 km2 globally, i.e., 0.04% of the area covered by wild seaweed habitats or 0.004% of the coastal ocean (Duarte et al., 2017).

Many caveats apply to this estimate. This estimate may not include carbon sequestered by massive pelagic seaweed blooms which appear to sequester carbon via fragmentation and advection to deep waters, sometimes in large storm-driven pulses. The areal extent of seaweed distribution appears to be highly variable and difficult to quantify, with estimates ranging from 1.4 million km2 to 5.7 million km^2 (Krause-Jensen and Duarte, 2016). Changes over time are highly region- and species-specific. For example, macroalgae cover in the Mexican Caribbean increased from ~17% in the late 1980s to ~25% in 2016 (Contreras-Silva et al., 2020), while regional averages for the Mesoamerican Reef showed significant increases in macroalgal cover within a subset of this time period as well (Suchley et al., 2016). Conversely, over the past 50 years, 65% of kelp forests have experienced significant geographic variation, with 38% of ecoregions experiencing significant declines (Krumhansl et al., 2016).

Moreover, while C flow through seaweed systems also depend on species, the C stock and flow estimates reported in the literature have been derived from studies on a small subset of the over 800 seaweed species, introducing a major source of uncertainty into estimated C sequestration rate. Because C sequestration by seaweed systems is highly species and context dependent, shifts in the distribution and abundance of different seaweed species are likely have major impacts on C sequestration.

Significant scientific uncertainties continue to surround all aspects of seaweed C sequestration. Seaweeds take up C and grow much faster than most plant species. Therefore, if rates of biomass burial and biomass transfer to the deep ocean exceed rates of C remineralization through grazing and microbial respiration of dissolved organic C released by macroalgae, C sequestration rates by natural stands of macroalgae could be quite high. However, standing stocks of C within such stands would be relatively low; moreover, this C turns over relatively rapidly, reducing potential for long term sequestration Lack of data on these rates as well as the lack of good estimates of areal extent are key uncertainties that prevent accurate quantification of C sequestration by natural seaweed stands. Moreover, these rates and hence C sequestration are likely to be highly context-specific and depend on dominant seaweed species presence, areal density, nutrient availability, food web characteristics, oceanographic conditions, and other variables.

It is possible to take advantage of the very high C uptake and growth rates of seaweeds to enhance C sequestration by farming seaweed and creating sequestration pathways and to reduce GHG emissions (see above on the role of seaweed products). While estimates of suitable aquaculture areas in the ocean are not well constrained, it seems clear that less than 0.01% of suitable ocean area is currently being used for that purpose, all in nearshore waters (Duarte et al., 2017; Froehlich et al., 2019). While almost all seaweed farming occurs in Asia, the potential for seaweed aquaculture in other parts of the world in nearshore waters is large but constrained by other claims on marine space, markets, regulatory gaps, and other factors.

While a range of logistical, financial and jurisdictional challenges have traditionally discouraged the offshore farming of seaweeds, the past five years have seen increased investment by government, for-profit and non-profit entities in seaweed farming. This has resulted in new technologies and practices for growing seaweed in the open ocean. If these are successful at commercial scale, open-ocean seaweed farming could become a significant C sequestration pathway. However, C sequestration by seaweed farms would depend on how the seaweed yield is used. Moreover, there may be tradeoffs between C sequestration and the many other benefits that can be derived from seaweeds, including food, nutraceuticals, biodiversity enhancement, fishery enhancement, biofuels, and emerging new products such as seaweed-based textiles, bioplastics, purified protein, and livestock feed additives that could reduce methane emissions from ruminants. Finally, because macroalgae can sometimes produce massive blooms that may at first seem to contain excess biomass unused by nature – such as the case with recent growth of

Sargassum in the subtropical North Atlantic – there is increasing interest in harvesting the resulting biomass and converting it to food and other products, as well as in sequestering the C contained in the bloom biomass. It is important to note that while these blooms are often considered a nuisance, they provide important habitat for a wide range of species as well as important sources of nutrient transfer; any purposeful cultivation of macroalgae in the open ocean must take these positive externalities into account.

While we distinguish here between nearshore and offshore, it is important to note that C sequestered by seaweed systems is likely to transcend arbitrary boundaries, presenting a challenge for defining the boundaries of the system for the purposes of C accounting.

The use of seaweed to generate value in conventional markets and to create non-market benefits such as biodiversity enhancement could be key for expanding seaweed farming to scales capable of sequestering meaningful amounts of C. Some studies suggest that using seaweeds to remove nutrient pollution can become cost-effective relative to upgrading sewage treatment to remove nutrients if the seaweed were to be used as fertilizer or as food for human consumption (Wu et al., 2022). However, certain proposed uses of seaweed yield, such as sinking large amounts of seaweed in deep ocean waters to maximize C sequestration, could result in adverse ecological impacts that are currently not understood.

No C markets currently exist for seaweed-based C sequestration, but the Oceans 2050 initiative and several other entities are seeking certifications for seaweed-based C credits by mid-2022. There are existing opportunities for emissions reductions within the existing macroalgae aquaculture industry, and the restoration of natural seaweed stands as well as the establishment of seaweed farms that sequester C safely could represent no-regrets strategies for removing some C while producing substantial co-benefits. However, many critical knowledge gaps must be addressed before seaweed farming could be widely exploited as a source of significant, high-quality C credits.

Macroalgae

Global Areal Extent: Poorly constrained. Likely combined extent of natural and farmed marine macroalgal beds is approximately 3,500,000 km^2 (350,000,000 ha, or approximately 1% of global ocean surface area) (Krause-Jensen and Duarte, 2016)[11]

Carbon Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?	• Global stock: 1.3 – 9.5 Pg C (very rough estimate which based in many simplifying assumptions, and which excludes massive pelagic seaweed rafts) • Average per hectare (est.): 9.3 – 16.7 Mg C ha-1 • The extent and C density of the world's macroalgal ecosystems remain very poorly constrained, necessitating further research. To obtain the rudimentary estimates presented here, we combined data reported in several sources (Muraoka, 2004; Gattuso et al., 2006; Graham et al., 2007; Duarte et al., 2017) and assumed that elemental composition and areal density for Laminaria sp. (giant kelp) were broadly representative of all macroalgae.
At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	• The seaweed system (natural seaweed beds, plus farms and seaweed products) *likely functions* as a *net C sink*. Carbon is taken up and stored by both natural seaweed beds and seaweed farms; however, the latter constitute a small fraction of the total global standing stock. Within seaweeds, C is stored for a relatively short time in fronds, stipes, and holdfasts. Some C is also stored in the products that are made from harvested seaweed. • The total net primary productivity of the current natural seaweed system is approximately 1.5 Pg C (5.51 Pg CO_2) yr^{-1} (Krause-Jensen and Duarte, 2016). One recent study estimated that 0.173 Pg C (0.635 Pg CO_2), or approximately 11.5% of this total annual production, may be sequestered each year in the ocean through direct burial of biomass below seaweed beds, export and burial of seaweed biomass in sediments in the deep ocean or by transformation of the biomass into degradation-resistant DOC in the water column (Krause-Jensen and Duarte, 2016). This estimate of sequestration was reported with extraordinarily high uncertainty; the authors estimated the sequestration rate could be as high as 0.268 Pg C yr^{-1} (0.98 Pg CO_2 yr^{-1}) or as low as 0.061 Pg C yr^{-1} (0.22 Pg CO_2 yr^{-1}). The seaweed sequestration rate and associated uncertainty are of the same magnitude as the 0.077 – 0.204 Pg C yr^{-1} (0.28 – 0.75 Pg CO_2 yr^{-1}) estimated to be sequestered by all coastal blue C ecosystems combined (mangroves, tidal marshes and seagrass beds) (Howard et al., 2017). • While C uptake by seaweeds is very rapid, the very fast turnover of biomass in macroalgal ecosystems compared with terrestrial forests (compare 1 – 2 years for some kelp forests with 50 – 100 years for the woody biomass in some tropical forests) results in relatively little C

[11] Various methods have placed the extent of natural algal beds, including kelp forests, at between 1.4 × 10^6 million ha (minimum estimated extent) (Duarte et al., 2013) and 5.7 × 10^6 ha (max. possible extent based on modeled habitat) (Gattuso et al., 2006). The 3,500,000 km^2 reported by Krause-Jensen and Duarte (2016) is based on a Monte Carlo bootstrap simulation that combined all available literature values. The global extent of farmed macroalgal beds has been estimated at 1,600 km^2 (Duarte et al., 2017).

storage in standing stocks of seaweeds over timescales relevant for climate change. Rapid C uptake by seaweeds could result in significant C sequestration in sediments and deep water despite high biomass turnover rates, if rates of burial and transport greatly exceed rates of C remineralization in seaweed stands.

- The presence of calcifying organisms and calcareous substrates and the presence of food webs in ocean-based seaweed systems (as opposed to land-based tank farms) also complicates the quantification of C sequestration due to the release of CO2 via calcification and respiration.
- Our ability to more precisely estimate the overall rate of C sequestration by seaweeds is limited by a lack of knowledge about several key processes and biogeochemical fluxes in the current seaweed system. These key uncertainties include:
    - *The magnitude of greenhouse gas emissions produced during harvesting and processing of farmed seaweeds:* These emissions are estimated to be small relative to C uptake, but we do not know how much is emitted.
    - *Leakage and fate of dissolved C in the water column:* Seaweeds leak dissolved C into the surrounding water as a natural consequence of their growth. Most of this dissolved C is remineralized into CO_2, while some is eventually sequestered in refractory (degradation-resistant) dissolved forms in the deep sea. The fraction of dissolved C that is remineralized to CO_2, and the fraction of this CO_2 that then reenters the atmosphere, are determined by a range of competing factors including metabolism by bacteria, the preexisting concentration of dissolved CO_2 in the surrounding water mass, water temperature and the degree of water column stratification. Likewise, the degree to which seaweeds fragment (and are culled in farms) and the extent to which C absorbed by seaweeds is sequestered via advection of these culled and natural fragments to sediments and deep water are not well characterized.
    - *The degree of storage in farmed seaweed products:* The amount of C stored and the duration of C storage in products made from seaweed is probably fairly small, as 40% of seaweed was used as food for direct consumption in 2012 (Bjerregaard et al., 2016) and most of the other products made from seaweed have relatively short lifetimes. Consumption of seaweed would result in rapid return of the C sequestered in seaweed biomass to the atmosphere. Another 40% of seaweed production in 2012 was used to make agar, carrageenan, and other hydrocolloid products that are used in processed foods (Bjerregaard et al., 2016). During the extraction of hydrocolloids, the majority of the seaweed biomass goes unused, and thus only a negligible amount of C is expected to be sequestered. However, markets for direct consumption and hydrocolloids are growing as demand for substitutes for high impact foods (e.g., meat substitutes) grows; this creates some scope for reducing future GHG emissions. The remaining 20% of global seaweed yield was used in other non-food related seaweed products such as fertilizers or soil amendments, pharmaceuticals, cosmetics, and animal feed, some of which also use extracted seaweed hydrocolloids. Like the food products, these products are also not expected to provide much direct C sequestration due to their relatively short life cycle. Hence, we omit the C stored in seaweed products from our estimate of total C storage (Bjerregaard et al., 2016). However, these uses of seaweed may provide other ecological benefits such as enhancing C uptake of crops and replacing products that currently produce large amounts of GHGs or are more environmentally damaging.
    - *Other possible climate impacts of seaweed:* Carbon sequestration is not the only pathway through which seaweed may slow climate change. Like phytoplankton, some types of seaweed (e.g., the green alga *Ulva*) produce the osmolyte and antioxidant dimethylsulphoniopropionate (DMSP); once released into the water, DMSP is converted by bacteria into dimethylsulfide (DMS), a

	volatile organic compound that may play a role in cooling the atmosphere by catalyzing the formation of clouds (Yoch, 2003). Moreover, application of seaweed-based soil conditioners may spare the release of potent greenhouse gases such as N_2O from croplands if used to replace traditional nitrogen fertilizers. Use of seaweed as a biofuel could reduce GHG emissions to the extent it is substituted for fossil fuel or used as a feedstock in a bioenergy with C capture and storage (BECCS) system (Hughes et al., 2012) . Moreover, several studies suggest that inclusion of small amounts of seaweed in ruminant feeds can result in substantial reductions in methane emissions (Duarte et al., 2017; Kinley et al., 2020). • *Business as usual projection:* Absent an increase in seaweed aquaculture, *we project little change in C sequestration* by the seaweed system. Although natural kelp abundances have declined in certain regions due to habitat destruction, the global areal extent of kelp forest habitat does not appear to have changed significantly over the past 50 years (Krumhansl et al., 2016). However, this projection is very uncertain: Nothing is known about changes in the abundance of other macroalgal species on a global scale, and we do not know what effect climate-related changes in the ocean (e.g., warming, increased storm frequency) will have on global macroalgal abundances.
Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	• *Yes*, increases in C sequestration and decreases in emissions from the seaweed system are both possible. • *Significant potential for increased sequestration via seaweed farming:* Increased seaweed aquaculture could yield a large increase in net C sequestration, especially if farming activity were concentrated in areas of the ocean where there are no or few naturally-occurring seaweed beds. Additional increases in sequestration could be realized by enhancing rates of sequestration efficiency via a number of pathways. These include: ○ "assisted burial," i.e., moving a greater fraction of seaweed biomass into the deep ocean, either through natural or mechanical means, ○ increased storage of seaweed-derived C in durable products such as bioplastics and construction materials, and ○ optimizing harvest cycles to reduce the fraction of seaweed-derived DOC that is remineralized directly back into CO_2 • *Significant potential to reduce GHG emissions by converting seaweed into biofuel, bioplastics, and fertilizers.* Biofuel and fertilizer production may not be economically feasible due to low prices (however, fuel and conventional fertilizer prices are increasing currently, which could alter this situation). The creation of durable bioplastics and construction materials from seaweed is still under active investigation. • *Prevention/reductions in emissions from changes in seaweed aquaculture practices:* Operating processes (e.g., harvesting) and value-add processes (e.g., drying) could both be optimized to prevent C emissions (e.g., via conversion to fuel efficient or zero emission boats, changes in flushing rates, the use of low energy intensive drying methods, etc.). C emissions could also be reduced by altering the mix of products that are made from seaweed, since different products have very different emissions profiles. All of these changes could be applied to existing seaweed aquaculture operations or incorporated at baseline into any new farming activities. • *No large gains in sequestration likely to be realized from restoration of existing kelp beds:* Although natural kelp abundances have declined very steeply in certain regions due to habitat destruction (e.g., a 93% decline in kelp cover off California from 2008-2014), the global areal extent of kelp forest habitat does not appear to have changed significantly over the past 50 years due to concomitant increases in kelp habitat

	elsewhere (Krumhansl et al., 2016). However, there would likely be many co-benefits to restoring natural kelp forests in regions where large decreases have been observed. Warming may limit the success of such restoration efforts in some areas.
What is the range of estimates for how much additional C could be sequestered globally?	• Given the very small area currently devoted to seaweed farming, increased macroalgal aquaculture could sequester a very substantial amount of additional C. However, the extent of potential farmable ocean area remains poorly constrained and we still do not have a full understanding of relevant biogeochemical processes or the possible ecological consequences of such large-scale "ocean afforestation" (Barry et al., 2021). In addition, open-ocean aquaculture faces significant financial, logistical and jurisdictional challenges (Krause-Jensen et al., 2018). • Results from two studies suggest that seaweed farms currently occupy just 1,600 km^2, or 0.003%, of a potential 48,000,000 km^2 of ocean that is suitable for macroalgal culture (Duarte et al., 2017; Froehlich et al., 2019) (uncertainties not reported in either study). No studies have predicted with any fidelity the potential C sequestration that could accompany an expansion of farming into this new ocean area. The quantity of C sequestered by new seaweed farms is likely to vary dramatically depending on siting, operations, and the disposition (uses) of the yield. Hence, the range of C sequestration that may be possible as a result of expanded seaweed farming will likely be very large, even once sufficient data are available on rates of C absorption, remineralization, and storage to estimate C sequestration from seaweed farms. **T**he 2021 study board on ocean CDR convened by the U.S. National Academies of Science, Engineering and Medicine (NASEM) estimated that farming a 100 m wide continuous belt of ocean along 63% of global coastline (about 72,900 km^2) could sequester 0.1 Gt CO2/yr (see footnote 1) if all the biomass were sunk directly into the deep ocean. This would represent a 45-fold increase from current areal extent of seaweed farming to about 0.2% of the total suitable farmable area estimated by Froehlich et al (2019). This estimate rests on several simplifying assumptions: (1) 8% of DOC exuded by the seaweed is refractory (undefined in the NASEM 2021 report) and becomes sequestered (low contribution of refractory DOC to sequestration results from harvesting and sinking the biomass); (2) 20% of the biomass is lost to breakage, grazing, and other factors; (3) yield will approximate that of a natural kelp forest (1 kg dry weight/m2); and (4) 1.5 harvests will be completed each year. Nutrient availability may constrain the expansion of large-scale seaweed farming.

How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that system?	• We have a moderate to low degree of confidence in the ability of current methods to detect and quantify C sequestration in seaweed beds and farms, although this science is evolving quickly. A growing number of for-profit and non-profit entities are working in the macroalgal aquaculture space to demonstrate the viability of seaweeds for commercial-scale C sequestration. Ongoing or planned initiatives that will help to narrow the existing uncertainties include: ○ The Oceans 2050 initiative[12] will likely result in high quality data on C sequestration by a variety of types of seaweed farms; Oceans 2050 hopes to submit a verified C standard based on macroalgal sequestration to an international accrediting agency by mid-2022. ○ Ocean Wise is working with an indigenous group in Patagonia (Chile) to measure C sequestration in a natural seaweed forest. ○ The Bigelow Laboratory for Ocean Science is exploring how kelp can remediate the impacts of climate change, tracking carbon dioxide, oxygen, nutrient concentrations, salinity and temperature in three kelp farms, data which will be used to parameterize a computer model for projecting kelp growth and changes in water quality. ○ The Grantham Environmental Trust is investing in startups such as Maine-based Running Tide, which is developing methods to enhance and quantify macroalgal C sequestration from floating seaweed platforms. ○ The U.S. Department of Energy continues to invest in a wide range of projects via its ARPA-E MARINER program, which is focused generally on improving U.S. seaweed biomass yields. ○ The Environmental Defense Fund plans to implement a seaweed-shellfish farm in the Philippines that would use part of the seaweed yield as a soil conditioner/fertilizer. The project will include a C sequestration monitoring program. ○ EDF is also hoping to initiative projects to develop low cost sensor and monitoring systems for seaweed farms in order to estimate C sequestration, starting with closed-system farms in which estimate C sequestration should be substantially easier than in open water or flow-through tank farms.

C Markets

Is there a market (or proposed market) for carbon credits from the system?	Despite the large uncertainties that remain, some investment based on anticipated C reduction via seaweed farming has occurred. E-Commerce site Shopify donated a portion of its USD 5 million “Sustainability Fund” to organizations including Maine-based Running Tide.

[12] See https://www.oceans2050.com/seaweed

Are there protocols (or proposed protocols) for such credits?	Oceans 2050 is working on the development of a formal protocol for estimating additional C sequestration by seaweed forests and seaweed forms to drive mandatory C markets, to be put into approval in 2022. Kelp Blue, Syntec, Running Tide, Pull to Refresh and other companies are also trying to develop protocols to do this (Werner, 2021). At least one company, Pull to Refresh, intends to begin selling C credits based on kelp sequestration as soon as possible, even if there is not yet a standard in place (Temple, 2021).
If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	Not applicable.
If there are protocols, have there been any registered projects or credits generated? If so, where?	Not applicable.

Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc. within any existing or proposed market?	None at present, but EDF has a strong potential role to play in this area. The many logistical, financial and jurisdictional challenges associated with offshore macroalgal aquaculture will require new cooperative approaches and legal frameworks before the sector is mature enough to support widespread C market activity.
Is there controversy surrounding the markets or credits for the NCS pathway? Why?	There are no major controversies at present, largely because the seaweed C credit market is still very much in its infancy. Substantial scientific uncertainties surround the global extent of macroalgal ecosystems, the amount of C these systems sequester, the potential area for new seaweed farms and many of the associated biogeochemical processes. In addition, there are substantial logistical, financial and jurisdictional challenges associated with offshore macroalgal aquaculture projects — the most promising pathway for C sequestration within the broader macroalgal landscape.

Open Ocean Blue Carbon: *Sequestration via restoration of whales and other large marine animal biomass & Avoided emissions through limits or prohibitions on new fishing in the mesopelagic zone*

Covering 71 percent of the Earth's surface, the ocean system currently stores between 41,000 and 55,000 Pg C more than all the C in soils and forests combined (Emerson and Hedges, 2008; Pidwirny and Jones, 2010). Most of this C (ca. 39,000 Pg C) is dissolved in seawater (Emerson and Hedges, 2008), with a substantial additional amount of organic C stored in ocean sediments (between 2,322 and 16,000 Pg C, depending on the sediment depth that is considered (Estes et al., 2019; Atwood et al., 2020). Living marine biota – plants and animals – contain a much smaller amount of C, though there is reason to believe the biomass of fishes in the ocean's understudied mesopelagic depths has been significantly underestimated. However, marine animals ingest, transform, and produce carbon at rapid rates with significant sequestration potential (Saba et al., 2021; Martin et al., 2021). Therefore, significant disruption to or biomass removal of these key players could affect their capacity to fix and sequester C(Macreadie et al., 2017; Martin et al., 2020).

The oceans currently serve as a major C sink, absorbing from the atmosphere as CO_2 approximately 2.5 Pg C yr^{-1}, via a combination of biological processes and physical forcing (Sabine and Feely, 2007). From the surface ocean, biological and physical processes export a total of 8 – 15 Pg C yr^{-1} in various particulate and dissolved forms to depths where it may be considered sequestered from the atmosphere on timescales relevant for climate change (Sabine and Feely, 2007; Hauck et al., 2020).There is a broad range of proposals to increase net C sequestration by enhancing or manipulating ocean biogeochemical processes, ranging from approaches that have been characterized as geoengineering (e.g., surface-ocean iron fertilization and artificial alkalinization) to natural climate solutions such as those EDF is currently evaluating. These NCS include the restoration of large marine animal biomass (Pershing et al., 2010; Lavery et al., 2010, 2014), conservation of fish communities that inhabit the mesopelagic "ocean twilight zone" (Irigoien et al., 2014; Mariani et al., 2020) and C sequestration through open ocean macroalgal aquaculture[13]. However, there are currently no reliable estimates for how much additional C could be sequestered globally in the open ocean through any of these pathways. The level of confidence in current methods to detect global changes in C sequestration with the precision and specificity necessary to support C markets is very low. For example, we do not even know yet whether whales serve as net sources or sinks of C with respect to the atmosphere over the course of their life histories, let alone how much C the restoration of a single additional whale might sequester or how we might track and attribute such sequestration.

While there are currently no proposed markets for C credits in the open ocean, there has been some recent discussion among nonscientists about the possible C market value of whale restoration. Importantly, each of these NCS pathways is unto itself a "no regrets" conservation strategy replete with potential co-benefits for people and society. The ecosystem restoration and/or enhancement necessary in each case – protecting mesopelagic fishes on the one hand or restoring whale populations on the other – will almost certainly make the oceans more resilient

[13] EDF is evaluating the cultivation of macroalgae in the open ocean as an NCS pathway distinct from restoration of large animal biomass and preservation of mesopelagic fishes; see separate table.

in the face of climate change, stabilize global fisheries populations and support human livelihoods, regardless of how much C is sequestered.

Ocean Blue Carbon

Global Areal Extent: 361,900,000 km² (71% of Earth's surface) (Pidwirny and Jones, 2010)

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?	The global ocean stores approximately 39,000 Pg C in the water column, the vast majority of it as inorganic, dissolved carbonates, with a smaller 700 Pg C pool in various dissolved organic forms (Emerson and Hedges, 2008). This ocean reservoir includes approximately 140 Pg of anthropogenic C absorbed from the atmosphere since 1800, amounting to approximately 0.4 % of the total current ocean inventory (Gruber et al., 2019). The top meter of marine sediments stores an estimated 2,300 Pg of organic C, with recent work suggesting the total amount of organic C below the ocean floor may be as much as 16,000 Pg (Estes et al., 2019; Atwood et al., 2020). The amount of C stored in living marine biota is highly uncertain, but there is no doubt it is orders of magnitude lower than the amount of C in ocean water or marine sediments. Mass balance suggests living marine biota may contain 1 – 3 Pg C (Mackenzie and Lerman, 2006), although more recent work focused on "twilight zone" mesopelagic communities (i.e., those fishes found between 200 and 1000 m deep) suggests the amount of C in ocean biota could be substantially greater. For example, Irigoien et al. (2014) estimated that fishes inhabiting the mesopelagic between 40° N and 40° S likely contain between 1.4 and 1.9 Pg C but could contain as much as 25 Pg C.[14] These are likely underestimates because they do not include productive higher latitude areas or mesopelagic invertebrates.
At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	The ocean is a strong sink for anthropogenic C. The surface ocean currently *absorbs* approximately 2.5 Pg C yr^{-1} from the atmosphere as CO_2, through a combination of biological processes (dominated by uptake during primary production by phytoplankton) and physical forcing (the rise in atmospheric CO_2 concentrations continues to "push" more and more C into the ocean).[15] The surface ocean exports 8 – 15 Pg C (equivalent to 29 – 55 Pg CO_2) yr^{-1} to deeper waters in a variety of particulate and dissolved forms, where the C can then be considered *sequestered* from the atmosphere over the decadal to centennial timescales relevant for climate change (Sabine and Feely, 2007; Hauck et al., 2020) Between 0.2 – 0.4 Pg C (equivalent to 0.7 – 1.5 Pg CO_2) yr^{-1} from the surface and deep oceans ends up in seafloor sediments, where it is sequestered over much longer timescales (Middelburg, 2019). While these ocean sequestration mechanisms vary in strength and type, the same generality applies within each: The deeper C gets in the water column, the longer the timescale of sequestration.

[14] Calculation is based on assumption of Mariani et al. (2020) that biomass contains 12.5% C by mass.

[15] Models and reconstructions of past ocean chemistry indicate that the ocean served as a source of C to the atmosphere prior to the onset of the Industrial Revolution (Sabine and Feely, 2007)

Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	*Yes, but potential is very poorly constrained in all cases* • There are several proposed carbon dioxide reduction strategies and natural climate solutions (NCS) which aim to harness biogeochemical processes in the open ocean to store more C in the ocean interior. There are also several policy interventions that could prevent additional emissions from the ocean system. *Whales and other large marine animals* • A small number of scientific studies have suggested that whales and other marine mammals may sequester C through two primary mechanisms: directly, through "whale fall" (i.e., the sinking of whale carcasses, and the C within them, to the ocean floor upon death) (Pershing et al., 2010) and/or (2) indirectly, via a "fertilization" mechanism in which whales recycle nutrients from deep waters back to the surface in their feces, stimulating phytoplankton growth followed by some export of the newly fixed C (Pershing et al., 2010; Lavery et al., 2010, 2014). The limited evidence for sequestration via this second fertilization pathway based on scientifically liberal assumptions and an incomplete consideration of uncertainties in the many underlying biogeochemical processes. Marine mammals and fishes (see below) may also stimulate primary production through their swimming movements, helping to mix deeper waters containing dissolved nutrients into the ocean's nutrient-depleted surface layer; however, as in the case of fertilization through fecal deposition, the overall effect of animal advection on C export has not been well demonstrated. *Mesopelagic fish and invertebrates* • While we understand very little about the ocean's mesopelagic communities – for example, ~~we do not even know~~ how much biomass is contained in mesopelagic fishes (compare (Irigoien et al., 2014; Mariani et al., 2020) – these species may export as much as 2 Pg C (equivalent to 7.3 Pg CO_2) yr^{-1} from the ocean's surface through their diel vertical migrations (equivalent to 13 – 25% of the total annual ocean C export flux; (Boyd et al., 2019). During these migrations, mesopelagic organisms rise to the ocean's surface at night to feed on ~~phytoplankton~~ and ~~smaller~~ animals, then retreat down to depths where they respire and excrete (feces or dissolved forms) much of the C consumed at the surface. Even though we do not fully understand the important role these species appear to play in the global C cycle, they are nevertheless being targeted for commercial fishing (Scoulding et al., 2015; Caiger et al., 2021). Limiting or prohibiting commercial harvest of mesopelagic organisms may be the most straightforward way to enhance or ~~maintain~~ the oceanic biological pump while avoiding additional emissions from both fishing and degradation of the ocean's C sequestration capacity. *Other open ocean emissions avoidance strategies* • Other potential interventions to reduce or avoid new emissions within the ocean system include reducing fossil fuel use by the global fishing fleet and reducing seafloor disturbance from activities like bottom trawling or deep-sea mining, which can cause organic matter in sediments to be resuspended from the ocean floor and then metabolized by bacteria back into CO_2 (Sala et al., 2021). In the case of the former, for example, Mariani et al. (2020) estimated that 82% of current emissions from the targeting of large pelagic fishes comes from fossil fuel use

	by fishing vessels. In the case of bottom-disturbing activities, limiting extent or penetration depth into the seafloor may protect some of the stored C from being remineralized (De Borger et al., 2021). However, the extent of emissions that could be avoided by limiting these activities is still debated in the scientific literature. For example, the majority of CO_2 ~~remineralized~~ by bottom trawling ~~would likely~~ remain out of contact with the atmosphere for decades or centuries, ~~, depending on water depth and ocean circulation~~.
What is the range of estimates for how much additional C could be sequestered globally?	*Poorly constrained* • Calculating the precise contribution of individual organisms such as whales or fishes to ocean C sequestration is extremely difficult due to the number of different, interconnected biogeochemical processes that must be considered. In addition, nearly all the parameters required for these calculations (e.g., nutrient concentrations, or the strength of advective mixing between ocean water masses) vary significantly over time and across the expansive spatial scales of the oceans, demanding the attachment in nearly all cases of significant uncertainties. • However, using even the most generous scientific assumptions, it is extremely doubtful that restoration of large marine animals could sequester additional C in quantities commensurate with petagram scales of anthropogenic emissions or terrestrial C sequestration approaches such as reforestation. Pershing et al. (2010) calculated that the restoration of large baleen whale populations to estimated pre-whaling abundances would sequester just 1.6×10^{-4} Pg of additional C (equivalent to 5.9×10^{-4} Pg of additional CO_2) each year through increased whale falls. No reliable published estimates exist of the potential additional C sequestration that could be realized through increased fertilization of primary production by the same restored whale populations. One study, currently in preprint, estimated that the restoration of baleen whales could result in a total additional sequestration of 8.7×10^{-3} Pg C (equivalent to 3.2×10^{-2} Pg CO_2) yr^{-1} if fertilization were considered in addition to whale fall (Durfort et al., 2021).
How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that?	*Low confidence* • There are no adequate baselines against which to compare any increased sequestration or avoided emissions. Further, large, 2- to 3-fold discrepancies exist between estimates of ocean C export rates based on biogeochemical models on the one hand, and those derived from chemical tracers and *in situ* measurements on the other (Burd et al., 2010; Boyd et al., 2019). Significant advances in both biogeochemical modeling and direct observations of biogeochemical processes in the ocean will be required before we can convincingly attribute fractional changes in net C sequestration to specific organisms or groups of organisms with the precision necessary to drive reliable C markets.

C Markets	
Is there a market (or proposed market) for carbon credits from the system?	There are no present or proposed markets for credits based on open ocean NCS pathways. The International Monetary Fund has suggested in a recent, nonscientific concept paper that C markets could be used to enable whale conservation (Chami et al., 2019), and the idea has garnered interest within the popular media (e.g., (Yeo, 2021; Carrere, 2021).
Are there protocols (or proposed protocols) for such credits?	Not applicable.
If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	Not applicable.

If there are protocols, have there been any registered projects or credits generated? If so, where?	Not applicable.
Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc. within any existing or proposed market?	Not applicable at present.
Is there controversy surrounding the markets or credits for the NCS pathway? Why?	Not applicable.

Peatlands: *Avoided conversion and degradation of tropical peatlands: Avoided conversion and degradation of boreal and temperate peatlands & Restoration*

Peatlands[16], defined as wetlands with a naturally accumulated peat layer at the surface which contains more than 30% of dead organic material (FAO, 2021), cover only about 4×10^6 km^2 of the global land surface (about 4% of global land) (IUCN, 2017; Qiu et al., 2020). Even though most peatlands are located at high northern latitudes, extensive tropical peatlands are also found in South-East Asia, the Congo Basin and South America (Dargie et al., 2017; Page et al., 2011; Turetsky et al., 2015). The global carbon stock of peatlands is estimated to be 500 Pg C which corresponds to 266.67 megatons per hectare globally (Griscom et al., 2017). Nevertheless, carbon stocks differ drastically by region, with northern peatlands comprising most of this global estimate and tropical peatlands storing about 100 Pg C (Turetsky et al., 2015; Dargie et al., 2017). Goldstein et al. (2020), in order to compare carbon stocks across peatlands in different systems, estimate carbon stored in combined aboveground, belowground, and soil organic C to depths of 1m. They estimate that boreal peatlands store 181 Pg C (500 Mg C ha^{-1}), temperate peatlands store 9.3 (500 Mg C ha-1), and tropical peatlands store 30 Pg C (504 Mg C ha^{-1}). Overall peatlands are considered the largest carbon storage unit on Earth and store significantly more carbon than all vegetation globally (Turetsky et al., 2015; IUCN, 2017).

Globally, peatlands are considered carbon sinks, sequestering about 0.4 Pg CO2e yr^{-1} (0.1 Pg C yr^{-1}) (Yu et al., 2010; Dunn and Freeman, 2011; Gallego-Sala et al., 2018; Qiu et al., 2020; Huang et al., 2021). Peatlands also release methane, which is largely driven by the water table depth. Boreal and Temperate peatlands are responsible for the majority of methane peatlands' emissions (Couwenberg et al., 2010; IPCC, 2019a). However, peatlands still have a net long-term cooling effect (Amesbury et al., 2019). Degraded peatlands (drained and burned), mostly located at temperate and tropical latitudes, are net carbon sources. Degraded peatlands are responsible for 2.6 – 5.6% of global CO_2 anthropogenic emissions (10% of land-use sector GHG emissions (IUCN, 2017; Humpenöder et al., 2020)) and they add 0.9 – 3 Pg CO_2e every year to the atmosphere (IPCC, 2019b; Humpenöder et al., 2020). (Couwenberg et al., 2010; IPCC, 2019a)

Concerning business-as-usual projections for carbon dynamics of peatlands, peatlands are expected to become net carbon sources by the end of the century owing to anthropogenic drainage and burning, climatic drying, and increased wildfires frequency and severity (IPCC, 2019a; Qiu et al., 2020; Loisel et al., 2021; Nelson et al., 2021; Datta and Krishnamoorti, 2022). Recent research demonstrates that peatland drainage and burning ha already transformed large areas of peatland from net sources to sinks (Leifeld et al., 2019; Datta and Krishnamoorti, 2022). Further, increased peatland wildfires frequency and severity, especially in northern regions are predicted to promote C emissions from peatlands and change them to net carbon sources (Nelson et al., 2021). Nevertheless, recent studies have demonstrated that it is possible, via active management, to either increase net C sequestration or prevent C emissions from peatlands.

[16] We recognize that wetlands and peatlands are typically studied together; however, at the time of this writing, existing protocols separate them, so they are analyzed separately in this paper.

The establishment of agricultural crops (Paludiculture crops) that do not require drainage as well as limiting fertilization of drained peat soils or reducing peatland drainage (improved water management) and restoring natural vegetation cover can limit carbon emissions from these ecosystems and, under the appropriate site conditions and time scales, increase C stocks (Page et al., 2009; Joosten et al., 2016; Uda et al., 2020). The peatland restoration mitigation pathway has a mitigation potential of 0.6 – 1.3 Pg CO_2e yr^{-1} (Griscom et al., 2017; IPCC, 2019b; Roe et al., 2021). However, the IPCC (2019) has low confidence in this estimate and only a portion of this mitigation potential (18%) is feasible due to economic and technical constraints (Griscom et al., 2017; Drever et al., 2021).

The mitigation potential of the Avoided Peatland Conversion/Impacts strategy is estimated to be 0.205 – 0.443 Pg CO_2e yr^{-1} (Roe et al., 2021). Because of the lower costs associated with this mitigation technique, the scientific community believes that it could be rapidly deployed (Griscom et al., 2017; IPCC, 2019a; Drever et al., 2021). However, challenges remain in terms of quantifying both the areal extent of peatlands and GHG fluxes from peat soils, which lends a degree of uncertainty in estimating their contribution to climate mitigation (Warren et al., 2012; Comas et al., 2017; Loisel et al., 2021).

Knowledge gaps, such as a lack of data on the spatial and temporal patterns of SOC across peatland landscapes and lack of cost-effective sampling methods (especially for remote tropical peatlands) have contributed to medium uncertainty in our ability to understand GHG dynamics and carbon storage potential of peatlands (Joosten et al., 2012; Warren et al., 2012; Bonn et al., 2014). Despite those knowledge gaps, markets for Avoided Peatland Conversion and Peatland Restoration carbon credits have grown. There is a voluntary market for peatland carbon credits. Carbon crediting protocols for generating credits can generally be divided into jurisdictional and project-based approaches. These protocols have been developed by several international standards including Verra and American Carbon Registry as well as regional standards such as MoorFutures, The Peatland Carbon Code and Max.moor, Most of the protocols account for additionality, permanence, leakage, reversals, and uncertainty in varying ways. A sizeable number of credits have been generated for peatlands across the world, descriptions of projects and credits are detailed in registry websites.

The increasing popularity of peatland carbon credits highlights concerns surrounding protocols and project approaches. For example, experts have raised concerns about additionality, permanence, and land tenure rights for project-scale peatland projects within tropical forests and therefore subject to REDD+ credits. Concerns about peatland restoration projects have also been formulated and scientists claim that tradeoffs of carbon storage and methane emissions (which can increase if a peatland is flooded) need to be addressed when considering net GHG mitigation and carbon credits. Additional concerns are described in more detail in the associated table.

Peatlands

Global Areal Extent: Between 3 and 4 × 10^6 km^2 (IUCN, 2017; Qiu et al., 2020)
Occupy about 3 to 4% of global terrestrial land (Yu et al., 2011; Turetsky et al., 2015; IPCC, 2019b). Peatlands are mostly located in high northern latitudes (north of the 45N latitude) (Yu et al., 2011; IPCC, 2019b; Qiu et al., 2020).

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?	• Carbon stocks of peatlands: 500 +-100 Pg C (Yu et al., 2011; Australian Government Department of Industry, Science, Energy and Resources, 2012; Yu, 2012; IUCN, 2017; Hugelius et al., 2020). • Carbon stocks (Temperate, Tropical and Boreal peatlands): 266.67 Mg C ha^{-1} (Griscom et al., 2017) • Agus et al (2011,p.1): "The concentration of carbon in peat soils globally 30 × 10^{-9} Pg – 700 × 10^{-9} Pg C ha^{-1} m^{-1} of peat depth." Goldstein et al. (2020) split up peatlands into boreal, temperate, and tropical peatlands focusing on combined aboveground, belowground, and soil organic C to depths of 1m. They estimate that boreal peatlands store 181 Pg C (500 Mg C ha^{-1}), temperate peatlands store 9.3 (500 Mg C ha^{-1}), and tropical peatlands store 30 Pg C (504 Mg C ha^{-1}). These estimates focus on 1 m depth (recognizing that total peatland carbon storage greatly exceeds these estimates) since this is the C stock that is in imminent threat of being lost over the next 30 years. , globally.*Note: Peatlands are the largest carbon storage unit on terrestrial land globally* (IUCN, 2017) *and stores more carbon than all plant tissues globally* (IUCN, 2017). *Turetsky et al. (2015) stated that the peatlands carbon stocks were nearly equivalent to atmospheric carbon pool.* *Regional stocks* *The central Congo Basin peatland complex stores about 30.6 Pg C (Dargie et al., 2017)* • Tropical peatlands (primarily located in Southeast Asia), store about 100 Gigatons of carbon (Turetsky et al., 2015). • Average C stocks in tropical peatlands: 2,009 Mg C ha^{-1} (Dargie et al., 2017; Page et al., 2011). *Note: Estimates of carbon stocks vary from study to studyas a result of different estimation methods* (Amesbury et al., 2019). *Estimates have also known sources of sampling bias* (Nichols and Peteet, 2019)
At the global level, is the system currently a C source or sink? What is the business-as-usual	• Gallego-Sala et al. (2018) estimated that global peatlands represented a carbon sink of 0.52 Pg CO_2 yr^{-1} over the last millennium. • (Yu et al., 2010) estimated that global peatlands are a carbon sink which have sequestered 0.40 Pg CO_2 yr^{-1} since the last glacial maximum. • Degraded (drained) peatlands are a net carbon source as a result of human activity and climate change (IPCC, 2019a). They are responsible for 2.6 – 5.6% of global CO_2 anthropogenic emissions (10% of land-use sector GHG emissions) and they add between 0.9 – 3 Pg CO_2e yr^{-1} to

projection for its C dynamics?	the atmosphere (Humpenöder et al., 2020; IPCC, 2019) . Only 15 – 20% of peatlands are degraded and drained peatlands cover less than 0.4% of the global land surface (IUCN, 2017; IPCC, 2019a; Leifeld et al., 2019; Humpenöder et al., 2020). • (Nelson et al., 2021; Datta and Krishnamoorti, 2022) Emissions from burned peatlands due to deforestation fires accounted for 40 to 60% emissions associated to deforestation in both Brazil and Indonesia (Datta and Krishnamoorti, 2022). Once emissions from deforestation fires in peatlands in both countries were taken into consideration, the total GHG impact of deforestation nearly doubled (Datta and Krishnamoorti, 2022). Datta & Krishnamoorti (2022) highlighted that previous studies have underestimated the true emission impact of deforestation fires by 200 to 300% for severe fire years. Pristine peatlands are a weak natural sink of atmospheric carbon dioxide and source of methane (Frolking et al., 2011; Nichols and Peteet, 2019; Qiu et al., 2020; Alexandrov et al., 2020). On net, they sequester 0.37 Pg CO_2e per year (Dunn and Freeman, 2011; Frolking et al., 2011; Qiu et al., 2020; Huang et al., 2021). *Note: Currently, natural peatlands worldwide are an annual source of methane, however, this persistent emission is not increasing the CH4 concentration in the atmosphere because a steady state in peatland-derived atmospheric CH4 concentration has been reached. Boreal and temperate peatlands are responsible for the majority of peatlands' methane* (Couwenberg et al., 2010; IPCC, 2019b). *Business as usual projections*: Low certainty concerning future peatlands C stocks and fluxes even if peatlands are very sensitive to climate change (Page et al., 2009; IPCC, 2019a): • Loisel et al. (2021) suggest that "carbon balance of peatlands is predicted to shift from a sink to a source this century." • Leifeld et al. (2019) estimate that the draining of large areas of peatlands for agriculture and forestry has shifted their carbon balance from sinks to sources • Under rapid climate change, peatlands extent is likely to shrink and Western Canadian and Northern European peatlands are expected to become net carbon sources (Dunn and Freeman, 2011; Qiu et al., 2020) • Under business-as-usual climate scenarios (RCP8.5), peatlands are likely to become net carbon sources or near neutral at the global scale by the end of century (Qiu et al., 2020) • Northern peatlands are predicted to become a stronger carbon sink by the end of this interglacial period (3,211 ± 459 Pg CO_2) (Alexandrov et al., 2020). Nonetheless, the authors assumed that "the present climate is typical for the remainder of the present interglacial period" (Alexandrov et al., 2020, p.52). They added that this conclusion was valid if cumulative carbon emissions do not exceed 3,670 Pg CO_2. • Nelson et al. (2021) predicted that the cumulative effects of climatic warming, anthropogenic peatland fragmentation, and subsequent peatland drying will further increase boreal peatland wildfires frequency and severity in the future which will promote northern peatlands carbon loss to the atmosphere, driving a positive C feedback cycle (shifting peatlands from a gradual carbon sink to a net source). • Gallego-Sala et al. (2018) found that the current global peatland sink magnitude could rise until 2100 and decrease afterward. The authors specified that large uncertainties were associated to those projections, but they claimed that "the direction of change and a shift from initially negative to subsequent positive feedback is a plausible and robust result" (Gallego-Sala et al., 2018).

Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	Yes, it is possible. Two major pathways for peatlands as a natural climate solution are restoration and avoided conversion/degradation *Note: Griscom et al. (2017) highlighted the avoiding peatlands conversion pathway was more cost-effective than peatlands restoration, which makes the former more rapidly deployable.* *Avoided conversion and degradation of peatlands* (Griscom et al., 2017; Fargione et al., 2018; IPCC, 2019b) • Drainage of peatlands generally results in loss of C because soil organic matter previously stored under anaerobic conditions is aerated and exposed to atmospheric oxygen (Humpenöder et al., 2020). The process of complete peat oxidation will take centuries, meaning that each unit of drained peatland is a contributor to global warming, until it is totally oxidized. • Depending on the context and land-use, peatland oxidation can reduce nitrous oxide and methane emissions but in terms of global warming potential, carbon dioxide is the most important greenhouse gas from degraded lands (Humpenöder et al., 2020). • Stopping regular peatlands burning also reduces C emissions from peatland ecosystems (Page et al., 2009; IPCC, 2021; Nelson et al., 2021; Datta and Krishnamoorti, 2022). • Avoiding plowing since tillage enhances peat oxidation by increasing soil surface roughness (Joosten et al., 2012). • Establishment of agricultural crops (e.g. Paludiculture crops) that do not require drainage reduces C emission from peatlands (Joosten et al., 2012; Uda et al., 2020). Though this needs to be balanced in consideration of methane emissions that can result if water levels remain at the surface (Evans et al., 2021). *Restoration of degraded peatlands* (Griscom et al., 2017; IPCC, 2019b). • Vegetation restoration (natural and human-assisted regeneration); restoration of hydrology (water table depth higher than 40cm (Joosten et al., 2012; Günther et al., 2020), restoration of local livelihoods (Page et al., 2009). • Reducing peatland drainage (improved water management) has been shown to cause reductions in annual C emissions from peatlands and fire risks (Hooijer et al., 2010; Joosten et al., 2016; Griscom et al., 2017; IPCC, 2021). • Cultivating permanent crops whose shade reduces surface temperatures may be one way to curb peat oxidation (Joosten et al., 2012). • Construction by local communities of dams to block drainage of abandoned drained peatlands (Parish et al., 2011) • Limiting fertilization because it increases peat oxidation and nitrogen fertilization on drained peat soils could also lead to emissions of nitrous oxide (Joosten et al., 2012) • Rewetting of drained peatlands can lead to renewed emission of methane over short timescales before a steady state in atmospheric methane concentrations is reached (over a few decades); however, drained peatlands are a much larger source of CO_2 emissions.

What is the range of estimates for how much additional C could be sequestered globally?	*Pathway mitigation potential (Roe et al., 2021)* • *Reduced peatland degradation pathway (Avoided peatland conversion) (include temperate, boreal and tropical peatlands): 0.443 Pg CO_2e yr^{-1} (Technical mitigation potential)* • *Reduced peatland degradation pathway (Avoided peatland conversion) (include temperate, boreal and tropical peatlands): 0.205 Pg CO_2e yr^{-1} (Cost-effective mitigation potential)* • *Peatland restoration pathway (include temperate, boreal and tropical peatlands): 1.3 Pg CO_2e yr^{-1} (Technical mitigation potential)* • *Peatland restoration pathway (include temperate, boreal and tropical peatlands): 0.6 Pg CO_2e yr^{-1} (Cost-effective mitigation potential)* *Pathway mitigation potentials (Griscom et al., 2017)* • Avoided Peatland Conversion pathway (include temperate, boreal and tropical peatlands): 754 Tg CO_2e yr^{-1} (Maximum Additional Mitigation potential). • Avoided Peatland Conversion pathway (include temperate, boreal and tropical peatlands): 452 Tg CO_2e yr^{-1} (Low-cost Mitigation potential). • Peatland restoration pathway (include temperate, boreal and tropical peatlands): 815 Tg CO_2e yr^{-1} (Maximum Additional Mitigation potential). • Peatland restoration pathway (include temperate, boreal and tropical peatlands): 149 Tg CO_2e yr^{-1} (Low-Cost Mitigation potential). *Note: Griscom et al. (2017) included all non-tidal freshwater forested and non-forested wetlands in their Peatlands pathways.* *Tropical NCS Pathways mitigation potential (Griscom et al., 2020)* • *Peatland restoration pathway (Tropical peatlands only): 487.92 Tg CO_2e yr^{-1} (Maximum mitigation potential)* • *Peatland restoration pathway (Tropical peatlands only): 234.16 Tg CO_2e yr^{-1} (Cost-effective mitigation potential: <100 USD $MgCO_2e^{-1}$)* • *Avoided Peat Impacts (Conversion) pathway (Tropical peatlands only): 629.19 Tg CO_2e yr^{-1} (Maximum mitigation potential)* • *Avoided Peat Impacts (Conversion) pathway (Tropical peatlands only): 566.26 Tg CO_2e yr^{-1} (Cost-effective mitigation potential: <100 USD $MgCO_2e^{-1}$)* *IPCC mitigation potential (and confidence level)* • Peatland restoration has mitigation potential of 0.15 – 0.81 Pg CO_2e yr^{-1} (low confidence) (Couwenberg et al., 2010; Griscom et al., 2017). • Restoration and reduced conversion of peatlands (0.6 – 2 Pg CO_2e yr^{-1} (Medium confidence) (IPCC, 2019b). • Reducing annual emissions from peatland conversion, draining and burning could mitigate 0.45 – 1.22 Pg CO_2e yr^{-1} up to 2050 (medium confidence) (IPCC, 2019b). *Other estimates* • U.S.: Peatland restoration mitigation potential: 8.2 Mg CO_2e ha^{-1} yr^{-1} (Fargione et al., 2018). • Canada: Avoided peatland conversion: 10.1 Tg CO_2e yr^{-1} in 2030 and 3.7 Tg CO_2e yr^{-1} in 2050 (Drever et al., 2021).

	• Ditch blocking mitigations potential: 2.5 Mg CO_2e ha^{-1} yr^{-1} within the first 10 years and total of 3.1 Mg CO_2e ha^{-1} yr^{-1} for fully restored peatlands (Bonn et al., 2014). • Re-wetting drained peatlands under grassland or cropland mitigation potential: 20 t CO_2eq ha^{-1} yr^{-1} (Bonn et al., 2014).
How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that system?	*Medium Uncertainty/Medium confidence* (Page et al., 2007; Warren et al., 2012). • Important progress has been made recently in quantifying GHG fluxes from peat soils (CO_2 and CH_4) (Joosten et al., 2012). Reliable and detailed methods for measuring, reporting and verifying (MRV) emissions and emissions reductions from peatlands are available and several assessment methodologies are being developed and tested (Joosten et al., 2012; Lees et al., 2018). Nevertheless, several uncertainties/challenges remain. *(Loisel et al., 2017) highlighted several challenges associated with C stock estimations and C changes detection* • Large-scale (regional or continental) peatland C storage estimates rely on the extrapolation of peatland-scale datasets that are sometimes based on a limited number of peat cores • A simple extrapolation of soil C density values from such cores without taking into account the geometric shape of the peat mass (and, potentially, the variability of volumetric peat C content within the peatland) could lead to errors in peatland-scale C estimates. • Omission of open-water pools in peatland C stocks estimation could induce erroneous results. • Sampling bias leads to an overestimation of total C stocks. • Basin heterogeneity is often ignored when scaling up to the regional and global scales (also mentioned by Lees et al., 2018). *Other concerns* • Lack of data on the spatial and temporal patterns of SOC across peatlands (Comas et al., 2017) and lack of data on thickness of peatlands (Page et al., 2007) • Measuring C stocks in peatlands is challenging because of their remoteness (Warren et al., 2012; Comas et al., 2017) • Lack of cost-effective sampling methods (especially for remote tropical peatlands) limit our ability to characterize C stocks and detect changes in concentration and emissions over small and large scales (Warren et al., 2012; Bonn et al., 2014; Joosten et al., 2016; Lees et al., 2018). • Eddy covariances towers and flux chambers are rare on peatlands sites which complicates upscaling small-scale measures to landscape or regional scales (Lees et al., 2018) • Lees et al. (2018, p. 870) stated that “eddy covariance data are not a truly accurate measure of carbon flux, yet they are often treated as though they are a direct measurement”

	• Flux chambers measures C fluxes at microscales (cm2) but tend to be taken infrequently and over short period, limiting their exploitation (Lees et al., 2018) • Lack of suitable facilities in developing countries, where most of tropical peatlands are located, limits our ability to measure C stocks and fluxes (Warren et al., 2012) • Walkley-Black wet combustion loses precision when soil organic matter content is too high (Warren et al., 2012) • Remote sensing models used to estimate peatlands C fluxes are not very accurate yet (Lees et al., 2018) • Remote sensing techniques used to quantify C fluxes tend to be limited by cloud cover and heterogeneity of peatland landscapes (Lees et al., 2018). Additional research is needed to better estimate C fluxes in peatlands using remote sensing.

C Markets	
Is there a market (or proposed market) for carbon credits from the system?	Yes, voluntary markets exist.
Are there protocols (or proposed protocols) for such credits?	*Jurisdictional approaches* = government-led, comprehensive approach to forest and land use across one or more legally defined territories (CIFOR) **Voluntary** • ART's TREES (The REDD+ Environmental Excellence Standard) [b]; international • American Carbon Registry Nested REDD+ Standard [b]; international • FCPF's Carbon Fund (pilots results-based payments for REDD+ activities in developing countries) [b]; international *Project-based protocols/methodologies* = receive credits on a project level basis **Voluntary** • Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0 [a]; international (Inactive)

	• Revision to Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0 [a] ; international (Under Development) • Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6 [b]; international • Verra VM0027 Methodology for Rewetting Drained Tropical Peatlands, v1.0; international • Verra VM0036 Methodology for Rewetting Drained Temperate Peatlands v1.0 [1] ; international • ACR Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests[a]; international • UK Peatland Carbon Code, Peatland restoration, v1.1;United Kingdom • The German MoorFutures Standard: Methodology for MoorFutures projects; Germany • WSl-Max.moor Compensation approach; Switzerland [a] *Protocol applied to peatland, and tropical forest systems* [b] *Protocol applies to peatland, agroforestry, and tropical forest, coastal blue carbon and freshwater wetland systems* [1] *The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) accepts carbon offset projects that use this protocol*
If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	*Jurisdictional approaches* **ART TREES** • **Permanence:** 5-year crediting periods, risk assessment considers a period of 100 years • **Additionality:** Performance-based approach in that only emissions achieved below a conservative historical baseline will be eligible for crediting • **Leakage:** Where TREES participants submit a subnational Crediting Level, then negative leakage of emissions to outside the accounting area can occur. Participants must apply specified TREES leakage deductions. Participants are classified as high, medium, or low leakage risk and are assigned a deduction of 20%, 10%, or 5%, respectively. • **Reversals:** ART maintains a combined buffer pool that includes contributions from all ART Participants. Reversals are reported and a volume of credits from the buffer pool equivalent to either the reversed volume or the total number of ERs previously issued to the Participant (whichever is lower) is retired to permanently remove the ERs from circulation and negate the reversal. If a participant exits ART, any unused buffer pool contributions are retired to account for any possible future reversals. TREES establishes a starting level of reversal risk for Participants of 25% (which can be lowered if demonstrated mitigating factors exist). After a reversal is reported, a Participant must increase its buffer contribution for a period of five years by 5%. • **Uncertainty:** A conservative approach is applied whereby, beyond an allowable uncertainty (15% at the 90% confidence level), the Crediting Level is reduced by the calculated percentage uncertainty quantified in terms of the half-width of the 90% confidence interval as a percentage of the estimated emissions

	ACR Nested REDD+ Standard • **Permanence**: 40 years • **Additionality:** Additionality as described in the ACR Forest Carbon Project Standard does not need to be separately demonstrated at the nested project level, since a jurisdictional baseline meeting minimum criteria by definition indicates that in the absence of the project activity a given area would be deforested • **Leakage:** Where the jurisdiction is monitoring leakage within the jurisdiction, nested REDD+ projects shall use the jurisdictional leakage accounting framework. The jurisdictional accounting framework must outline how leakage will be addressed within the jurisdiction. Where there is a jurisdictional crediting system, jurisdictions shall have clear policies and procedures in place for attributing leakage to nested projects. a Leakage Buffer Account for nested REDD+ projects, modeled on but separate from the ACR non-permanence buffer account. All nested projects will be required to calculate leakage per the requirements of the applicable project-level methodology, but rather than simply being deducted from net emission reductions, leakage tons will be created in the Leakage Buffer Account • **Reversals:** calculates risk of non-permanence using the VCS AFOLU Non-Permanence Risk Tool – project proponents may contribute to a buffer pool OR purchase insurance for their credits • **Uncertainty:** ± 10% of the mean at 90% confidence interval **FCPF Carbon Fund** • **Permanence:** if an ER program transits into a new GHG program or standard, the applicable GHG program shall monitor for the Reversals and have in place a Reversal management mechanism to compensate for material Reversals for at least until 15 years following the end of Carbon Fund in 2025 (i.e. 31 December 2040) • **Additionality:** Additionality primarily is addressed through conservative approaches to setting Reference Levels (e.g., including existing and clearly funded programs or activities within the Reference Level), rather than through additionality tests often utilized by project-level initiatives, which have proven difficult to operationalize. • **Leakage:** Potential sources of domestic and international displacement of emissions (Displacement) are identified by assessment of all drivers of land-use change relevant for the ER Program; and measures to minimize and/or mitigate the risk of displacement of domestic emissions are incorporated into ER Program design and the estimation and monitoring of ERs. ER Programs should seek to minimize and mitigate Displacement outside the Accounting Area (domestic and international) to the extent possible via design of the ER Program. However, due to accounting and attribution challenges and following UNFCCC guidance on REDD+, potential international Displacement should not have to be accounted for or deducted from the ERs credited to ER Programs. • **Reversals:** ER Program are deposited in an ER Program CF Buffer, managed by the Carbon Fund, based on a Reversal risk assessment Leakage; amount of emissions reductions contributed are based on total aggregate uncertainty of emission reductions ranging from 0 – 15%. If forest degradation is measured through a separate approach using proxy-based approaches, a general conservativeness factor of 15% is applied.

	• **Uncertainty:** includes an 'Uncertainty Buffer' to create incentives for improving (reducing) uncertainty associated with the estimation of ERs and manage the risk that the emission reductions were overestimated for prior reporting periods Equal to the Reversal buffer. Each program is required to conduct an uncertainty analysis which consists of a three-step process laid-out in three different criteria: identification (Criterion 7); reduction (Criterion 8) and quantification (Criterion 9). The final objective of the Uncertainty Analysis is to provide an estimate of uncertainty of Emission Reductions in the form of the relative half-width confidence interval at the 90% confidence level. *Project-based methodologies/protocols* **Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0** • Permanence: 30 years. In the VCS Program all AFOLU projects have a longevity of 30 years as established in the AFOLU Non-Permanence Risk Tool. The project crediting period for AFOLU projects must be between 20 and 100 years. Risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool (T-Bar). • Additionality: Demonstrated using the latest version of the ―Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities‖ approved by the VCS Board. • Leakage: Account for displacement of pre-project activities to areas outside the project boundary and market effects. Market effects leakage must be estimated as the baseline emissions from logging multiplied by a leakage factor. • Reversal: not specified beyond use of VCS AFOLU Non-permanence risk tool • Uncertainty: A precision target of a 90% confidence interval equal to or less than 10% of the mean recorded value shall be targeted. Conservative estimates can also be used instead of uncertainties, provided that they are based on verifiable literature sources or expert judgement. In this case the uncertainty is assumed to be zero **Revision to Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests (Under development)** • Permanence: 100 years. In the VCS Program all AFOLU projects have a longevity of 30 years as established in the AFOLU Non-Permanence Risk Tool. The project crediting period for AFOLU projects must be between 20 and 100 years. Risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool (T-Bar). • Additionality: Demonstrated using the latest version of the ―Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities‖ approved by the VCS Board. • Leakage: Account for displacement of pre-project activities to areas outside the project boundary and market effects. Market effects leakage must be estimated as the baseline emissions from logging multiplied by a leakage factor. • Reversal: not specified beyond use of VCS AFOLU Non-permanence risk tool

	• Uncertainty: A precision target of a 90% confidence interval equal to or less than 10% of the mean recorded value shall be targeted. Conservative estimates can also be used instead of uncertainties if they are based on verifiable literature sources or expert judgement. In this case the uncertainty is assumed to be zero **Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6** • **Permanence**: Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage**: Leakage must be considered for all activities, calculated using leakage modules which are defined in the methodology based on project activities • **Reversals**: Not specified beyond use of VCS AFOLU Non-permanence risk tool to determine contribution percentage to VCS buffer pool • **Uncertainty**: allowable uncertainty under this methodology is +/- 15% of Total net GHG emission reductions of the REDD+ project activity (NERRED+) at the 95% confidence level. Where this precision level is met then no deduction should result for uncertainty. Where uncertainty exceeds 15% of NERREDD+ at the 95% confidence level then the deduction must be equal to the amount that the uncertainty exceeds the allowable level. **Verra VM0027 Methodology for Rewetting Drained Tropical Peatlands, v1.0** • **Permanence**: Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage**: Does not account o activity-shifting leakage, market leakage as well as ecological leakage. Justifications: "Since emissions from deforestation and degradation are not included in the quantification of baseline emissions, reductions in GHG emissions from preventing these activities are not included in the project scenario, and no agents of deforestation or drainage remain in the project area at the project start date (please refer to the applicability conditions), it is not relevant for this methodology to account for market and activity-shifting leakages. Does not account for emissions due to ecological leakage since although rewetting activities in the project scenario may result in an increase of CH4 emissions outside the project area, these are considered de minimis because they amount to less than 5 percent of the CO_2 emissions • **Reversals**: Not specified beyond use of VCS AFOLU Non-permanence risk tool to determine contribution percentage to VCS buffer pool • **Uncertainty**: Assessment of uncertainty must follow guidance provided by IPCC 2000, IPCC GPG-LULUCF and IPCC AFOLU. The allowable uncertainty is +/- 30% of cumulative total net GHG emission reductions at the 95% confidence level. Where this precision level is met, then no deduction must result for uncertainty. Where uncertainty exceeds 30% of cumulative total net GHG emission reductions at the 95% confidence level, then the deduction must be equal to the amount that the uncertainty exceeds the allowable level

	Verra VM0036 Methodology for Rewetting Drained Temperate Peatlands v1.0 • **Permanence**: Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage**: Does not account for activity-shifting leakage, market leakage as well as ecological leakage. Justifications: "Since emissions from deforestation and degradation are not included in the quantification of baseline emissions, reductions in GHG emissions from preventing these activities are not included in the project scenario, and no agents of deforestation or drainage remain in the project area at the project start date (please refer to the applicability conditions), it is not relevant for this methodology to account for market and activity-shifting leakages. . Does not account for emissions due to ecological leakage since although rewetting activities in the project scenario may result in an increase of CH4 emissions outside the project area, these are considered de minimis because they amount to less than 5 percent of the CO_2 emissions. • **Reversals**: A percentage of credits goes to buffer pool. Not specified beyond use of VCS AFOLU Non-permanence risk tool to determine contribution percentage to VCS buffer pool • **Uncertainty**: A precision target of a 90% or 95% confidence interval equal to or less than 20% or 30%, respectively, of the recorded value must be targeted. Focuses on two sources of uncertainty; Uncertainty associated with estimation of stocks in carbon pools and changes in carbon stocks and uncertainty in assessment of project emissions **ACR Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests** • **Permanence**: Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool. • **Additionality:** Demonstrated using the latest version of the ACR —Tool for Determining the Baseline and Assessing Additionality in REDD Project Activities. • **Leakage**: Leakage emissions, including carbon stock decreases and peat emissions outside the project boundary, are accounted for activity displacement and market effects. • **Reversals**: A percentage of credits goes to buffer pool. Not specified beyond use of VCS AFOLU Non-permanence risk tool to determine contribution percentage to VCS buffer pool. • **Uncertainty**: Assessment of uncertainties should follow guidance offered by IPCC 2000, IPCC GPG-LULUCF and IPCC AFOLU. A precision target of a 90% confidence interval equal to or less than 10% of the mean recorded value shall be targeted. Focuses on uncertainties associated with area, carbon stocks, biomass growth rates, expansion factors. **UK Peatland Carbon Code, Peatland restoration, v1.1 (United Kingdom)**

	• **Permanence**: Requirement of 30 years (project duration is 30 years minimum), with risk of non-permanence calculated using the Peatland Code Risk Assessment tool. • **Additionality: Demonstrated by meeting** the requirements of a series of additionality tests (Test one: Legal Compliance; Test two: Financial Feasibility; Test Three: Economiv Alternative; Test Four: Barriers) • **Leakage**: Assessment of leakage and its significance is project specific. The project shall carry out an assessment to determine whether the change will result in significant GHG emissions (≥5% of the emissions reduction over the duration of the project). If leakage has been determined as significant, it shall be quantified (Mg CO_2e yr^{-1}) for the duration of the project • **Reversals**: A percentage of credits goes to buffer pool. The project shall contribute 15% of net GHG emissions reduction over the project duration to the Peatland Code Risk Buffer. • **Uncertainty**: Not specified in protocol **The German MoorFutures Standard (Germany): Rewetting of temperate drained peatlands** • **Permanence**: Requirement of 100 years. Project duration should be between 20 and 30 years. • **Additionality:** There are currently no uniform guidelines for fulfilling the criterion of additionality. • **Leakage**: Account for activity-shifting leakage, market leakage and ecological leakage. • **Reversals**: A percentage of credits goes to buffer pool. Contribution percentage not specified. Reversals must be prevented with long-term contracts or legal measures such as restriction on use and designation as a protected area. • **Uncertainty**: Not specified in protocol. **WSL-Max.moor Compensation approach** • **Permanence**: Requirement of 50 years, with risk of non-permanence calculated using with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool. • **Additionality:** Proof of additionality can be realized with a simple cost analysis. • **Leakage**: Does not account for leakage. Justification: In the case of inventoried raised bogs, there is no risk of relocation (e.g. more intensive use on other organic soils). Such bogs were only used very extensively before the renaturation. Litter production or not used at all. Further due to the moor protection it is ruled out that new peat areas are drained to allow this use to be transferred to other areas to relocate. • **Reversals**: A percentage of credits goes to buffer pool. Contribution percentage is 5% to the buffer pool. If this 5% contribution is not reached, because for a project on the Buffer fund had to be used, the proportion of the risk buffer (RPi) must be used for further projects are temporarily increased to 10% until the buffer fund returns at least 5% of the issued ERs. • **Uncertainty**: Not specified in protocol.

If there are protocols, have there been any registered projects or credits generated? If so, where?	*Jurisdictional approaches*
	ART TREES
	• No projects yet registered (ART operates on a jurisdictional scale)
	• Five jurisdictional concept notes already submitted to ART Directory, more proposals (~20) are going to LEAF for review in 2021 to be listed on registry
	
	ACR Nested REDD+ Standard
	• No credits yet generated
	
	FCPF Carbon Fund
	• No credits generated yet
	• Forty-seven developing countries have been selected to join the FCPF (18 in Africa, 18 in Latin America, and 11 in the Asia-Pacific region)
	
	Project-based methodologies/protocols
	Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0
	• 1 project registered (Indonesia)
	  ○ Rimba Raya Biodiversity Reserve Project
	  ▪ Estimated Annual Emission Reductions: 3,527,171 Mg CO_2e
	  ▪ Total number of credits issued: 33,625,616 Mg CO_2e
	
	Revision to Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests (Under development)
	• No projects registered
	
	Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6
	• 2 projects registered for peatlands restoration (2 Indonesia)
	  ○ Katingan Peatland Restoration and Conservation Project (Indonesia)
	  ▪ Estimated Annual Emission Reductions; 7,451,846 Mg CO_2e
	  ▪ Total number of credits issued: 33,578,017 Mg CO_2e
	  ○ Sumatra Merang Peatland Project (SMPP) (Indonesia)
	  ▪ Estimated Annual Emission Reductions; 1,338,569 Mg CO_2e
	  ▪ Total number of credits issued: 1,755,737 Mg CO_2e
	• 1 “registration requested” peatlands restoration project (Indonesia)

- Riau Ecosystem Restoration Carbon Project (Indonesia)
  - Estimated Annual Emission Reductions; 6,870,411 Mg CO_2e
- 1 project under development (Brazil)
  - Evergreen REDD+ Project (Brazil)
    - Estimated Annual Emission Reductions: 794,158 Mg CO_2e

Verra VM0027 Methodology for Rewetting Drained Tropical Peatlands, v1.0

- No project registered

Verra VM0036 Methodology for Rewetting Drained Temperate Peatlands v1.0

- No project registered

ACR Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests

- No project registered

ACR Methodology for Restoration of Pocosin Wetlands

- 1 project listed: Pocosin Lakes National Wildlife Refuge Clayton Blocks Pocosin Restoration (North Carolina)

UK Peatland Carbon Code, Peatland restoration, v1.1 (United Kingdom) (Total number of PIUs issued: 150,748)

- 7 projects validated (Wales and Scotland)
  - Blaen y Coed project (Wales, Conwy)
    - Total predicted emission reductions over project lifetime: 8,724 Mg CO_2e
    - Total PIUs issued: 7,415
  - Bwlch y Groes (Wales)
    - Total predicted emission reductions over project lifetime: 2,747 Mg CO_2e
    - Total PIUs issued: 2,335
  - Dryhope (Scotland)
    - Total predicted emission reductions over project lifetime: 7,628 Mg CO_2e
    - Total PIUs issued: 6,484
  - Lochrosque Estate (Scotland)
    - Total predicted emission reductions over project lifetime: 102,475 Mg CO_2e
    - Total PIUs issued: 87,084
  - Talla, Gameshope and Carrifran (Scotland)

	▪ Total predicted emission reductions over project lifetime: 21,622 Mg CO_2e ▪ Total PIUs issued: 20,217 o Glaslyn (Wales) ▪ Total predicted emission reductions over project lifetime: 1,108 Mg CO_2e o Rottal Estate (Phase 1) ▪ Total predicted emission reductions over project lifetime: 6,462 Mg CO_2e • 25 projects registered and under development **The German MoorFutures Standard (Germany): Rewetting of temperate drained peatlands** • 3 projects registered o Gelliner Bruch Peatland restoration (Germany, Mecklenburg West Pomerania): 6.7 hectares of drained peatlands are rewetted ▪ Total number of MoorFutures issued: 5,800 Mg CO_2e o Rehwiese (Germany, Brandenburg): 9.7 hectares of drained peatlands are rewetted ▪ Total number of MoorFutures issued: 6,744 Mg CO_2e o Konigsmoor (Germany, Schleswig-Holstein): 68 hectares of drained peatlands are rewetted ▪ Total number of MoorFutures issued: 39,520 Mg CO_2e • 1 project finished o Polder de Kieve (Germany, Mecklenburg): 54.5 hectares of drained peatlands rewetted ▪ Total number of MoorFutures issued: 14,325 Mg CO_2e **WSl-Max.moor Compensation approach** • No project found (No public registry)
Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc.	*Jurisdictional approaches* **ART TREES** • The Architecture for REDD+ Transactions (ART) has been developed as a mechanism to achieve the environmental integrity needed for REDD+ emission reductions (ERs) at national and jurisdictional scale. It uses The REDD+ Environmental Excellence Standard (TREES). **ACR Nested REDD+ Standard** • Provides technical guidance for registration on ACR of REDD+ projects nested within a jurisdictional accounting framework **FCPF** • FCPF is a mechanism for performance-based payments for the successful implementation of jurisdictional emission reductions programs

within any existing or proposed market?	• As of August 2021, Mozambique became the first FCPF country to successfully verify emissions reductions, becoming the first-ever accredited verification of JREDD+ ERs *Project-based methodologies/protocols* **Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0 (International)** • Not specified in protocol **Revision to Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests (Under development)** • Not specified in protocol **Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6 (International)** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements **Verra VM0027 Methodology for Rewetting Drained Tropical Peatlands, v1.0 (International)** • Grouped projects are permitted **Verra VM0036 Methodology for Rewetting Drained Temperate Peatlands v1.0 (International)** • Grouped projects are permitted **ACR Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests (International)** • Not specified in protocol **UK Peatland Carbon Code, Peatland restoration, v1.1 (United Kingdom)** • Not specified in protocol **The German MoorFutures Standard: Methodology for MoorFutures projects (Germany)** • Grouped projects are permitted **WSl-Max.moor Compensation approach**

	• Not specified in protocol
Is there controversy surrounding the markets or credits for the NCS pathway? Why?	*Concerns with proper inclusion of emissions from degraded peatlands* • Joosten et al. (2012) highlighted that the major challenge of concerning peatlands restoration/avoided conversion and REDD+ projects was the proper inclusion of degraded peatland's emissions in baseline calculations and REDD+ reference emission levels. They further stated that "national plans and international financial support also need to be in place to address these emissions, otherwise countries will have a significant incentive to either ignore peat emissions or abandon REDD+ entirely" (Joosten et al., 2012). • Recent news revealed countries such as Indonesia struggled to measure peatland's emissions because of scientific, societal and structural obstacles (Zwick and Barrett, 2016). Data on Indonesian peatland management and emissions are hold by several agencies, research organizations and private companies which do not necessarily collaborate with each other. Peatlands also vary in depth which complicates emissions measurements and estimations (Zwick and Barrett, 2016).. • Main controversy in using peatlands for carbon credits is accounting for their methane emissions (Humpenöder et al., 2020). According to Lees et al. (2018), the limitations associated with accounting for methane emissions must be addressed in order to design plausible financing mechanisms targeting peatlands. • By omitting current peatland emissions, the mitigation potential of the pathway might be overestimated (Humpenöder et al., 2020). *Concerns about the ecological benefits of avoided peatland conversion versus peatland restoration/rehabilitation* • Emissions from peatlands will continue for decades after drainage (conversion) activities have been halted. Conversely to deforestation situations, where emissions are significantly reduced after activities have stopped because most of the emissions come from biomass losses and rapid revegetation takes place afterwards, in the context of peatlands, non-restored peatlands will still emit carbon dioxide, until they are fully rewetted. Therefore, decreasing the rate of peatlands conversion will lower the quantity of "additional" emissions but won't eliminate them. In other words, this mitigation strategy might induce lower additional emissions. In contrast, re-wetting drained peatlands will eliminate these "additional" emissions from peatlands (though not methane emissions). Günther et al. (2020)revealed that rewetting of drained peatlands reduces climate warming despite methane emissions. *Concerns about leakage* • There is little chance that after a peatland-drainage activity is stopped for a particular location, this land-use activity will occur on another adjacent non-degraded peatland because nowadays almost all peat swamp forests are degraded, and particular policy frameworks exist to prevent this type of activity displacement (Joosten et al. 2012). Nevertheless, it has been recently revealed that existing regulations to protect peatlands are frequently not enforced, increasing thereby the risks of leakage associated with avoided peatland conversion and peatland restoring carbon project (Nature4Climate, 2021).

	Note: Concerns with project-scale REDD+, jurisdictional-scale REDD+ and general concerns with REDD+ as offsets formulated in the "Tropical Forests" table also apply here since Avoided peatland conversion and peatland restoration activities fall within REDD+ scheme.

Shrublands: *Avoided degradation and conversion*

Shrublands, ecosystems dominated by shrubs (> 10 % cover) with herbaceous grasses and forbs forming lesser components and located between the 30° and 40° North and South latitudes (FAOSTAT, 2020; NASA, 2021), cover about 14% of the earth's surface (ca. 3.04×10^7 km^2 desert/semi desert shrublands and ca. 1.37×10^7 km^2 temperate shrublands) (Meyer, 2011; Broxton et al., 2014; Biederman et al., 2018). Shrublands have extended in recent years through the expansion of abandoned agricultural lands and encroachment of shrubs into, pastures and open forests (Van Auken, 2009; Meyer, 2011; Maestre et al., 2011; Daryanto et al., 2013). Nevertheless, shrublands are may also be subject to degradation because of changing precipitation and temperature, livestock grazing, pollution, severe wildfires and invasive species (Meyer, 2011; Barger et al., 2011; Xian et al., 2015).

The global carbon stock stored in shrubland systems is estimated to be 199 Pg C for desert/semi-desert shrublands and 304 Pg C for temperate ones (Meyer, 2011). Most of the carbon stored by shrublands resides in soil and belowground tissues; the location of carbon storage is strongly influenced by local climatic conditions (Piao et al., 2009; Meyer, 2011). Carbon stocks of shrublands vary regionally (see the associated table) and with shrubland type (Hui-Feng et al., 2005). Globally, shrublands are considered carbon sinks, although they may pivot between C sink and source function in years that are wetter/drier than the long-term average (Scott et al., 2015). Nevertheless, the magnitude of this carbon sink has not been determined at a global scale yet; only regional estimates have been formulated.

Most business-as-usual projections for C dynamics in shrublands under future climate change and management regimes suggest that shrublands may lose their C sink abilities or even become C sources. Shrublands have been shown to function as C sources to the atmosphere during dry years, especially those with reduced winter precipitation (Scott et al., 2015; Biederman et al., 2017). Potential causes of this potential shift from net C sink to source include more frequent droughts, lower average winter precipitation, and invasions by non-native grasses, which cause increased competition for resources and wildfire risk. While declines in shrub biomass reduce short-term ecosystem productivity (Luo et al., 2007; Tan et al., 2015), it remains unclear whether ecosystem shifts from shrubland to grassland affect the long-term ecosystem C balance (Hinojo-Hinojo et al., 2019). As a result, C dynamics in shrubland ecosystems are still under investigation and no consensus on their potential as a C sink exists.

Strategies such as controlling annual invasive weed infestations, protecting from overgrazing through improved grazing management), promoting plant diversity, maintaining optimal shrub cover and establishment of species in the interspaces, and keeping the cryptobiotic crust and herbaceous components intact could increase the C sequestration potential of shrublands (Meyer, 2011; Elbert et al., 2012; Daryanto et al., 2013; Chen et al., 2018a; Artaxo et al., 2019). There are currently no direct estimates of the global GHG mitigation potential of shrublands. The avoided conversion of grassland to cropland pathway, which bundles grasslands and shrublands, has been estimated to have a global GHG mitigation potential of 116 Tg CO_2e yr^{-1} (Griscom et al., 2017). Knowledge gaps remain, such as a lack of data on the spatial and temporal patterns of SOC across shrubland landscapes and lack of a standard set of methods and procedures to monitor C stocks in shrublands. These contribute to high uncertainty in our current ability to

understand the carbon storage potential of shrubland systems (Navarro Cerrillo and Oyonarte, 2006; Corona et al., 2011; Yao et al., 2021).

Despite these knowledge gaps, a voluntary market for shrubland carbon credits exists. Organizations such as Verra, American Carbon Registry, and Climate Action Reserve have all created different carbon crediting protocols for this system. All the protocols account for additionality, permanence, leakage, reversals, and uncertainty in varying ways. A small number of credits have been generated for shrublands across the world; detailed descriptions of projects and credits from the major voluntary offset carbon registries and at the Berkeley Trading Carbon Project website.

Shrublands

Global Areal Extent: Desert/Semi desert shrubland: 3.04×10^7 km^2 (Meyer, 2011); Temperate grassland/shrubland: 1.37×10^7 km^2 (Meyer, 2011).

Some regional estimates:
Shrubland areas currently cover more than 2.0×10^4 km^2 of the inland Portuguese territory (Enes et al., 2020).
Non-forest lands undergoing shrub encroachment are estimated to cover $2.2 \times 10^6 – 3.3 \times 10^6$ km^2, most in the xeric western North America (Knapp et al., 2008).
Shrublands cover about 7.5×10^5 km^2 of the Brazilian tropical savanna (Cerrado) (Sano et al., 2010).

Note: Shrublands are often lumped together with Grasslands (White et al. 2000), and specific estimates of shrubland extent are relatively rare. Together, grasslands, shrublands and savannas occupy about 40% of the terrestrial earth's surface (White et al. 2000)

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?

Global estimates of C stocks

- Global carbon stocks (temperate shrublands and grassland combined): 304 Pg C or 89 Pg $\times 10^9$ ha^{-1} (Meyer, 2011).
- Desert Semi-desert shrublands: 199 Pg C or 58.2×10^9 Pg C ha^{-1} (Meyer, 2011).
- Tropical Shrub Ecozone: Median Carbon Density of Primary Vegetation (36 Mg C ha^{-1}) and Carbon Density of Undisturbed Soils (35 Mg C ha^{-1}) (Houghton and Nassikas, 2017).

Note: Most of the carbon sequestered by shrubland ecosystems is stored in belowground tissues and in soils (Beier et al., 2009; Piao et al., 2009; Meyer, 2011). *The distribution of carbon in these systems is influenced by the local climate* (Meyer, 2011). *"Cold desert shrublands store much of their carbon belowground, and because the carbon is stored in deeper soil layers, these deserts are likely to store more carbon per unit area than warm deserts with monsoonal moisture regimes"* (Meyer, 2011, p. 4).

Regional estimates of C stocks

China

- Shrublands contained 6.69 ± 0.32 Pg C (Accounts for both biomass and soil C) (Tang et al., 2018).
- The total carbon sequestration of shrubland was 0.045 Pg C with a mean annual carbon sequestration of 0.0015 Pg C (Liu et al., 2014a)
- Biomass (aboveground and belowground) C contained in Chinese shrublands: 8.9 ± 3.2 Mg C ha^{-1} (Tang et al., 2018).
- SOC of Chinese Shrublands: 80.5 ± 6.8 Mg C ha^{-1} (Tang et al., 2018).

	• 6 major Shrublands in China contained together 1.68 Pg C, average carbon density was 10.88 Mg C ha^{-1} (5.92 – 17.00 Mg C ha^{-1}) (Hui-Feng et al., 2005). **United States** • Great Basin: shrubland systems accounted for one third of aboveground total carbon (9.845×10^2 Pg C) (Fusco et al., 2019). Fusco et al., (2019) stated that "regional estimates of aboveground carbon were lacking" • Federal lands across the conterminous United States (CONUS): Baseline ecosystem C density for shrublands was 19 Mg C ha^{-1} for shrublands (Tan et al., 2015). • Southern California: 35 Mg C ha^{-1} kg m^{-2} (Los Padres) to 23 Mg C ha^{-1} (Los Angeles and Cleveland) (Schrader-Patton and Underwood, 2021). **Spain** • Southern regions: The shrublands ecosystems contained between 2.23 Mg C ha^{-1} and 9.83 Mg C ha^{-1} (Navarro Cerrillo and Oyonarte, 2006). • Iberian Peninsula: The carbon stock values were 10.07 Mg C ha^{-1} and 2.19 Mg C ha^{-1} for the shoots and roots, respectively (Carrión-Prieto et al., 2017). • Aboveground shrub biomass accounts for more than 0.091 Pg C which represents 8.2% of the tree carbon stock in Spanish forests (Ruiz-Peinado et al., 2017). **Portugal** • The accumulated shrub biomass ranged from 0.12 up to 28.88 Mg C ha^{-1} (Enes et al., 2020). *Notes: Ruiz-Penado et al (2017) stated that the carbon stock associated with shrubs has been often overlooked, even though it could play an important role as a carbon sink that is increasing with the current rapid rate of shrub encroachment.*
At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	• Shrublands are considered as a net carbon sink globally (Meyer, 2011; Schrader-Patton and Underwood, 2021). Nonetheless, the magnitude of this carbon sink is unknown at a global scale (Daryanto et al., 2013). • Regional estimates of the carbon sink have been calculated: China (0.081 ± 0.037 Pg CO_2 yr^{-1}) (Piao et al., 2009); U.S.: 0.44 Pg CO_2 yr^{-1} (Pacala et al., 2001).

	Nevertheless, this carbon sink is under the threat of losing some of its strength or even becoming a net carbon source because of land conversion and climate change. • Estimations at the regional scale showed that, by 2050 shrublands across the conterminous United States (CONUS) could become net carbon source (small source of 0.6 Mg C ha^{-1} in shrublands) (Tan et al., 2015). They showed that by 2050, shrubland could lose "53 Tg C (about 4% reduction in C stock) which offsets the total C gain by 2.4%." This shift from carbon sink to source is explained by the increase in conversions of shrublands to agricultural and urban land uses (Tan et al., 2015). • Luo et al (2007) observed that Californian old-growth chapparal shrublands were a strong carbon sink (-3.52 to -5.69 Mg CO_2 ha^{-1} yr^{-1}) but they became weaker (-0.66 Mg CO_2 ha^{-1} yr^{-1}) as droughts become more severe and even a carbon source (7.59 Mg CO_2 ha^{-1} yr^{-1}) when droughts were highly severe. Current research predicts that droughts will become more common and severe in the future due to climate change (CE2S, 2017), which could lower the carbon sink abilities of shrublands or convert them to a carbon source. • Barger et al., (2011) observed that shrub encroachment resulted in a net ecosystem C gain (385 g C/m2) across most species and ecoregions over time in the U.S., suggesting that as shrub encroachment progresses, this ecosystem might become a stronger carbon sink. Nevertheless, they also emphasized that those C gains could be compensated over time by C losses resulting from wildfires, land management practices and drought (Barger et al., 2011). • Invasion of shrublands by non-native invasive grass species such as cheatgrass might also threaten their sink capacity in the future (Bradley et al., 2006; Meyer, 2011). Bradley et al., (2006) observed that the invasion of native Western U.S shrublands (Great Basin) by invasive grasses has induced a release of 8 Tg C to the atmosphere. They now expect that additional 60 Tg C will be released in the coming decades as this process continues, turning Western U.S. shrublands from net carbon sinks to net carbon sources. • Biederman et al. (2017) suggested that the shrubland net carbon sink might be further reduced in the future because of lower average winter precipitation. They observed that the net carbon sink of the three shrubland deserts was reduced by an average of 0.025 Pg CO_2 yr^{-1} as a result of lower average winter precipitation during the 21st century. • Petrie et al. (2015) revealed that shrublands in New Mexico were carbon sinks (1.79 Mg CO_2 ha^{-1} yr^{-1}) and this sink will be very likely to persist in a more arid future climate. Additionally, Chen et al., (2018) found that high temperatures have a strong negative effect on Chinese shrubland SOC storage and Doblas-Miranda et al., (2013) revealed that Spanish shrublands SOC was strongly negatively associated to mean annual temperatures, suggesting that climate change characterized by higher temperatures and reduced precipitation could reduce the potential of shrublands as a carbon sink. • Scott et al. (2015) showed that dryland ecosystems, including shrublands, may "pivot" between functioning as C sinks in wet years and C sources in dry years. As winter and annual precipitation are forecast to continue declining in many shrubland areas, there is potential for a declining shrubland carbon sink.

Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	*Yes, increases in C sequestration and decreases in emissions from shrublands are both possible.* • Avoided conversion of shrublands to croplands can prevent C emissions from that system (IPCC, 2019b). • Managing for resilient shrubland communities that can rebound from severe disturbances such as prolonged droughts and wildfires without high risk of conversion to annual grasslands (Meyer, 2011). • Prevention of further degradation and restoration of degraded shrublands can increase net C sequestration by this ecosystem type (Meyer, 2011). • Keeping the cryptobiotic crust and the interspaces intact to minimize the risk of annual grass expansion after fire and increase surface stability should enhance shrubland conditions and favor C sequestration (Meyer, 2011). • Controlling against annual invasive weed infestations will preserve shrubland integrity and promote productivity (Annual grass weed control) (Meyer, 2011). • Maintaining optimal shrub cover and the establishment of understory species could promote ecosystem heath and carbon sequestration rates (Meyer, 2011; Daryanto et al., 2013). • Promoting plant diversity in shrubland ecosystems proved to increase SOC stocks and C sequestration (Chen et al., 2018a). • Protection from overgrazing (improved grazing management) can increase C stocks (Daryanto et al., 2013; IPCC, 2019b). • Passive restoration of shrubland (i.e., protection) increases C sequestration rates and is also generally more cost-effective (IPCC, 2019b).
What is the range of estimates for how much additional C could be sequestered globally?	*No estimate for global carbon sequestration potential of shrublands* *Note:* Gratani et al., (2013)*stated that the contribution of shrublands to the global carbon cycle has been largely overlooked* Global estimate of land management practices • The Avoided Grassland Conversion pathway (including shrublands) has a climate mitigation potential in 2030 of 116 Tg CO_2e yr^{-1} (Griscom et al., 2017). The climate mitigation potential of this pathway ranges between 0.07 and 0.37 Pg CO_2e yr^{-1} (Griscom et al., 2017). • *Note: The term "Grassland" in this work includes temperate grasslands, tropical savannahs and shrublands.* Regional estimate of land management practices • Fargione et al., (2018) estimate that avoided conversion of grassland (including shrubland) to cropland in the United States prevents emissions from soils and root biomass, by a maximum of 107 Tg CO_2e yr^{-1}; however, at a price of USD 10 Mg^{-1} CO_2e, the authors estimate that avoided grassland conversion could prevent emissions by about 24 Tg CO_2e yr^{-1}. Estimates of potential carbon sequestration rates for different regions • Mediterranean shrublands: The total annual CO_2 sequestration potential of the Mediterranean shrublands was 80 Mg CO_2 ha^{-1} yr^{-1} (Gratani et al., 2013).

	• Australia: Carbon sequestration potential was estimated to be 0.07 Mg CO_2 ha^{-1} yr^{-1} over 100 years for chenopod shrublands of the pastoral zone of South Australia (Henry et al., 2015). • North America (Northern Chihuahuan Desert): Established shrubland sequestered 1.79 Mg CO_2 ha^{-1} yr^{-1} on average, being net carbon sinks (Petrie et al., 2015).
How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that?	*Low confidence but important progress has recently been made* **Biomass carbon estimation challenges** • The lack of experimental data on the shrub species and the highly variable composition of shrub communities makes it harder to estimate biomass (belowground and aboveground) at both small and large scales (Navarro Cerrillo and Oyonarte, 2006; Corona et al., 2011). • There is a need for site-specific localized allometric equations to estimate shrubby biomass. Allometric equations derived outside the shrubland ecosystem in question do not take into consideration spatial or temporal variability present within that ecosystem. • Few studies identify allometric equations for estimating the biomass of shrubs around the world (Huff et al., 2017). • Biomass estimations computed using allometric equations are focused on single species or on specific communities, while shrublands are generally composed of mixed communities. This reduces the applicability of these equations and thereby our ability to detect any changes in C stocks or fluxes (Corona et al., 2011; Meyer, 2011; Huff et al., 2017). • Current allometric equations developed for shrubs often only provide precise and accurate biomass estimations for shrubs with a "regular" shape (Wang, 2006; Corona et al., 2011). • "Lack of aboveground shrub biomass equations and the inability to predict shrub growth and accumulation has affected the accuracy of assessing forest fuel loads in California's forests" (Huff et al., 2017, p. 49). • "The choice of the appropriate allometric equation in [sic] which to estimate biomass involves a tradeoff involving precision, simplicity, and practical application" (Huff et al., 2017, p. 59). • Shrub biomass allometric equations are derived from equations designed for trees while shrubs and trees show significant differences in morphology (Yao et al., 2021). *Note: Nevertheless, new biomass estimations models for shrubs have been recently developed and proven to deliver good estimations* (Conti et al., 2013, 2019; Huff et al., 2017). **Soil C estimation challenges** • Lack of confidence and uncertainty in our ability to detect changes in shrubland soil C sequestration (Oldfield et al., 2021): • Although the methodology for relatively accurate and precise measurement of SOC is understood, it is labor-intensive and expensive and change detection is typically only possible over multiple years (or decades). We currently lack reliable data on the spatial and temporal

	patterns of SOC across shrubland landscapes“, given that current data are 1) largely based on modeled products, 2) limited to 50 cm – 1 m depth despite significantly deeper rooting depths in shrublands, and 3) limited to recent years (e.g., (Endsley et al., 2020). • Long-term datasets often lack a baseline measurement of SOC and bulk density value, which is critical to determining the trajectory of change in SOC • Changes in SOC are small in comparison to the existing stock; it can take a long time before enough SOC has been accrued to be detected • High spatial variability of SOC across shrublands further hampers detection of SOC changes

C Markets	
Is there a market (or proposed market) for carbon credits from the system?	Yes, voluntary markets exist.
Are there protocols (or proposed protocols) for such credits?	Project-based protocols/methodologies **Voluntary** • ACR Avoided Conversion of Grasslands and Shrublands to Crop Production[a]; United States and Canada • CAR Canada grassland protocol[a]; Canada • Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0[b]; international • Verra Avoided Planned Conversion of Grasslands and Shrublands to Crop Production (Under Development)[a]; United States or Canada [a] *Protocol applies to grassland and shrubland systems* [b] *Protocol applies to grassland, shrubland, and multiple forest systems*

If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	Project-based protocols/methodologies **ACR Avoided Conversion of Grasslands and Shrublands to Crop Production** • Permanence: Minimum project term is 20 years, and may be renewed up to four times, for a total duration of 100 years. • Additionality: Additionality must be satisfied using an independent appraisal that satisfies ACR's three prong additionality test through the demonstration of regulatory surplus, a lack of common practice, and a financial implementation barrier • Leakage: Project proponents should use a conservative default value of 20% market leakage for avoided conversions of grassland or shrublands to commodity crops in the U.S. Proponents are encouraged to use a leakage decision tree to determine if accounting for activity shifting leakage is necessary. • Reversal: use the VCS AFOLU Non-Permanence Risk Tool until the ACR Tool for Risk Analysis and Buffer Determination is available • Uncertainty: Must account for uncertainty of avoided conversion using avoided conversion discount factor. Also, estimation of uncertainty is required for each baseline and project carbon pool and GHG sources **CAR Canada Grassland Protocol** • Permanence: for this protocol, an emission reduction is considered "permanent" if the quantity of carbon associated with that reduction is stored for at least 100 years following the issuance of a credit for that reduction. • Additionality: Projects must satisfy a performance test and legal requirement test. Also, any type of conservation or ecosystem service payment or credit received for activities on the project area must be disclosed by the Project Owner to the verification body and the Reserve on an ongoing basis • Leakage: Assumes 20% leakage effect, like the U.S. CAR Grassland Protocol • Reversal: If the Reserve determines that there has been an unavoidable reversal, it shall retire a quantity of CRTs from the Reserve Grassland Buffer Pool equal to the size of the reversal in metric tons of CO_2 (for each reporting period, project owner must transfer a quantity of credits to the Reserve Grassland Buffer Pool at time of credit issuance). Avoidable reversals must be communicated to the Reserve and compensated for by the Project Owner by transferring a quantity of CRTs from its reserve account equal to the size of the reversal • Uncertainty: discount factors for the uncertainty of conversion and uncertainty of modeling future management practices and climatic conditions. The baseline emissions quantified in this protocol are discounted to account for increasing uncertainty about input assumptions and model outputs into the future. Consistent with the U.S. Grassland Project Protocol, the Reserve has set the discount as one percent to start, increasing an additional one percent every five years • *Note: Canada one includes shrublands and grasslands while U.S. one only includes grasslands* **Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0**

	• Additionality: Must demonstrate additionality using the latest version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities. The common practice test must demonstrate that project activities will address at least one driver of conversion in such a way that the driver would not have been addressed had the project not been undertaken • Leakage: Emissions from activity-shifting leakage are calculated using the Leakage Emissions Model and an activity-shifting leakage area. Emissions from market leakage are estimated using a market leakage area and default values specified in the AFOLU Requirements • Permanence: Crediting period is a minimum of 20 years, maximum of 100 years • Reversals: Project proponent must estimate the final level of cumulative baseline emissions at the end of a crediting period. If this estimate is greater than the number of credits issued during the project crediting period, then this difference must be addressed through the AFOLU Pooled Buffer Account • Uncertainty: Deductions for uncertainty are determined by a linear combination of weighted standard errors of estimates from baseline emissions models and carbon stock measurement **Verra Avoided Planned Conversion of Grasslands and Shrublands to Crop Production (under development)** • Permanence: Project crediting period minimum of 20 years, renewable up to four times for a maximum project duration of 100 years. Crediting for avoided conversion may only occur for 20 years following the occurrence of conversion activities in the baseline on each Participant Field • Additionality: Additionality shall be satisfied using a Project Method, demonstrated with the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities • Leakage: An overall leakage factor that accounts for market and activity shifting leakage is calculated. Project Proponents are encouraged to use the Leakage Decision Tree to determine if accounting for Activity Shifting Leakage (ASL) is necessary. A default market leakage factor is used for all projects using this methodology • Reversal: not specified beyond use of VCS AFOLU Non-permanence risk tool • Uncertainty: Where uncertainties exceed 15% at the 95% confidence interval or 10% at the 90% confidence interval, an appropriate confidence deduction shall be applied. Uncertainties should be estimated with default values (such as those by the IPCC), estimates from peer-reviewed literature, or directly estimated with appropriate statistical techniques. Where there are a range of uncertainty values, project proponents must choose the most conservative value, so as to not overestimate project emissions reductions

If there are protocols, have there been any registered projects or credits generated? If so, where?	Project-based protocols/methodologies
	ACR Avoided Conversion of Grasslands and Shrublands to Crop Production
	• ACR222 "Prairie Pothole Avoided Conversion of Grasslands and Shrublands" in North Dakota.
	  ○ 2018 Verification report indicates net GHG emission reductions or removals of 37,238 Mg CO_2e.
	  ○ 166,197 credits registered.
	
	CAR Canada Grassland Protocol
	• N/A
	
	Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0; international
	• Avoided Grassland Conversion Cerrado Project in Brazil.
	  ○ The Cerrado biome is a tropical wet and dry grassland/savanna, and since 1985 has lost 47% of its native vegetation to agriculture. The Avoided Grassland Conversion Cerrado Program was launched as a grouped project to provide an alternative for landholders with surplus native vegetation to receive payments for conservation by leveraging the voluntary carbon market. Under the program, the private landholder foregoes their legal right to convert native vegetation, and in doing so avoids GHG emissions. The project is implemented across 10,841 ha
	  ○ 100,000 estimated annual emissions reductions.
	
	Verra Avoided Planned Conversion of Grasslands and Shrublands to Crop Production (Under Development, inactive)
	• N/A

Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc.	Project-based protocols/methodologies **ACR Avoided Conversion of Grasslands and Shrublands to Crop Production** • Not specified in the protocol **CAR Canada grassland protocol** • Not specified in the protocol **Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0; international** • Grouped projects permitted **Verra Avoided Planned Conversion of Grasslands and Shrublands to Crop Production (Under Development)**

within any existing or proposed market?	• Aggregation permitted
Is there controversy surrounding the markets or credits for the NCS pathway? Why?	*Concerns with project-scale protocols* • Accurate estimation*:* **Lack of consistency in the C pools included in GHG calculations across protocols.** ○ In Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0 protocol, SOC pool is considered as "optional." On the contrary, CAR Canada grassland protocol and ACR Avoided Conversion of Grasslands and Shrublands to Crop Production required the accounting of SOC pool in their GHG reductions calculations. • Concerns about accurate estimation of SOC across a project area, given the challenges around estimating SOC • **Permanence** and **reversal** issues due to SOC vulnerability. • **Additionality**: anticipated low costs of grassland/shrubland C sequestration are intertwined with issues of additionality. If barriers/costs for adopting practices that sequester C are low, they are more likely to be adopted in the absence of policies to promote them (Bol, 2010). • **Leakage**: Shrubland conversion could happen elsewhere. • **Additional social/equity concerns**: Pastoralists occupy substantial portions of grasslands/shrublands across the world, but they are often socially marginalized and have insecure land-tenure rights, which makes it difficult to participate in C markets.

Temperate Forests: *Avoided temperate forest conversion and degradation: Reforestation & Improved Forest Management*

Temperate forests cover over 6.66×10^6 km^2 globally (FAO FRA, 2020a). They are found within middle latitudes, usually between the subtropical domain equatorward and the boreal domain poleward (FAO, 2001). Temperate forests store an estimated 159 – 315 Pg of C (Dixon et al., 1994; Trumper et al., 2009). Given this estimated C stock and the global areal extent of temperate forests, the average C stock is 150 – 320 Mg C ha $^{-1}$ (Trumper et al., 2009). In a different study, Goldstein et al. (2020) split temperate forests into two different categories in order to estimate their carbon storage: temperate broadleaf forests and temperate conifer forests. They estimate that temperate broadleaf forests store 133 Pg C (268 Mg C ha^{-1}), while temperate conifer forests store 66 Pg C (272 Mg C ha^{-1}) in combined aboveground, belowground, and at soil organic C depths of 30 cm. Temperate forests are currently an overall C sink, with a net sequestration rate of approximately 3.6 Pg CO_2e yr $^{-1}$ (Harris et al., 2021). However, this number is highly uncertain. Since local stand characteristics and disturbances control C dynamics, some forests are C sinks while others are C sources.

Practices that conserve and sequester C in forests can be grouped into 3 categories: (1) maintain existing C pools (slow deforestation and forest degradation), (2) expand existing C sinks and pools through forest management, and (3) create new C sinks and pools by expanding tree and forest cover (reforestation and afforestation[17]) (Dixon et al., 1994).

While certain practices can conserve and sequester C, it is unclear how much additional C can be sustainably sequestered in temperate forests at a global scale. Griscom et al., (2017) estimate that reforestation of temperate forests globally could sequester an additional 2,1 Pg CO_2 yr^{-1} and that fire management in fire prone temperate forests could avoid 0.019 Pg CO_2 yr^{-1} of emissions. Walker et al.(2022) recently estimated that restoring global temperate forests (reforestation, improved plantations, avoided woodfuel) could sequester an additional 0.682 PgCO_2 yr^{-1}. They also computed that maintaining and managing global temperate forests (avoided conversion, avoided woodfuel, fire management) has a modeled mitigation potential of 1.776 PgCO_2 yr^{-1}. In addition, in forests that have a high carbon carrying capacity and are harvested at a young age relative to their projected growth, such as many forests in the coastal Pacific Northwest of the United States, an extension of timber harvest rotations may increase forest carbon sequestration while maintaining production of long-lasting wood products and minimizing leakage (Foley et al., 2009; Law and Waring, 2015). Other proposed methods, particularly those that ignore the role of climate limitations and disturbance regimes, must be regarded with caution, however, as they may lack permanence. For example, stocking of low-density forests has been proposed as a major opportunity for additional carbon sequestration (Domke et al., 2020a). However, increases in tree density may greatly increase the risk for severe and widespread insect outbreaks, moisture stress, and fire, thus causing a net loss of carbon in the long term; this risk is particularly acute in semi-arid regions such as many areas of the western United States, where a large proportion of restocking opportunity is located (Parker et al., 2006; Ager et al., 2010). Relatedly, climate change is intensifying disturbance regimes, particularly in temperate forests with dry summers (for example, western North America, Chile, and Australia), and the disturbance regimes in this

[17] EDF does not endorse afforestation but recognizes that many authors consider both reforestation and afforestation as methods for increasing forest cover.

region greatly limit the sustainable biomass carbon stocks in these regions (Sommerfeld et al., 2018; Pugh et al., 2019).

Measurement and monitoring also present challenges. There are more regional estimates for additional C sequestration; for example, the C storage potential of existing forests in China is 50.86 Pg CO_2 (Liu et al., 2014b). Although scientists are generally confident in their ability to detect changes in temperate forest C at a regional scale, there is a lack of consensus and confidence in the methods to estimate C stocks and changes on broader regional and global scales. Collating larger scale forest C estimates into composite global estimates can expand errors, since data sources and methods for quantifying forest C vary. Climate change further complicates quantification of forest C since models will need to account for shifting climate regimes and resulting range shifts, disturbance regime shifts, and changing species interactions.

Currently, there are both voluntary and compliance markets for temperate forest C credits. Organizations like Verra, American Carbon Registry, Gold Standard, Climate Action Reserve, and Family Forest Carbon Program all have voluntary, temperate forest-specific protocols that either have generated credits to highly varying degrees or have not generated any credits. California's Cap-and-Trade, British Columbia's Forest Carbon Offset Program, and the U.S.'s Regional Greenhouse Gas Initiative are all part of the compliance market, but only California's Cap-and-Trade and British Columbia's Forest Carbon Offset Program have generated credits. Most of these protocols account for permanence, additionality, leakage, reversals, and uncertainty to varying degrees. Details are noted in the associated table.

Temperate Forests

Global Areal Extent: 6.658×10^6 km2 (6.658×10^8 ha) (FAO FRA, 2020a)

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?	• Global stock: ~159 – 315 Pg C, with 40 – 63% of that C found in forest soils (Dixon et al., 1994; Trumper et al., 2009). A study by Pan et al. (2011) estimates a lower stock of 119 ± 6 Pg C. Goldstein et al. (2020) split temperate forests into two different categories in order to estimate their carbon storage: temperate broadleaf forests and temperate conifer forests. They estimate that temperate broadleaf forests store 133 Pg C (268 Mg C ha^{-1}), while temperate conifer forests store 66 Pg C (272 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 30cm • Average per hectare: 150 – 320 Mg C ha^{-1} (vegetation and soil) (Trumper et al., 2009). 63 Mg C ha^{-1} (just vegetation) (Gower, 2003), within the lower end of the range for vegetation (55.5 – 90 Mg C ha^{-1}) from Trumper et al. (2009)
At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	• Currently an overall C sink. Temperate forests have been increasing in extent for past several decades (Trumper et al., 2009). • From 2001-19, temperate forests have had a net sequestration rate of ~ 3.6 Pg CO_2e yr^{-1} (Harris et al., 2021), however there is high uncertainty in these estimates. • Local stand characteristics and disturbances control C dynamics; some forests act as C sinks while others act as C sources. • Due to China's relatively young forest age and a large area of planted forests, China's forest C stocks are estimated to increase between 55% (Hu et al., 2015) and 96% (Yao et al., 2018) by 2050. Current estimates of C in China's forest range from 6.43 Pg C (Hu et al., 2015) – 10.75 Pg C (Yao et al., 2018) and projected estimates for 2050 range from 9.97 (Hu et al., 2015)– 21.12 Pg C (Yao et al., 2018), suggesting these forests will act as a major C sink in the coming years. • From 2001-16, Australian forests experienced near net zero change in C, with the State of the Forest Report (2018) reporting that forest stocks have varied by less than 0.7% of the total stock in that period. More recently, intense wildfires have likely forced Australia's forests to be a net C source; wildfires in east coast forests during spring and summer 2019/20 resulted in an estimated loss of 0.65 Pg C (Bowman et al., 2021). • Warmer temperatures and higher CO_2 concentrations stemming from climate change may support increased temperate forest productivity initially, but ecosystem stability is threatened due to altered species behavior and habitat paired with more frequent and intense forest disturbances such as drought, intense wildfires, disease and pest outbreaks (Peters et al., 2013; Anderegg, 2021; Coffield et al., 2021).

Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	• Most temperate forests are not at maximum C storage because of natural disturbances and harvesting (Lorenz & Lal, 2010). • Forest management practices to conserve and sequester C are grouped into three major categories: (1) maintain existing C pools (slow deforestation and forest degradation), (2) expand existing C sinks and pools through forest management, (3) create new C sinks and pools by expanding tree and forest cover (reforestation and afforestation) (Dixon et al., 1994). • Similarly, Ontl et al. (2020) identify seven broad forest management strategies for increased/maximization of C sequestration and climate adaptation: (1) Maintain or increase extent of forest ecosystems, (2) Sustain fundamental ecological functions, (3) Reduce C losses from natural disturbances including wildfire, (4) Enhance forest recovery following disturbance, (5) Prioritize management of locations that provide high C value across the landscape, (6) Maintain or enhance existing C stocks while retaining forest character, and (7) Enhance or maintain sequestration capacity through significant forest alterations. Specific practices include altering forest structure or composition to reduce wildfire severity and intensity, reducing stocking in high-vulnerability forests, increasing stocking in understocked forests, extending rotation length, and controlling for invasive species (Ontl et al., 2020). However, the C effects of management on existing forest C have not been quantified. • Increasing stocking in under-stocked forests provides an opportunity for large C sequestration in already forested areas. This can eliminate competition between reforestation and other land-uses. Domke et al. (2020) Domke et al. (2020) find that fully stocking under-stocked stands in the U.S. would result in 20% increase in C sequestration per year, however current infrastructure only has the capacity to plant less than a one-thousandth trees per year of the total trees required to accomplish this goal (Domke et al., 2020b). • There is limited literature on using enhanced mineral weathering (EMW) products in forests. However, one study in China estimates biologically enhanced silicate weathering (from the combined action of afforestation/reforestation, controlled harvesting and rock powder amendment) could increase chemical weathering CO_2 sequestration by ~32% in forests globally and result in a CO_2 consumption rate of 7.9 ± 4.1 Tg CO_2 yr^{-1} in Chinese forests (Song et al., 2018).
What is the range of estimates for how much additional C could be sequestered globally?	• Restore land with high suitability for forestry-based NCS (Reforestation, Improved plantations, Avoided woodfuel): 19.818 $PgCO_2$ over the period 2000-2050 (0.396 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain and Manage land with high suitability for forestry-based NCS (Avoided conversion, Natural Forest/Savana Management, Improved plantations, Avoided woodfuel, Fire management): 74.501 $PgCO_2$ over the period 2000-2050 (1.49 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain land with high suitability for forestry-based NCS (Avoided conversion, Fire management): 4.037 $PgCO_2$ over the period 2000-2050 (0.081 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Restore land with low suitability for forestry-based NCS (Avoided woodfuel): 14.313 $PgCO_2$ over the period 2000-2050 (0.286 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain and Manage land with low suitability for forestry-based NCS (Avoided conversion, Avoided woodfuel, Fire management): 14.313 $PgCO_2$ over the period 2000-2050 (0.286 $PgCO_2$ yr^{-1}) (Walker et al., 2022)

	• Maintain land with low suitability for forestry-based NCS (Avoided conversion, Avoided woodfuel, Fire management): 2.202 $PgCO_2$ over the period 2000-2050 (0.044 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Griscom et al. (2017) look at the mitigation potential of several practices in temperate forests, globally. They estimate that reforestation of temperate forests can sequester an additional 2,100 Tg CO_2 yr^{-1} and that fire management in temperate, fire prone forests can avoid 19 Tg CO_2 yr^{-1} of emissions. • The C storage potential of China's forests is modeled to range between 19.90 – 26.40 Pg C (73.03 – 96.88 Pg CO_2) (Liu et al., 2014b). Assuming the lowest estimate of C storage potential (19.90 Pg C or 73.03 Pg CO_2), *the additional* C that could be stored by existing Chinese forests is 13.86 Pg C (50.86 Pg CO_2) (Liu et al., 2014b). • One study by Keith et al. (2010) reported an average C storage potential of 360 Mg C ha^{-1} (1321.2 Mg CO_2 ha^{-1}) in southeast Australia, while the authors note that IPCC estimated a C storage potential of 202 Mg C ha^{-1} (741.34 Mg CO_2 ha^{-1}) for the same region (Keith et al., 2010). • A case study of 17 Australian forest stands estimated that current biomass stocks are at approximately 60% of their predicted carbon storage potential (Roxburgh et al., 2006). • Planting additional trees in all U.S. forestlands where less than <35% of the area is occupied by trees is estimated to result in a 20% increase in C sequestration per year. However, planting capacity is a barrier to this scale of reforestation (Domke et al., 2020b). • In its review of the science, the National Academies of Sciences, Engineering, and Medicine (NAS) (2019) estimated that a "modest program" of reforestation and afforestation could sequester 0.15 Pg CO_2 yr^{-1} for the U.S. over the next 50 – 100 years without disturbing protected areas, food supply or biodiversity. Fargione et al. (2018) estimate that reforestation in the U.S., particularly in the northeast and south central U.S., could sequester 0.31 Pg CO_2e yr^{-1}, or double the NAS (2019) estimate. Fargione et al. (2018) estimate that this mitigation potential increases to 0.38 Pg CO_2 yr^{-1} if all pastures in historically forested areas are reforested. • Fargione et al. (2018) also estimate that improved natural forest management (extending harvest cycles having the maximum mitigation potential; reduced impact logging and improved silvicultural practices that release suppressed forest growth are also effective but show lower sequestration rates) in privately held U.S. forests could sequester 0.267 Pg CO_2e yr^{-1}. Fire management (restoring frequent, low-intensity, understory fires in fire-prone forest ecosystems) could sequester 18 Tg CO_2e yr^{-1} in the U.S. Finally, they estimate that avoided forest conversion has a mitigation potential of 38 Tg CO_2e yr^{-1} particularly in Sothern and Pacific Northwest regions of the U.S. (Fargione et al., 2018).

How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent of that?	• Fair confidence regionally, lack of consensus and confidence on broader regional and global scales. • With incomparable data sources and various methods for forest C quantification, collating larger scale forest C estimates into composite global estimates is currently not possible. Furthermore, coarser scale estimates often discount ecosystem complexities (Sun and Liu, 2019). There is a need for a standard forest C quantification method that accounts for finer scale ecosystem complexity and diversity, and allows for composite, upscaled C estimates. • Scaling is a critical barrier to quantifying global forest C stocks. For example, the 56% difference between the potential C sequestration estimated by Keith et al. (2010) and the one estimated by IPCC in southeast Australia resulted partially from the grouping of regional forests into broader characterizations, or upscaling, a topic also challenged in forest C crediting (Badgley et al., 2021). • Ecosystem adaption to climate change will vary by geography and forest type, making future predictions of C storage difficult (Peters et al., 2013). Identifying realistic potential of forest C must account for regionally predicted shifts in climatic regimes while accounting for species interactions with anticipated environmental change.

C Markets

Is there a market (or proposed market) for carbon credits from the system?	• Yes, voluntary and compliance markets exist. Markets are quite active, particularly in the U.S. • One indicator of projected market momentum: Finite Capital, a forest C project developer, was purchased by BP in December 2020. Finite has already developed 50 projects, generating 7.0×10^6 credits, generating USD 500 million in revenue for landowners. They estimate doubling that revenue between now and 2030.
Are there protocols (or proposed protocols) for such credits?	*Voluntary* • Climate Action Reserve (CAR) Forest Project Protocol, v5.0[a]; U.S. and U.S. territories only • American Carbon Registry's (ACR) Improved Forest Management on Non-Federal US Forestlands Methodology, v1.3[a]; U.S. • American Carbon Registry Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Improved Forest Management on Canadian Forestlands [a]; Canada • American Carbon Registry (ACR) Afforestation and Reforestation of Degraded Lands [b]; international • American Carbon Registry (ACR) IFM on small non-industrial private forestlands [b]; U.S. • Verra VM0003 Methodology for Improved Forest Management through Extension of Rotation, v1.2[b]; International. • Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0[c]; international • Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3[c]; international

	• Verra VM0012 Improved Forest Management in Temperate and Boreal Forests, v1.3[a, 1]; International. • Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1[d]; international • Verra VM0034 Canadian Forest Carbon Offset Methodology, v2.0[a]; Canada • Verra VM0035 Improved Forest Management through Reduced Impact Logging, v1.0[b]; International. • Gold Standard's Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0[d]; International. • Family Forest Carbon Program's (FFCP) Methodology for Improved Forest Management, v1.0; Only Pennsylvania, but is expanding to West Virginia and Maryland. • Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)[e]; China *Compliance* • California Cap-and-Trade, Compliance Offset Protocol US Forest Projects, June 2015 ; U.S. • Regional Greenhouse Gas Initiative's Forest Offset Protocol, v1.0; U.S. • British Columbia's Forest Carbon Offset Program, Forest Carbon Offset Protocol, v2.0; British Columbia [a] Protocol applies to temperate and boreal forests only [b] Protocol applies to multiple forest systems [c] Protocol applies to multiple forest systems, grasslands, and shrublands [d] Protocol applies to multiple forest types, agroforestry, and coastal blue carbon systems [e] Protocol applies to multiple forest types, agroforestry, grasslands, and shrublands [1] The Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) accepts carbon offset projects that use this protocol Note: The Panda Standard Sectoral Specifications applies to temperate forests, however, we have not been able to verify that the protocol has been approved by the Chinese government, and/or has generated temperate forest credits to date. Additional protocols that cover temperate forest pathways in China may exist, but we have not been able to review all of them due to limited publicly available information.
If there are protocols, do they buffer or discount credits for permanence,	*Voluntary* **Climate Action Reserve Forest Project Protocol, v5.0** • **Permanence:** Permanence must be maintained for 100 years. • **Additionality:** To be considered as additional, forest projects (Improved Forest Management and Avoided Conversion) must satisfy a legal requirement test (Forest Projects must achieve GHG reductions or removals above and beyond any GHG reductions or removals that would result from compliance with any federal, state, or local law, statute, rule, regulation, or ordinance) as well as a performance test.(Forest

additionality, leakage, reversals, and uncertainty?	projects must achieve GHG reductions or removals above and beyond any GHG reductions or removals that would result from engaging in business-as-usual activities) • **Leakage:** Excludes activity-shifting leakage but includes market-shifting leakage. Market leakage is quantified as 0%, 10%, or 40%, based on the total decrease in wood products produced. • **Reversals:** A percentage of credits goes to buffer pool. Unavoidable reversals are compensated with credits in a shared buffer pool; every project contributes to the buffer pool at rates based on risk level. Avoidable reversals or computational reversals must be compensated for by the forest owner or project operator. • **Uncertainty:** Use a confidence deduction based on the sampling error for required onsite C pools derived from sampling for IFM projects. If sampling error is below 5%, the confidence deduction is zero. If sampling error is between 5% and 20%, the confidence deduction is the sampling error minus 5%. If the sampling error is 20% or more, the confidence deduction is 100%. **American Carbon Registry Improved Forest Management on Non-Federal U.S. Forestlands Methodology, v1.3** • **Permanence:** Permanence must be maintained for 40 years. • **Additionality:** The project proponent shall demonstrate that the proposed project activity exceeds the common practice of similar landowners managing similar forests in the region. • **Leakage:** ACR excludes activity-shifting leakage but includes market-shifting leakage. Market leakage is quantified as 0%, 10%, or 40%, based on the total decrease in wood products produced. • **Reversals:** A percentage of credits goes to buffer pool. Unavoidable reversals are compensated with credits in a shared buffer pool; every project contributes to the buffer pool at rates based on risk level. Avoidable reversals or computational reversals must be compensated for by the forest owner or project operator. • **Uncertainty:** Defines uncertainty as the square root of the summed errors in each of the measurement pools. The errors in each pool shall be weighted by the size of the pool so that projects may reasonably target a lower precision level in pools that only form a small proportion of the total stock. **American Carbon Registry Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Improved Forest Management on Canadian Forestlands** • **Permanence:** A minimum commitment of 40 years is needed for Improved Forest Management practices and any potential loss of sequestered C must be first addressed by means of either a buffer pool or insurance**.** • **Additionality:** Projects must apply a three-prong additionality test to demonstrate that they exceed currently effective and enforced laws and regulations; exceed common practice in the forestry sector and geographic region; and face a financial implementation barrier. • **Leakage:** Project proponents must demonstrate there is no activity-shifting leakage above the de minimis threshold. Market leakage must be assessed and accounted for in the quantification of net project benefits**.**

	• **Reversals:** Projects must have effective risk mitigation measures in place to compensate fully for any loss of sequestered C. Such mitigation measures can include contributions to the buffer pool, insurance, or other risk mitigation measures approved by ACR. • **Uncertainty:** The ACR Standard sets a statistical precision requirement of ±10% of the mean with 90% confidence. When total project uncertainty is beyond this threshold, an uncertainty deduction affects the calculation of Emission Reduction Tons (ERTs.). **American Carbon Registry Forest Carbon Standard: Improved Forest Management (IFM) on Small Non-Industrial Private Forestlands v1.0** • **Permanence:** 40 years • **Additionality:** ACR three prong additionality test (regulatory surplus, common practice, implementation barriers) and the CDM's "Combined tool to identify the baseline scenario and demonstrate additionality" • **Leakage:** Market leakage deduction of 20% where project activities decrease total wood products produced by the project relative to the baseline by more than 5% over the crediting period • **Reversals:** Calculates risk of non-permanence using the ACR Tool for Risk Analysis and Buffer Determination – project proponents may contribute to a buffer pool OR purchase insurance for their credits. • **Uncertainty**: +/- 10% of the mean at 90% confidence interval. If calculated uncertainty exceeds 10% then the estimated amount of the combined carbon stock at the project area level cannot be verified without additional sampling or stratification to improve statistical confidence. **American Carbon Registry, Forest Carbon Standard: Afforestation/Reforestation on Degraded Lands v1.2** • **Permanence:** 40 years • **Additionality:** ACR three prong additionality test (regulatory surplus, common practice, implementation barriers) and the CDM's "Combined tool to identify the baseline scenario and demonstrate additionality" • **Leakage:** leakage estimated based on CDM method: Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity • **Reversals:** calculates risk of non-permanence using the ACR Tool for Risk Analysis and Buffer Determination – project proponents may contribute to a buffer pool OR purchase insurance for their credits • **Uncertainty:** +/- 10% of the mean at 90% confidence interval applied to final calculation of emission reduction/removal enhancements **Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction and Sequestration Methodology, v1.0** • **Permanence:** Does not specifically require permanence of its projects. It only requires projects maintain C stocks during the crediting period. If the C stocks are not maintained during the crediting period, a shortfall is declared, and projects must demonstrate to the Gold Standard how the project will realistically address the performance shortfall and recover appropriate levels of C stocks. Performance risks is

	assessed following the "Risk and Capacities" guideline. A risk scoring system assesses pre-defined risk categories and determines whether the risks of a project are acceptable to Gold Standard or whether mitigation measures shall be adopted. Uses high/medium/low scoring system based on defined thresholds. Risk categories are: 1. Natural Disturbance risks 2. Political risks 3. Project Management risks 4. Financial risks 5. Market risks. • **Additionality:** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice). • **Leakage:** Accounting for activity shifting required. Leakage shall be determined on a Modelling Unit (MU) level using the following formula: Leakage MU,t [tCO_2 ha^{-1}] = Leakage Project area [tCO_2] / Eligible planting area [ha]. Leakage is deducted in the first year. Four categories of leakage resulting from collection of wood (for firewood, charcoal), timber harvesting, agriculture (crop cultivation, shrimp cultivation) and livestock. All potential Leakage caused by a project within its crediting period is accounted for in year 1. Parameter is not subject to monitoring. Market leakage not accounted for under this methodology. Projects must submit a Leakage Template which includes information and calculations of potential leakage from different project activities. Provides default values when exact data is not available. • **Reversals:** A percentage of credits go to a buffer pool; projects must contribute to a risk of reversals buffer (20%). Pooled compliance buffer remains untouched even after the crediting period of the project, further reducing the risk of reversal and non-permanence. • **Uncertainty:** +/-20% at a 90% confidence interval. Where the error is above 20%, the additional difference shall be deducted. Gold Standard provides 3 approaches to uncertainty: Approach 1: Data is measured within each stratum and shall follow accepted sampling and analysis protocols, Approach 2: Data is derived from peer reviewed published literature, Approach 3: Project owners may use published default factors such as IPCCs. **Verra VM0003 Methodology for Improved Forest Management through Extension of Rotation, v1.2** • **Permanence:** Crediting period is a minimum of 20 years, maximum of 100 years • **Additionality:** The project proponent must test the additionality of the project using the current CDM Tool for the demonstration and assessment of additionality • **Leakage:** Leakage emissions due to market effects resulting from a shift in harvest must be accounted • **Reversals:** Credits are issues to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Uncertainty deduction must be calculated. Uncertainty at all times is defined as the 90% confidence interval as a percentage of the mean **Verra VM0012 Improved Forest Management in Temperate and Boreal Forests, v1.3**

	• **Permanence:** For Improved Forest Management (IFM) projects, the crediting period must include a complete harvest/cutting cycle and must be a minimum of 20 years up to a maximum of 100 which may be renewed at most four times • **Additionality:** Project proponents must use the newest version of the VCS tool: "Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities". • **Leakage:** All leakage must be assessed and accounted for in GHG calculations. Positive leakage effects must be discounted. Leakage within this methodology is assessed against a national leakage area. • **Reversals:** Credits are issued to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** Must calculate and apply an uncertainty factor to net GHG emission reductions at each verification and apply it annually until next verification. To be conservative, this methodology employs an over-riding project confidence deduction as a proxy for collective project uncertainty by assessing statistical uncertainty in the forest C inventory and associated modeling **Verra VM0035 Improved Forest Management through Reduced Impact Logging, v1.0** • **Permanence:** For Improved Forest Management (IFM) projects the crediting period must include a complete harvest/cutting cycle and must be a minimum of 20 years up to a maximum of 100 years • **Additionality:** Uses a performance method for additionality, whereby emission reductions are assigned as a function of the difference between a set crediting baseline for each emission source category (i.e., felling, skidding and hauling) and the measured impact of those parameters in the project scenario. Projects may only be credited for emission reductions from one or more impact parameters if they are deemed additional. A project is deemed additional for one or more impact parameters if the impact parameter is below the additionality benchmark assigned for that impact parameter. • **Leakage:** Leakage assumed to be zero because the applicability conditions do not allow for changes in harvest levels; there should be no difference in harvest levels between the baseline and project scenarios • **Reversals:** Credits are issued to VCS Buffer Pool, calculated by the VCS AFOLU Non-Permanence Risk Tool • **Uncertainty:** No uncertainty deduction deemed necessary **Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities. Project description must include set of requirements to expand on project additionality • **Leakage:** quantified using an activity-shifting leakage area(s) and a market leakage area(s), which may or may not overlap with the reference area. Methodology includes a Leakage Emissions Model (LEM) which accounts for emissions from activity-shifting leakage.

	• **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** Determined through equation F.57 included in methodology. Constant 1.64 is the Z value at the 90% confidence level. **Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage:** Accounts for Activity Shifting Leakage (can be 0) and leakage due to market effects. The leakage factor is determined by considering where in the country logging will be increased as a result of the decreased timber supply caused by the project. The geographic boundaries for leakage from market effects are those of the country in which the project area is located. • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** defined at the 95% confidence interval where the estimated variance exceeds +/- 15 percent from the mean. Procedures including stratification and the allocation of sufficient measurement plots will help ensure that low uncertainty results and ultimately full crediting can result **Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using methodological equation • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities noting that the earliest start date of the proposed AUD project activity is January 1st, 2002. However, the start date can be earlier than January 1st, 2002, provided the requirements for projects with a start date prior to 2002, as set out in the most recent version of the VCS Standard, are met. • **Leakage:** Accounts for emissions from increased grazing activities, increased emission from displaced forest fires, decrease in carbon stocks due to displaced deforestation; see leakage calculation section of methodology which details the calculation process. If the project area is located within a jurisdictional program the most recent VCS JNR Requirements must be applied to determine whether a leakage belt is required. In all other cases, a leakage belt is required. • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification

	• **Uncertainty:** If the uncertainty of the total average carbon stock of a class is less than 10% of the average value, the average carbon stock value can be used. If the uncertainty is higher than 10%, the lower boundary of the 90% confidence interval must be considered in the calculations if the class is an initial forest class in the project area or a final non-forest class in the leakage belt, and the higher boundary of the 90% confidence interval if the class is an initial forest class in the leakage belt or a final non-forest class in the project area. **Verra VM0034 Canadian Forest Carbon Offset Methodology, v2.0** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** Must be demonstrated by completing the following steps a) Identification of alternative scenarios, b) Barrier analysis, c) Investment analysis, and d) Common practice analysis. This procedure is based on *CDM Tool 02 Combined tool to identify the baseline scenario and demonstrate additionality* • **Leakage:** Accounts for activity shifting leakage (GHG emissions from areas outside the project area, which is cause by the project activity) and market leakage • **Reversals:** Credits are issues to a buffer pool using VCS AFOLU Non-Permanence Risk Tool. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. Also requires the use of the VCS Non-permanence Risk Report Template, which entails a Risk Mitigation and Contingency Plan that tries to minimize the likelihood that a natural or human-induced reversal event will occur up to 100 years into the future from the time an emission offset is created by the project. • **Uncertainty:** Methods used for estimating uncertainty must be based on recognized statistical approaches such as those described in the IPCC Good Practice Guidance and Uncertainty Management in National GHG Inventories. Where the width of the 90 percent confidence interval of the sampled data exceeds +/-10% of the estimated value, the amount that the calculated confidence interval is greater than +/- 10% must be added to the average (in the case of the baseline scenario) or subtracted from the average (in the case of the project scenario), and the resulting number used in quantification of carbon in the sampled carbon pool. **FFCP Methodology for Improved Forest Management, v1.0** • **Permanence:** Permanence must be maintained for 20 years. • **Additionality:** Baseline determination represents the without-treatment via representative sampling of business-as-usual practices at a regional scale. • **Leakage:** Project managers must calculate the national average ratio of merchantable stocking to total stocking compared to the equivalent ratio in the project area. Then, they must apply a leakage factor, ranging from 10% to 70%, depending on the difference between the national ratio and the project area ratio. • **Reversals:** A percentage of credits goes to buffer pool. Unavoidable reversals are compensated with credits in a shared buffer pool; every project contributes to the buffer pool at rates based on risk level. Avoidable reversals or computational reversals must be compensated for by the forest owner or project operator.

	• **Uncertainty:** Uncertainty associated with sample error is quantified and accounted for. **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • **Permanence**: Minimum project term varies with the type of project; Project generating net C sequestration (or GHG removals) have a minimum project term of 30 years; Project generating net emission reductions have a minimum project term of 20 years; Project generating net irreversible net GHG emission reductions have a minimum project term of 5 years. Project Proponents must conduct a risk assessment using the Panda Standard Risk Analysis Tool. The result of the Risk Assessment is an overall risk category for the Project, translating into a percentage or number of PS Credits that must be deposited into the Panda Buffer Pool. • **Additionality**: Additionality can be demonstrated using 2 approaches: o **Three-prong approach**: The project activity must meet the following criteria: a. Complies with regulatory requirements b. Exceeds common practice c. Faces investment, technological or institutional barriers); o **Performance standard approach** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice)). • **Leakage:** Accounting for activity shifting required. Any leakage identified must be quantified and subtracted from the net emission reduction/removal benefits except when leakage arises from the creation of poles and fencing to implement Project Activities • Fossil fuel combustion resulting from ground transportation. Leakage accounting might also be omitted if the following criteria are met: Displacement of baseline activities occurs on less than an average of 5% of the land area for a given project activity during the crediting period • Total quantity of a given good/commodity (e.g. lumber, crop, fuelwood, grazing animal) supplied to market in the project scenario for a given project activity is reduced by less than 20% of in comparison to the Baseline during the crediting period • All Leakage emissions are estimated to be below the de minimis threshold on average during the crediting period. o Accounting for market leakage is not required if the following conditions are satisfied: ▪ Average quantity of a given good/commodity supplied to market in the with-Project Scenario for a given Project Activity is reduced by less than 20% in comparison to the Baseline. ▪ Average quantity of a given good/commodity in the Baseline per year supplied to market is less than 5% of total commodity produced per year within the PRC Prefecture (s) where the Project is taking place. • **Reversals:** A percentage of credits go to a buffer pool (Panda buffer pool). 2 options to mitigate risk: o **Option 1**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, this percentage of offsets from the Project itself for deposit to the Panda Buffer Pool";

	○ **Option 2**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, the number of PS credits of any type and vintage that equates to the percentage drawn from the risk assessment". Percentage of contribution to buffer pool is not explicitly stated. • **Uncertainty:** If the 90% confidence interval is greater than 10% of the mean the reportable amount must include an uncertainty deduction. The uncertainty deduction shall be equal to the calculated % of the mean represented by the confidence interval minus the allowable 10% *Compliance* **California Cap-and-Trade, Compliance Offset Protocol US Forest Projects, v2.0** • **Permanence:** Permanence must be maintained for 100 years. • **Additionality:** Emission reductions or removal enhancements achieved by a forest project must exceed those likely to occur in a conservative business-as-usual scenario. Details for each activity (reforestation, IFM, AC) can be found in the protocol. • **Leakage:** Reforestation: Leakage is determined through a flow diagram (Figure 5.1), which includes factors such as viability of cropland, tree canopy coverage, and grazing. Leakage ranges from 0% to 50%. • **Reversals:** A percentage of credits goes to buffer pool. Unavoidable reversals (fires, insects, hurricanes, etc.) are compensated with credits in a shared buffer pool; every project contributes to the buffer pool at rates based on risk level. Avoidable reversals (harvesting trees) or computational reversals (due to confidence deductions or leakage) must be compensated for by the forest owner or project operator. • **Uncertainty:** Use a confidence deduction based on the sampling error for required onsite C pools derived from sampling for IFM projects. If sampling error is below 5%, the confidence deduction is zero. If sampling error is between 5% and 20%, the confidence deduction is the sampling error minus 5%. If the sampling error is 20% or more, the confidence deduction is 100%. **Regional Greenhouse Gas Initiative's Forest Offset Protocol, v1.0** • **Permanence**: Permanence must be maintained for 100 years. • **Additionality:** Emission reductions or removal enhancements achieved by a forest project must exceed those likely to occur in a conservative business-as-usual scenario. • **Leakage:** RGGI uses a 20% deduction, applied to the difference in harvest volume relative to baseline to address activity-shifting leakage. Market effects is applied as 80% of the difference in wood products produced. • **Reversals:** There is not a buffer pool. For a Reforestation or AC project, a quantity of CO_2 Allowances equal to the total number of CO_2 offset allowances awarded to the project over the preceding 100 years must be retired. For an IFM project, a quantity of CO_2 allowances equal to the total number of CO_2 offset allowances awarded to the project over the preceding 100 years, multiplied by the appropriate compensation rate must be retired.

	• **Uncertainty:** Only accounts for uncertainty in AC projects. If the fair market value of the anticipated alternative land use for the project area is not more than 80% greater than the value of the current forested land use, then a discount must be applied each year to the offset project's quantified GHG reductions and GHG removal enhancements. **British Columbia's Forest Carbon Offset Program, Forest Carbon Offset Protocol, v2.0** • **Permanence:** Permanence must be maintained for 100 years. • **Reversals:** A percentage of credits goes to buffer pool. Unavoidable reversals are compensated with credits in a shared buffer pool; every project contributes to the buffer pool at rates based on risk level. Avoidable reversals or computational reversals must be compensated for by the forest owner or project operator. Once a Reversal occurs, the Project and Baseline Scenarios must be adjusted for subsequent Project Reports. • **Leakage:** Where a risk of leakage exists, project proponents may undertake leakage mitigation measures to reduce Leakage. If any significant increase in emissions occurs because of these measures, the resulting emissions must be accounted for using the appropriate emission source. • **Additionality** Emission reductions or removal enhancements achieved by a forest project must exceed those likely to occur in a conservative business-as-usual scenario. • **Uncertainty:** For sampling the forest reservoir, the targeted sampling error for total biomass/carbon should be less than or equal to 20 percent at 90 percent confidence level for both plantation and natural forests.

If there are protocols, have there been any registered projects or credits generated? If so, where?	*Voluntary*
	CAR Forest Project Protocol, v5.0
	• 11 reforestation projects registered (11 United States)
	  o Total credits issued: 0
	• 145 Improved Forest Management projects registered (148 United States)
	  o Total credits issued: 70,062,611
	• 8 Avoided Forest Conversion projects registered (8 United States)
	  o Total credits issued: 1,938,282
	
	American Carbon Registry
	• 7 reforestation projects registered (7 United States)
	  o Total credits issued: 5,091,586
	• 113 Improved Forest Management project registered (117 United States)
	  o Total credits issued: 77,544,817

	• 4 Avoided Forest Conversion project registered
	  ○ Total credits issued: 4,532,805
	• ACR's Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Improved Forest Management on Canadian Forestlands has registered no credits yet since it was approved in September 2021
	
	Note: Fewer details provided for American Carbon Registry due to the inability to search the registry by methodology. The registry can be searched for "forest carbon" but methodologies are not distinguished in the results.
	
	Verra VM0003 Methodology for Improved Forest Management through Extension of Rotation, v1.2
	• 3 projects in U.S., 2 under validation in the U.S. and Chile
	
	Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0
	• None for temperate forests
	
	Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3
	• Projects in China (29 registered or requesting registration), Australia (4), Canada (1), Chile (1 under validation) and Russia (1 under validation)
	  ○ Total credits issued: 3,801,652
	
	Verra VM0012 Improved Forest Management in Temperate and Boreal Forests, v1.3
	• Projects in Romania (2 registered or under development), Canada (4 registered, awaiting registration and verification approval, or under validation), Germany (1 under development) and United States (2 registered).
	  ○ Total credits issued: 3,082,691
	
	Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1
	• No projects for temperate forests. While this protocol applies to all forest types, the protocol is based off a draft REDD+ project description in Brazil, and all current projects appear to be in tropical forests
	
	Verra VM0034 Canadian Forest Carbon Offset Methodology, v2.0
	• 1 project in Quebec, Canada**.** No credits generated as of January 2023, however estimated annual emissions reductions of 115,408
	
	Verra VM0035 Improved Forest Management through Reduced Impact Logging, v1.0

	• No credits generated as of January 2023. **Gold Standard's Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0** • 24 projects registered o Total credits issued: 4.897,962 *Note: This is not the number of credits specific to temperate forest system, but rather the total number of credits listed under the methodology* **VM0045 Methodology for Improved Forest Management Using Dynamic Matched Baselines from National Forest Inventories, v1.0** • No credits generated as of AJanuary 2023. **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • Can't find the registry *Compliance* **California Cap-and-Trade, Compliance Offset Protocol U.S. Forest Projects, v2.0** • Projects in the U.S.: top five states are AK, CA, WV, WA, and AZ. Total of 182,883,788 Mg CO_2 credited as of August 2021. **Regional Greenhouse Gas Initiative's Forest Offset Protocol, v1.0** • Unclear if credits have been generated as of January 2023. •
Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage, additionality, etc.	*Voluntary* **Climate Action Reserve (CAR) Forest Project Protocol, v5.0** • Aggregation is permitted under this protocol. **American Carbon Registry's (ACR) Improved Forest Management on Non-Federal US Forestlands Methodology, v1.3** • Aggregation is allowed under this methodology. Chapter 6 of the ACR standard, version 5 provides guidelines for aggregating multiple landholdings into a single forest carbon project

within any existing or proposed market?	**American Carbon Registry Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from Improved Forest Management on Canadian Forestlands** • Aggregation is allowed, but projects are advised against aggregating multiple forest types or attempting a geographic region that is too large **American Carbon Registry Forest Carbon Standard: Improved Forest Management (IFM) on Small Non-Industrial Private Forestlands v1.0** • Aggregation is allowed under this protocol **American Carbon Registry, Forest Carbon Standard: Afforestation/Reforestation on Degraded Lands v1.2** • Aggregation is allowed under this protocol **Verra VM0003 Methodology for Improved Forest Management through Extension of Rotation, v1.2** • Aggregation of forest properties with multiple landowners is permitted under the methodology with aggregated areas treated as a single project area **Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0** • Grouped projects are allowed **Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3** • Not explicitly addressed in the protocol **Verra VM0012 Improved Forest Management in Temperate and Boreal Forests, v1.3** • Allows combination of multiple projects into a single project **Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements **Verra VM0034 Canadian Forest Carbon Offset Methodology, v2.0** • Not explicitly addressed in the protocol **Verra VM0035 Improved Forest Management through Reduced Impact Logging, v1.0**

	• Not explicitly addressed in the protocol **Gold Standard's Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0** • Supports a landscape approach but has stated that REDD+ approaches have many challenges **Family Forest Carbon Program's (FFCP) Methodology for Improved Forest Management, v1.0** • Grouped project are allowed **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** • Not specified in protocol *Compliance* **California Cap-and-Trade, Compliance Offset Protocol US Forest Projects, v2.0** Aggregation of projects is not allowed, however, multiple landowners may jointly participate in an offset project if there is one baseline and one inventory for the entire project; the project would have to meet the geographic limitations identified in Section 4 of the Protocol: Project Area cannot extend across more than two adjacent Ecosections or Supersections. All participants would be equally considered as Forest Owners and subject to all the rights and responsibilities under Section 2.2 in the Protocol (see "Forest Owner Sells Land" for associated Q/A). Multiple Forest Owners representing individual offset projects may cooperate when soliciting bids for verification services for purposes of reducing cost through economies of scale. Each project must still have its own independent OPDR, verification and Offset Verification Statement. **Regional Greenhouse Gas Initiative's Forest Offset Protocol, v1.0** • Aggregation is allowed under this protocol **British Columbia's Forest Carbon Offset Program, Forest Carbon Offset Protocol, v2.0** • Not explicitly addressed in protocol

Is there controversy surrounding the markets or credits for the NCS pathway? Why?	• **Permanence:** Another issue among stakeholders is the idea of C offsets being permanent. Permanence is essential to the legitimacy of a C credit because it guarantees that C will be stored, out of the atmosphere, for a long time, typically 100 years. Monitoring is necessary to ensure permanence, but it is costly (Catanoso, 2020). However, the majority of this criticism is aimed at rainforests, especially in South America. Natural disasters, especially wildfires, have the potential to reverse C savings. As intended, thus far, the buffer pools have covered any C lost to wildfires. As climate change progresses and wildfires become more frequent, this becomes a significant problem (Kahn, 2021). • **Additionality:** Many critiques agree that there is a problem with the way that additionality is addressed in the protocols. Some argue that, as they currently stand, some forest offset projects are not actually additional. Projects are supposed to be credited for C sequestration in excess of what would have happened without the credit. However, critics claim that some projects are located on land that was never at risk of being logged or clear cut and is under the same management regime as before the credits were registered and awarded (Irfan, 2020; Elgin, 2020, 2021; Elgin and Mider, 2020) • **Leakage:** Leakage is an area that some stakeholders in the media and academia dispute. While forest protocols do account for some leakage, researchers argue that they are not accounting for enough. According to one study, 80% leakage should be deducted from some projects, based on the reduction in wood product production. However, a 20 – 40% deduction is typical for forest projects (Haya, 2019; Temple, 2021) • **Baseline**: The method of determining the baseline for a forest project is debated among stakeholders. Critics, published by CarbonPlan, argue that low baselines, based on unrealistic alternative scenarios, lead to over-crediting of forest projects (Badgley et al., 2021). When baselines are based on common practice, this can lead to inaccurate comparisons to logged forests or dissimilar tree species, which naturally store less C. Forest projects are then credited for more C than they are actually sequestering (Elgin, 2020) • **Low Price:** Most stakeholders agree that the current price of C offsets is too low. While it currently averages around USD 10 Mg C^{-1}, the price fails to account for co-benefits that forest projects provide and is a barrier to achieving higher quality credits. Quality C credits require careful sampling and monitoring, which requires more time and money. Microsoft is paying USD 15 MgC^{-1} for forest offset projects, which more accurately accounts for the costs associated with generating high quality credits (Catanoso, 2020; Roberts, 2020; Donofrio et al., 2020; Bangkok Post, 2020).

Tropical Forests: *Avoided and reduced deforestation and degradation, Reforestation & Improved Forest Management*

Tropical forests cover an estimated 1.83×10^7 km^2 (1.83×10^9 ha) globally (FAO FRA, 2020b) and sequester between 200 to 300 Pg C total (Mitchard, 2018). Given this C stock range and the global extent of tropical forests, tropical forest can, on average, store 109 – 164 Mg C ha^{-1}.

While tropical forests have historically been considered C sinks, there is some disagreement in the scientific community on whether global tropical forests are currently a net sink or source of C. This is in large part due to differences in the way that studies account for emissions; studies that are based on area change estimates of forest cover change tend to find the tropics as a net sink but studies that include forest degradation tend to find the tropics as a net source. For example, a recent study by (Harris et al., 2021) estimates that tropical forests are a net sink of -1.7 ± 8 Pg CO_2e yr^{-1}. However, when degradation estimates from Pearson et al. (2017) are included in (Harris et al., 2021) calculation, tropical forests become a net C source of 0.4 Pg CO_2e yr^{-1}.

At a regional scale, studies have found that certain tropical forests are currently C sinks while others are C sources. Under a business-as-usual scenario, climate change and deforestation pressures are expected to further push tropical forests towards becoming a net C source. However, reforesting, restoring degraded forests, avoiding and reducing forest degradation and deforestation, and improving forest management can help prevent emissions and increase net C sequestration in tropical forests. Importantly, setting a price on carbon to establish a functioning market, and the creation and strong enforcement of restrictive policies related to deforestation and degradation (legal and illegal), are two other major levers to reduce emissions from the tropical forest system. Estimates of how much additional carbon could be sequestered globally by tropical forests vary; Houghton & Nassikas (2018) estimate that mitigation activities (halting deforestation and forest degradation) could reduce emissions by as much as 12.11 Pg CO_2 yr^{-1}, while a more conservative analysis by Houghton & Nassikas (2017) state that these practices have a mitigation potential of 1.835 Pg CO_2 yr^{-1}. Regarding the management of these forests, Ellis et al (2019) suggest that improved timber harvesting techniques such as reduced-impact logging could reduce emissions by 0.37 Pg CO_2 yr^{-1}. Griscom et al., (2020) estimate that cost effective tropical reforestation, avoided forest conversion, and natural forest management have an estimated mitigation potential of 1.21 Pg CO_2 yr -1, 2.79 Pg CO_2 yr^{-1}, and 0.48 Pg CO_2 yr^{-1}, respectively — totaling 4.48 Pg CO_2 yr^{-1}. In a recent study which excludes areas critical for food and human habitations, Walker et al (2022) estimate that restoring tropical forests (reforestation, improved plantations, avoided woodfuel) could sequester an additional 0.822 Pg CO_2 yr^{-1}. They also state that maintaining and managing these forests (avoided conversion, natural forest management, improved plantations, avoided woodfuel, fire management) has a mitigation potential of 7.061 Pg CO_2 yr^{-1}.

Current methods to detect changes in C sequestration of tropical forests have different strengths and weaknesses, detailed below. Some major concerns with these methods include unreliable country-specific data on land use change and the difficulty in capturing carbon stock changes within remaining forests (e.g., changes from degradation or standing forest enhancement) with satellites.

There are both voluntary and compliance markets for tropical forest carbon credits. The majority of current markets are voluntary. Protocols for generating credits can generally be divided into jurisdictional and project-based approaches. These protocols have been developed by several organizations, including ART, Verra, Climate Action Reserve, Gold Standard, and more. Most of the protocols account for additionality, permanence, leakage, reversals, and uncertainty in varying ways. A multitude of credits have been generated by tropical forests across the world and detailed descriptions of projects and credits can be found by referring to registry websites.

The increasing popularity of tropical forest carbon credits has spotlighted concerns surrounding protocols and project approaches. For example, experts have raised concerns about additionality, permanence, underestimated transaction costs, and land tenure rights for project-scale REDD+ activities. For jurisdictional scale REDD+ programs, critics have raised concerns related to benefit sharing (particularly for Indigenous groups), program administration, and baseline setting. These concerns and challenges are described in more detail in the associated table. Although there is generally sufficient science for the development of tropical forest carbon markets, the challenge lies in ensuring that the markets are truly and effectively removing carbon from the atmosphere and decreasing tropical forest C emissions, while being equitable.

Tropical Forests

Global Area Extent: 1.83×10^7 km^2 (1.83×10^9 ha) (FAO FRA, 2020); this is 45% of total global forest area

C Sequestration Potential

How much C is currently stored (globally) in the system (total and on average per hectare)?	• Global stock range: Likely somewhere between 200 – 300 Pg C (Mitchard, 2018)
	  ○ Saatchi et al. (2011): 247 Pg C (193 Pg C stored aboveground and 54 Pg C stored belowground in roots, no soil carbon estimates)
	  ○ Xu et al. (2021): Tropical Moist Forests: 154 ± 1 Pg C (aboveground & belowground biomass); Tropical and Subtropical Dry Forests & Savannah: ~54.5 ± 0.6 Pg C (aboveground & belowground biomass); Total tropics & subtropics: 208.5 Pg C
	  ○ FAO FRA (2020): Rough estimate of the tropics (total carbon in Africa, excluding North Africa; South and Southeast Asia; Central America and the Caribbean; and South America): 272 Pg C (above and belowground biomass, deadwood / litter, soil carbon)
	  ○ Goldstein et al. (2020) also split up tropical forests into 2 categories: tropical dry forests and tropical moist forests. They estimate that tropical dry forests store 14 Pg C (166 Mg C ha^{-1}), while tropical moist forests store 295 Pg C (252 Mg C ha^{-1}) in combined aboveground, belowground, and soil organic C depths of 30cm
	• Per hectare range: 109 – 164 Mg C ha^{-1} based on the stock of 200 – 300 Pg C. Mackey et al. (2020) estimate that primary tropical forests store on average roughly 250 Mg C ha^{-1} of total above-ground biomass carbon stock, with ~175 Mg C ha^{-1} being above-ground living biomass and the remainder dead biomass. These estimates are based on Pan et al.'s (2011) larger C stock estimate for tropical forests (471 ± 93 Pg C).

At the global level, is the system currently a C source or sink? What is the business-as-usual projection for its C dynamics?	• There is some disagreement on whether tropical forests are a net C source or sink. Studies that are based on area change estimates tend to find the tropics as a net sink but studies that include forest degradation tend to find the tropics as a net source • Harris et al. (2021) find that globally, tropical forests are a net GHG sink (-1.7 ± 8 Pg CO_2e yr^{-1}). This estimate has high uncertainty. Much of the current uncertainty is related to estimating C removals accurately. There is also a particular challenge around measuring emissions from tropical forest degradation. Harris et al. (2021) note that if degradation were included in their emissions estimates, tropical forests would likely become a net source of C. They state that if Pearson et al. (2017) estimate of 2.1 Pg CO_2 of annual degradation emissions were included in their estimate of net emissions, tropical forests would become a net source of 0.4 Pg CO_2e yr^{-1}. • Harris et al. (2021) also find that of the major tropical forest regions, SE Asia is already a net source of C, while the Congo River Basin remains a net sink. The Amazon River Basin (the largest region, representing 28% of the world's tropical forests) is teetering on the edge of becoming a net source as it continues to lose carbon due to deforestation, degradation, and climate effects, like drought and fires. Notably, the Brazilian Amazon is already a net source of C (Harris et al., 2021).

	• Considering the globe currently emits around 59 Pg CO_2e yr^{-1} across all sectors and sources (United Nations Environment Programme, 2020), the Harris et al. (2021) work suggests that *gross* tropical forest emissions account for *9%* of annual global GHG emissions. When only CO_2 is considered, of which the global annual emissions across all sectors is around 35 Pg CO_2, then *gross* emissions from tropical forests represent *15%* of annual global CO_2 emissions. If estimates of emissions due to degradation are added from Pearson et al. (2017), then **gross emissions from tropical forest loss increase to *21%* of global CO_2 emissions** • Estimates from Baccini et al. (2017) indicate that tropical vegetation is a net source of 1.56 ± 0.3 Pg CO_2 yr^{-1}. This is a LiDAR based study that incorporates better estimates of degradation in the final figure. They do not include belowground biomass, which could be 20% or more of aboveground biomass. Thus, their net figures are not directly comparable to the Harris et al. (2021) estimates. • Baccini et al. (2017) estimate that 69% of *gross* tropical forest emissions are from forest degradation, amounting to roughly 2.2 Pg CO_2 yr^{-1}. This corresponds closely to the Pearson et al. (2017) estimate of 2.1 Pg CO_2 yr^{-1}. • Houghton & Nassikas (2017) use a bookkeeping approach accounting for live aboveground and belowground biomass and anthropogenic disturbance to estimate that tropical forests are a net source of 1.4 Pg C yr^{-1} (5.1 Pg CO_2 yr^{-1}). • Deforestation pressure, along with compounded climatic effects, is expected to further force tropical forests to become a net source of carbon emissions under a BAU scenario. Busch & Engelmann (2017) project that without new forest conservation policies, 2.89×10^8 hectares of tropical forest will be cleared from 2016–2050, releasing 169 Pg CO_2. • Under a BAU scenario, which includes shifting cultivation in the tropics, Houghton & Nassikas (2018) estimate that tropical forests will release 205.52 Pg CO_2 between 2016 and 2100.
Is it possible, via active management, to either increase net C sequestration in the system or prevent C emissions from that system?	• Yes, through reforestation, restoration of degraded existing forests, reduction of forest degradation and deforestation, and avoided forest conversion • Stopping all tropical deforestation and the draining and burning of peatland soils in SE Asia would reduce net emissions from tropical forests by 1.4 Pg C yr^{-1} (5.1 Pg CO_2 yr^{-1}) (Houghton and Nassikas, 2017). The capacity of forests to remove carbon from the atmosphere declines as they mature, thus after 50-100 years of growth, rates of carbon removal will decline. • Reforesting 5.0×10^8 ha could sequester at least 3.67 Pg CO_2 yr^{-1} for decades (Houghton et al., 2015) . See more conservative estimates below. • Improved timber harvesting or reduced-impact logging techniques (RIL-C) could help retain 0.59 Pg CO_2 yr^{-1} (Putz et al., 2008). Ellis et al. (2019) estimate that RIL-C could reduce emissions by 0.37 Pg CO_2 yr^{-1}. • Setting a price on carbon to establish a functioning market, and the creation and strong enforcement of restrictive policies related to deforestation and degradation (legal and illegal), are two other major levers to reduce emissions from the tropical forest system. For example, Busch & Engelmann (2017) estimate that Brazil's restrictive policies in the Amazon between 2004–2012 successfully decoupled potential agricultural revenue from deforestation and reduced deforestation by 47% below what would have otherwise occurred, preventing the emission of 5.2 Pg CO_2. All tropical countries enacting restrictive anti-deforestation policies as effective as those in the Brazilian Amazon between 2004–2012 would avoid 58 Pg CO_2 from 2016–2050. In relation to a price on carbon, the authors find that a price of USD 20

	$MgCO_2^{-1}$ across tropical countries would avoid 41 Pg CO_2 in emissions from 2016–2050. If the price were higher, at USD 50 $MgCO_2^{-1}$, then avoided emissions are projected to reach 77 Pg CO_2 over that same time period (Busch and Engelmann, 2017).
What is the range of estimates for how much additional C could be sequestered globally?	• Stopping deforestation, forest degradation, and associated gross emissions from harvests and re-clearing fallows, in addition to reforesting 500 million ha, could reduce net emissions by as much as 18.35 Pg CO_2 per year (reduced source of 3.67 Pg CO_2 yr^{-1} and increased sink of 14.68 Pg CO_2 yr^{-1}). The sink of 14.68 Pg CO_2 yr^{-1} would last until approximately 2065, and then decline linearly to zero by 2095 (Houghton et al., 2015). Importantly, this estimate does not include a food production safeguard. • Halting deforestation, forest degradation could reduce net emissions from tropical forests by 12.11 Pg CO_2 yr^{-1} (Houghton and Nassikas, 2018) • Griscom et al. (2017) find that the tropical forest elements of their mitigation pathways could lead to an emissions reduction of 6.6 – 18.61 Pg CO_2 yr^{-1}, average of 12.48 Pg CO_2 yr^{-1} • Reducing emissions from deforestation and degradation and protecting existing tropical forests could contribute as much as 24 – 33% (12.66 – 14.17 Pg CO_2) of all carbon mitigation (44.22 – 45.73 Pg CO_2) (Prince's Charities' International Sustainability Unit., 2015). • Griscom et al. (2020) more conservative analysis, which accounts for "economically rational levels" of mitigation, estimates that cost effective tropical reforestation, avoided forest conversion, and natural forest management could represent a mitigation potential of ~1.2 Pg CO_2 yr^{-1}, ~2.8 Pg CO_2 yr^{-1}, and ~0.5 Pg CO_2 yr^{-1}, respectively. • Tropical forest avoided and reduced deforestation and degradation (maximum mitigation potential): 3.464 Pg CO_2e yr^{-1} (Griscom et al., 2020). • Tropical natural forest improved management (maximum mitigation potential): 0.68 Pg CO_2e yr^{-1} (Griscom et al., 2020). • Restore land with high suitability for forestry-based NCS (Reforestation, Improved plantations, Avoided woodfuel): 31.195 $PgCO_2$ over the period 2000- 2050 (0.6239 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain and Manage land with high suitability for forestry-based NCS (Avoided conversion, Natural Forest/Savana Management, Improved plantations, Avoided woodfuel, Fire management): 237.816 $PgCO_2$ over the period 2000-2050 (4.756 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain land with high suitability for forestry-based NCS (Avoided conversion, Fire management) : 9.9 $PgCO_2$ over the period 2000- 2050 (0.19818 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Restore land with low suitability for forestry-based NCS (Avoided woodfuel): 56.518 $PgCO_2$over the period 2000-2050 (0.19818 $PgCO_2$ yr^{-1}) (Walker et al., 2022) • Maintain and Manage land with low suitability for forestry-based NCS (Avoided conversion; Avoided woodfuel, Fire management): 115.238 $PgCO_2$ over the period 2000-2050 (2.305 $PgCO_2$ yr^{-1}) (Walker et al., 2022)

	• Maintain land with low suitability for forestry-based NCS (Avoided conversion; Avoided woodfuel, Fire management): 4.4 $PgCO_2$ over the period 2000-2050 (0.088 $PgCO_2\ yr^{-1}$) (Walker et al., 2022) *Notes: Estimates from Walker et al (2022) exclude areas critical for food production and human habitation.*
How much confidence do we have in current methods to detect any net increases in C sequestration in a system or net changes in areal extent?	• High variability exists in the predictions of the tropical carbon cycle using Earth Systems Models (ESMs). Predictions cannot agree whether tropical land surface will gain or lose carbon overall under different RCP scenarios. Uncertainties are caused by model structures, especially differences in the predicted effects of specific climate parameters and CO_2 concentration on net primary productivity and vegetation turnover (Mitchard, 2018). • Spatial information on how forests are changing is poor. Lack of field experiments means that ESMs cannot predict well how forests will respond to different scenarios of climate and land use change (Mitchard, 2018). WRI's Global Forest Watch project may improve these data but doesn't address the lack of experiments. • Techniques that observe integrated carbon flux over large regions exist, but there is little knowledge on the size of the processes involved, including degradation, regrowth, drought, fire, etc. This makes it difficult to design and implement policy. Little reliable information on country-specific rates of forest degradation makes it difficult to establish targets and policies to reduce degradation under REDD+ and receive payments (Mitchard, 2018). • Different methods to estimate changes in C stocks have different weaknesses: o Bookkeeping models compare reported rates of forest area loss or gain with reported area changes for other anthropogenic land uses. Weaknesses include variability in the quality of country-level reported data and missing estimates of degradation. o Satellite-based forest area change estimates ascribe area change estimates on the basis of aboveground carbon loss. This approach relies on identifying areas of forest loss and regrowth with satellite imagery. It can also restrict emission estimates to anthropogenic causes by making assumptions about underlying drivers of forest area change and "mask" for natural disturbances, though it is challenging to distinguish natural forests from plantations. This method cannot detect carbon stock changes in "forests remaining forests" (i.e., changes resulting from forest degradation or standing forest enhancement). o LiDAR-based estimates of carbon stock changes use satellite imagery with biomass density observations from LiDAR maps to detect changes in aboveground carbon density. This method is particularly good for detecting changes due to forest degradation or sequestration from forest enhancements. However, it cannot disaggregate anthropogenic and non-anthropogenic sources of emissions, and it can only directly measure changes in aboveground biomass carbon stocks. • New satellite missions (GEDI, OCO-3, BIOMASS) will produce high resolution, globally consistent maps of C stock changes that can assist with targeting and monitoring policies. However, they will require forest inventories and LiDAR data for calibration and validation (Mitchard, 2018).

C Markets	
Is there a market (or proposed market) for carbon credits from the system?	Yes, both voluntary and compliance markets exist. REDD+ has been the primary framework for performance-based payments, via public funding and carbon markets, to incentivize tropical forest protection. There are also other non-market pathways for funding and support. While these are not carbon markets, they support the development of carbon markets through both financial mechanisms and technical support. Such initiatives include: • Bilateral initiatives based on results-based payments — Norway's International Climate and Forest Initiative (NICFI); Germany's REDD+ Early Movers; Amazon Fund, GCF REDD+ Pilot Phase • Multilateral non-results-based schemes/programs — REDD+ Readiness; World Bank Partnership for Market Readiness and Partnership for Market Implementation; Global Environment Facility; Green Climate Fund; Governors' Climate and Forests (GCF) Task Force
Are there protocols (or proposed protocols) for such credits?	For tropical forests, there are both project based and jurisdictional approaches for generating carbon credits. To date, project-based protocols and methodologies have been the only ones to generate credits, but a growing number of jurisdictional and nested approaches demonstrates the increasing demand for this broader and more comprehensive approach that has the potential to address several issues raised with project-based protocols. *Jurisdictional Approaches = government-led, comprehensive approach to forest and land use across one or more legally defined territories (CIFOR)* **Voluntary** • Architecture for REDD+ Transaction's (ART) The REDD+ Environmental Excellence Standard (TREES) [f]; international • American Carbon Registry's (ACR) Nested REDD+ Standard [f]; international • California Air and Resources Board's (CARB) California Tropical Forest Standard [d]; international • Forest Carbon Partnership Facility's (FCPF) Carbon Fund (pilots results-based payments for REDD+ activities in developing countries) [f]; international • Verra Jurisdictional and Nested REDD+ Framework (webinar) [d]; international **Compliance** • ART-issued TREES credits and verified carbon units generated under Verra's VCS JNR framework are eligible to be used for compliance under the International Civil Aviation Organization's (ICAO) Carbon Offsetting Scheme for International Aviation (CORSIA)

Project Based = *receive credits on a project level basis*

Voluntary

- American Carbon Registry (ACR) Afforestation and Reforestation of Degraded Lands[a] (focused on non-REDD+ countries)**;** international
- Climate Action Reserve's (CAR) Mexico Forest Protocol [d]; Mexico
- American Carbon Registry (ACR) Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests [c]; Southeast Asia
- American Carbon Registry (REDD Methodology Modules) [a]; international
- Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology [e]; international
- Verra VM0003 Methodology for Improved Forest Management through Extension of Rotation Age (IFM ERA), v1.2 [a,1]; international
- Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0 [c]; international
- Revision to Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0 [c] (International) (Under Development)
- Verra VM0005 Methodology for Conversion of Low-productive Forest to High-productive Forest, v1.2; international
- Verra VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.2 [d]; international
- Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6 [f]; international
- Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0 [g]; international
- Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3 [a]; international
- Verra VM0011 Methodology for Calculating GHG Benefits from Preventing Planned Degradation, v1.0; international
- Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1 [e]; international
- Verra VM0029 Methodology for Avoided Forest Degradation through Fire Management, v1.0; eastern Miombo ecoregion
- Verra VM0035 Methodology for Improved Forest Management through Reduced Impact Logging v1.0 [a]; international
- Verra VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0 [d]; international
- Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU) [h]; China
- Plan Vivo Small-holder Agriculture Mitigation Benefit Assessment (SHAMBA) [d]; international
- Plan Vivo Reducing Locally-Driven Deforestation; international
- Plan Vivo Estimation of climate benefits from REDD in community managed forests; international

Compliance

- Clean Development Mechanism (CDM) AR-ACM0003: Afforestation and reforestation of lands except wetlands, v2.0; international
- CDM AR-AMS0003: Afforestation and reforestation project activities implemented on wetlands, v3.0 [b] (listed because it includes reforestation/afforestation on floodplain areas with inorganic soils and seasonally flooded areas on margins of waterbodies); international

	• CDM AR-AMS0007: Afforestation and reforestation project activities implemented on lands other than wetlands v3.1; international • The International Civil Aviation Organization's (ICAO) Carbon Offsetting Scheme for International Aviation (CORSIA) has approved the following carbon-offset programs as eligible to generate emissions units for its 2021-2023 pilot phase: American Carbon Registry, The Gold Standard, Clean Development Mechanism, Verra's Verified Carbon Standard [a] *Protocol applies to multiple forest systems* [b] *Protocol applies to tropical forest and coastal blue carbon systems* [c] *Protocol applies to tropical forest and peatlands systems* [d] *Protocol applies to tropical forest and AFSs* [e] *Protocol applies to multiple forest and agroforestry and coastal blue carbon systems* [f] *Protocol applies to tropical forest, agroforestry, peatlands, coastal blue carbon and freshwater wetland systems* [g] *Protocol applies to multiple forest, shrublands and grasslands systems* [h] *Protocol applies to multiple forest, agroforestry, grasslands and shrublands systems* [1] May be minimally applicable to tropical forest systems Note: The Panda Standard Sectoral Specifications applies to tropical forests, however, we have not been able to verify that the protocol has been approved by the Chinese government, and/or has generated tropical forest credits to date. Additional protocols that cover tropical forest pathways in China may exist, but we have not been able to review all of them due to limited publicly available information.
If there are protocols, do they buffer or discount credits for permanence, additionality, leakage, reversals, and uncertainty?	All listed programs and protocols buffer, in various ways, for permanence, additionality, leakage, reversals and uncertainty. Further detail is provided below. Protocols and programs are divided by jurisdictional and project level approaches. Importantly, programs and protocols also specify which activities are eligible to receive credits. This can be broken into two main categories — reduced emissions and carbon removals — with some programs crediting for both and others only crediting for one type. • Avoided Emissions = reducing deforestation/forest degradation (REDD+), avoided conversion • Carbon Removals = reforestation, afforestation, restoration, improved forest management, agroforestry, silvopastoral systems (the latter two are addressed in the Agroforestry Table) *Jurisdictional Approaches* **ART TREES** • **Eligible Activities:** REDD+, reforestation, afforestation

	• **Permanence:** 5-year crediting periods. For credits to be deemed eligible for ICAO's CORSIA, TREES requires Participant to monitor, report and verify under TREES for a minimum of four 5-year crediting periods (20 years). If a participant exits ART, any unused buffer pool contributions are retired to account for any possible future reversals. • **Additionality:** Performance-based approach in that only emissions achieved below a conservative historical baseline will be eligible for crediting • **Leakage:** Where TREES participants submit a subnational Crediting Level, then negative leakage of emissions to outside the accounting area can occur. Participants must apply specified TREES leakage deductions. Participants are classified as high, medium, or low leakage risk and are assigned a deduction of 20%, 10%, or 5%, respectively. • **Reversals:** ART maintains a combined buffer pool that includes contributions from all ART Participants. Reversals are reported and a volume of credits from the buffer pool equivalent to either the reversed volume or the total number of ERs previously issued to the Participant (whichever is lower) is retired to permanently remove the ERs from circulation and negate the reversal. If a participant exits ART, any unused buffer pool contributions are retired to account for any possible future reversals. TREES establishes a starting level of reversal risk for Participants of 25% (which can be lowered if demonstrated mitigating factors exist). After a reversal is reported, a Participant must increase its buffer contribution for a period of five years by 5%. • **Uncertainty:** A conservative approach is applied whereby, beyond an allowable uncertainty (15% at the 90% confidence level), the Crediting Level is reduced by the calculated percentage uncertainty quantified in terms of the half-width of the 90% confidence interval as a percentage of the estimated emissions **ACR Nested REDD+ Standard** • **Eligible Activities:** REDD+ • **Permanence:** 40 years • **Additionality:** Additionality as described in the ACR Forest Carbon Project Standard does not need to be separately demonstrated at the nested project level, since a jurisdictional baseline meeting minimum criteria by definition indicates that in the absence of the project activity a given area would be deforested • **Leakage:** Where the jurisdiction is monitoring leakage within the jurisdiction, nested REDD+ projects shall use the jurisdictional leakage accounting framework. The jurisdictional accounting framework must outline how leakage will be addressed within the jurisdiction. Where there is a jurisdictional crediting system, jurisdictions shall have clear policies and procedures in place for attributing leakage to nested projects. a Leakage Buffer Account for nested REDD+ projects, modeled on but separate from the ACR non-permanence buffer account. All nested projects will be required to calculate leakage per the requirements of the applicable project-level methodology, but rather than simply being deducted from net emission reductions, leakage tons will be created in the Leakage Buffer Account • **Reversals:** calculates risk of non-permanence using the VCS AFOLU Non-Permanence Risk Tool – project proponents may contribute to a buffer pool OR purchase insurance for their credits • **Uncertainty:** ± 10% of the mean at 90% confidence interval

	CARB Tropical Forest Standard ● **Eligible Activities:** REDD+ ● **Permanence:** 100 years, risk calculated through jurisdictional risk assessment ● **Additionality:** to demonstrate additionality implementing jurisdiction must reduce deforestation beyond a crediting baseline that is below historical emissions. Implementing jurisdictions must establish a crediting baseline that begins at least 10% below the reference level described in the Standard and linearly declines to a jurisdictional-specific 2050 GHG emissions target for the forest sector. ● **Leakage:** Projects must demonstrate how economic activities driving deforestation in the implementing jurisdiction have been either replaced with more sustainable economic activities, or improved in their sustainability, is important in assessing and transparently estimating leakage; suggests that ETS create a Sector Based Crediting Program Buffer Pool ● **Reversals:** implementing jurisdictions must contribute a minimum of 10 percent of the total credits issued by the implementing jurisdiction per year, or the amount of credits identified by the buffer pool contribution equation, which must be based on the reversal risk rating factors identified in the Standard, whichever is higher ● **Uncertainty:** Standard states that "A percent credit deduction shall be taken prior to issuance corresponding to the results of the uncertainty calculation" but does not state exact parameters **FCPF Carbon Fund** ● **Eligible Activities:** REDD+ ● **Permanence:** if an ER program transits into a new GHG program or standard, the applicable GHG program shall monitor for the Reversals and have in place a Reversal management mechanism to compensate for material Reversals for at least until 15 years following the end of Carbon Fund in 2025 (i.e. 31 December 2040) ● **Additionality:** Additionality primarily is addressed through conservative approaches to setting Reference Levels (e.g., including existing and clearly funded programs or activities within the Reference Level), rather than through additionality tests often utilized by project-level initiatives, which have proven difficult to operationalize. ● **Leakage:** Potential sources of domestic and international displacement of emissions (Displacement) are identified by assessment of all drivers of land-use change relevant for the ER Program; and measures to minimize and/or mitigate the risk of displacement of domestic emissions are incorporated into ER Program design and the estimation and monitoring of ERs. ER Programs should seek to minimize and mitigate Displacement outside the Accounting Area (domestic and international) to the extent possible via design of the ER Program. However, due to accounting and attribution challenges and following UNFCCC guidance on REDD+, potential international Displacement should not have to be accounted for or deducted from the ERs credited to ER Programs. ● **Reversals:** ER Program are deposited in an ER Program CF Buffer, managed by the Carbon Fund, based on a Reversal risk assessment Leakage; amount of emissions reductions contributed are based on total aggregate uncertainty of emission reductions ranging from 0 – 15%.

	If forest degradation is measured through a separate approach using proxy-based approaches, a general conservativeness factor of 15% is applied. ● **Uncertainty:** includes an 'Uncertainty Buffer' to create incentives for improving (reducing) uncertainty associated with the estimation of ERs and manage the risk that the emission reductions were overestimated for prior reporting periods Equal to the Reversal buffer. Each program is required to conduct an uncertainty analysis which consists of a three-step process laid-out in three different criteria: identification (Criterion 7); reduction (Criterion 8) and quantification (Criterion 9). The final objective of the Uncertainty Analysis is to provide an estimate of uncertainty of Emission Reductions in the form of the relative half-width confidence interval at the 90% confidence level. **Verra Jurisdictional and Nested REDD+ Framework** ● **Eligible Activities:** REDD+ ● **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS JNR Non-Permanence Risk Tool ● **Additionality:** The project must use the most recent version of the Clean Development Mechanism (CDM) additionality tool to identify the baseline scenario and demonstrate additionality ● **Leakage:** Accounts for GHG emissions from activity shifting, market leakage and ecological leakage. Determined either directly from monitoring, or indirectly using sound scientific knowledge or research, providing credible estimates of likely impacts through JNR Leakage Tool ● **Reversals:** A percentage of credits go to buffer pool. Buffer credits are applied via the JNR Non-Permanence Risk Tool; Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification ● **Uncertainty:** Jurisdictional programs shall undertake an analysis of uncertainty in estimating GHG emissions and GHG emission reductions. Before allocating project baselines and lower-level jurisdictional forest reference emission levels (FRELs), the higher level jurisdictional FREL is required to be conservatively discounted, in order to reduce the risk of overestimation. Nested projects and lower-level jurisdictional programs shall undertake an analysis of uncertainty in estimating GHG emissions. *Project Based Protocols/Methods* **ACR Forest Carbon Standard: Improved Forest Management (IFM) on Small Non-Industrial Private Forestlands v1.0** ● **Permanence:** 40 years ● **Additionality:** ACR three prong additionality test (regulatory surplus, common practice, implementation barriers) and the CDM's "Combined tool to identify the baseline scenario and demonstrate additionality" ● **Leakage:** Market leakage deduction of 20% where project activities decrease total wood products produced by the project relative to the baseline by more than 5% over the crediting period.

	• **Reversals:** Calculates risk of non-permanence using the ACR Tool for Risk Analysis and Buffer Determination – project proponents may contribute to a buffer pool OR purchase insurance for their credits. • **Uncertainty:** +/- 10% of the mean at 90% confidence interval. If calculated uncertainty exceeds 10% then the estimated amount of the combined carbon stock at the project area level cannot be verified without additional sampling or stratification to improve statistical confidence. **ACR Forest Carbon Standard: Afforestation/Reforestation on Degraded Lands v1.2** • **Permanence:** 40 years • **Additionality:** ACR three prong additionality test (regulatory surplus, common practice, implementation barriers) and the CDM's "Combined tool to identify the baseline scenario and demonstrate additionality" • **Leakage:** leakage estimated based on CDM method: Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity • **Reversals:** calculates risk of non-permanence using the ACR Tool for Risk Analysis and Buffer Determination – project proponents may contribute to a buffer pool OR purchase insurance for their credits • **Uncertainty:** +/- 10% of the mean at 90% confidence interval applied to final calculation of emission reduction/removal enhancements **ACR Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests** • **Permanence**: Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool. • **Additionality:** Demonstrated using the latest version of the ACR —Tool for Determining the Baseline and Assessing Additionality in REDD Project Activities. • **Leakage**: Leakage emissions, including carbon stock decreases and peat emissions outside the project boundary, are accounted for activity displacement and market effects. • **Reversals**: A percentage of credits goes to buffer pool. Not specified beyond use of VCS AFOLU Non-permanence risk tool to determine contribution percentage to VCS buffer pool. • **Uncertainty**: Assessment of uncertainties should follow guidance offered by IPCC 2000, IPCC GPG-LULUCF and IPCC AFOLU. A precision target of a 90% confidence interval equal to or less than 10% of the mean recorded value shall be targeted. Focuses on uncertainties associated with area, carbon stocks, biomass growth rates, expansion factors. **American Carbon Registry: REDD Methodology Modules (REDD-MF)** • **Permanence:** The project crediting period for AFOLU projects must be between 20 and 100 years. Risk of non-permanence calculated using the ACR AFOLU Non-Permanence Risk Tool (T-Bar). Buffer withholding percentages are based on the project's overall risk classification. The percentage of C credits generated by the approved project activity must be deposited into the AFOLU pooled buffer account to cover non-permanence related project risks

	• **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the ACR AFOLU approved- Risk assessment Tool • **Leakage:** The significance of leakage and the significance of C pools may be determined using T-SIG tool. Leakage is monitored and quantified using a leakage belt. The minimum leakage belt area (defined to address activity-displacement leakage) must equal at least 90% of the area of the project) • Source of leakage: Leakage due to displacement of planned deforestation (LK-ASP tool), Leakage due to displacement of unplanned deforestation (LK-ASU tool), Leakage due to displacement of fuelwood/charcoal collection (LK-DFW tool). Where leakage prevention leads to a significant increase in the use of fertilizers, CPES.H shall be used. T-SIG can be used to determine significance. Market leakage can be assessed when applicable using the LK-ME modules • **Additionality:** Use of tool (T-ADD) to determine additionality of a project (Must use the latest version). Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice). • **Uncertainty:** The allowable uncertainty under this methodology is ±10% of of total net GHG emission reductions of the REDD project activity at the 90% confidence level. Where this precision level is met then no deduction should result for uncertainty. Use this ACR module to determine uncertainty (Estimation of uncertainty for REDD+ project activities (X-UNC) **CDM AR-ACM0003: Afforestation and reforestation of lands except wetlands, v2.0** • **Permanence:** CDM projects produce temporary emissions credits. Specifically, these are either termed “temporary CERs” (tCERs) or “long-term CERs” (lCERs). Both types of CERs have expiration dates, after which they must be replaced by another tradable emissions unit under the Kyoto Protocol. If an Annex 1 country uses a tCER for compliance it must replace it with a permanent Kyoto unit or an unexpired tCER in the next commitment period. If the project is still performing as expected, the new tCERs will just replace the expired ones. Have either a single 30-year crediting period, or 20-year crediting periods that are renewable up to two times • **Additionality:** Project participants (PPs) shall identify the baseline demonstrate that the project activity is additional by selecting one of the following options: (a) Applying the “Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities”; (b) Applying an approved standardized baseline appropriate to their project • **Leakage:** leakage estimated based on CDM method: Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity • **Reversals:** Not specified in the protocol • **Uncertainty:** Not specified in protocol **CDM AR-AMS0003: Afforestation and reforestation project activities implemented on wetlands, v3.0** • **Permanence:** CDM projects produce temporary emissions credits. Specifically, these are either termed “temporary CERs” (tCERs) or “long-term CERs” (lCERs). Both types of CERs have expiration dates, after which they must be replaced by another tradable emissions unit under

	the Kyoto Protocol. If an Annex 1 country uses a tCER for compliance it must replace it with a permanent Kyoto unit or an unexpired tCER in the next commitment period. If the project is still performing as expected, the new tCERs will just replace the expired ones. Have either a single 30-year crediting period, or 20-year crediting periods that are renewable up to two times ● **Additionality:** Project participants (PPs) shall demonstrate that the project activity is additional by selecting one of the following options: (a) Using the barrier (Investment, Institutional, Traditional, Ecological, Social, Prevailing practice) analysis outline contained in appendix 1 of this methodology; or (b) Using an approved standardized baseline applicable to their project. ● **Leakage:** leakage estimated based on CDM method: Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity ● **Reversals:** Not specified in the protocol ● **Uncertainty:** Not specified in protocol **CDM AR-AMS0007: Afforestation and reforestation project activities implemented on lands other than wetlands V3.1** ● **Permanence:** CDM projects produce temporary emissions credits. Specifically, these are either termed "temporary CERs" (tCERs) or "long-term CERs" (lCERs). Both types of CERs have expiration dates, after which they must be replaced by another tradable emissions unit under the Kyoto Protocol. If an Annex 1 country uses a tCER for compliance it must replace it with a permanent Kyoto unit or an unexpired tCER in the next commitment period. If the project is still performing as expected, the new tCERs will just replace the expired ones. Have either a single 30-year crediting period, or 20-year crediting periods that are renewable up to two times. ● **Additionality:** Demonstrated by conducting a barrier analysis (Appendix 1 AR-AMS0007 Methodology) or an approved standardized baseline**.** ● **Leakage:** Accounting for activity shifting required. Landowners must determine the Leakage using the AR-TOOL 15. ● **Reversals:** not mentioned in method or standard ● **Uncertainty:** not mentioned in method or standard **Climate Action Reserve Mexico Forest Protocol** ● **Eligible Activities:** Improved Forest Management, afforestation/feforestation, silvopastoral systems, restoration, agroforestry, urban forestry (large and small scale) ● **Permanence:** 100 years; projects on communal/ejidal lands are limited to 30 years contracts renewable up to 100 years ● **Additionality:** Projects must pass both a legal requirements test (must achieve GHG removals above any GHG removals that would result from compliance with any law, statute, rule, regulation or ordinance) and a performance standard test (above business as usual) ● **Leakage:** Leakage addressed differently depending on activity type (grazing displacement or harvesting outside of activity area). Risk adjustment ranges from 10 – 50%. ● **Reversals:** All Forest Projects must contribute a percentage of CRTs to the Buffer Pool any time they are issued credits for secured carbon. Default value of 8% of issued credits adjusted based on differing factors

	• **Uncertainty:** Activity Area data will be accepted with sampling errors up to +/- 20% of the mean at the 90% confidence interval, deductions for uncertainty are applied to an Activity Area's inventory if the sampling error exceeds the Target Sampling Error (TSE). TSE information included in protocol based on number of activity areas. **Gold Standard Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology** • **Permanence:** Does not specifically require permanence of its projects. It only requires projects maintain C stocks during the crediting period. If the C stocks are not maintained during the crediting period, a shortfall is declared, and projects must demonstrate to the Gold Standard how the project will realistically address the performance shortfall and recover appropriate levels of C stocks. Performance risks is assessed following the "Risk and Capacities" guideline. A risk scoring system assesses pre-defined risk categories and determines whether the risks of a project are acceptable to Gold Standard or whether mitigation measures shall be adopted. Uses high/medium/low scoring system based on defined thresholds. Risk categories are: 1. Natural Disturbance risks 2. Political risks 3. Project Management risks 4. Financial risks 5. Market risks. • **Additionality:** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice). • **Leakage:** Accounting for activity shifting required. Leakage shall be determined on a Modelling Unit (MU) level using the following formula: Leakage $MU_{,t}$ [tCO_2 ha^{-1}] = Leakage Project area [tCO_2] / Eligible planting area [ha]. Leakage is deducted in the first year. Four categories of leakage resulting from collection of wood (for firewood, charcoal), timber harvesting, agriculture (crop cultivation, shrimp cultivation) and livestock. All potential Leakage caused by a project within its crediting period is accounted for in year 1. Parameter is not subject to monitoring. Market leakage not accounted for under this methodology. Projects must submit a Leakage Template which includes information and calculations of potential leakage from different project activities. Provides default values when exact data is not available. • **Reversals:** A percentage of credits go to a buffer pool; projects must contribute to a risk of reversals buffer (20%). Pooled compliance buffer remains untouched even after the crediting period of the project, further reducing the risk of reversal and non-permanence. • **Uncertainty:** +/-20% at a 90% confidence interval. Where the error is above 20%, the additional difference shall be deducted. Gold Standard provides 3 approaches to uncertainty: Approach 1: Data is measured within each stratum and shall follow accepted sampling and analysis protocols, Approach 2: Data is derived from peer reviewed published literature, Approach 3: Project owners may use published default factors such as IPCCs. **Verra VM0003 Methodology for Improved Forest Management through Extension of Rotation Age (IFM ERA) Version 1.2** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the Clean Development Mechanism (CDM) additionality tool to identify the baseline scenario and demonstrate additionality

	• **Leakage:** Accounts for GHG emissions due to market effects resulting from a shift in harvest through time • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** Uncertainty at all times is defined as the 90% confidence interval as a percentage of the mean. The total project uncertainty is calculated at the time of reporting through propagating the error in the baseline stocks and the error in the project stocks **Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage:** Accounts for activity displacement and market effects from carbon stock decreases and peat emissions outside the project boundary. Calculated through a stratification approach • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** Uncertainty is defined as the 90% confidence interval as a percentage of the mean; total uncertainty is calculated using uncertainties for several factors including allometric equation uncertainty, uncertainty in expert judgement and uncertainty in rate of deforestation. **Revision to Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests (Under development)** • **Permanence**: 100 years. In the VCS Program all AFOLU projects have a longevity of 30 years as established in the AFOLU Non-Permanence Risk Tool. The project crediting period for AFOLU projects must be between 20 and 100 years. Risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool (T-Bar). • **Additionality**: Demonstrated using the latest version of the ―Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities‖ approved by the VCS Board. • **Leakage:** Account for displacement of pre-project activities to areas outside the project boundary and market effects. Market effects leakage must be estimated as the baseline emissions from logging multiplied by a leakage factor. • **Reversal:** not specified beyond use of VCS AFOLU Non-permanence risk tool • **Uncertainty:** A precision target of a 90% confidence interval equal to or less than 10% of the mean recorded value shall be targeted. Conservative estimates can also be used instead of uncertainties, if they are based on verifiable literature sources or expert judgement. In this case the uncertainty is assumed to be zero

	Verra VM0005 Methodology for Conversion of Low-productive Forest to High-productive Forest, v1.2 ● **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool ● **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in IFM Project Activities ● **Leakage:** Accounts for GHG emissions due to market effects resulting from any increase in greenhouse gas emissions that occurs outside a project's boundary (but within the same country), that is measurable and attributable to the project activity. ● **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification ● **Uncertainty:** Not explicitly stated but methodology uses whenever possible the proven methods from the GPG-LULUCF, GPG-2000, and the IPCC's Revised2006 Guidelines. As well, tools and guidance from the CDM Executive Board on conservative estimation of emissions and removals are also used. If uncertainty is significant, project proponents should choose data such that it indisputably tends to under-estimate, rather than over-estimate, net GHG removals by sinks. **Verra VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.2** ● **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool ● **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities ● **Leakage:** monitored and quantified using a leakage belt approach for geographically constrained drivers, and a factor approach for geographically unconstrained drivers. Market-effect leakage is accounted for each project according to the discount factors provided in the VCS AFOLU Requirements. Does not only occur on forest land outside of the project area, but also on non-forest land, such as woodlands or grassland. The market leakage assessment only has to be included when illegal logging activities that supply timber to national or international markets as an identified driver. ● **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification ● **Uncertainty:** Not explicitly stated but methodology uses whenever possible the proven methods from the GPG-LULUCF, GPG-2000, and the IPCC's Revised2006 Guidelines **Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6** ● **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool

	• **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage:** Leakage must be considered for all activities, calculated using leakage modules which are defined in the methodology based on project activities • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are applied via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Different percentages will likely be calculated for each of the baseline types as relevant. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** allowable uncertainty under this methodology is +/- 15% of Total net GHG emission reductions of the REDD+ project activity (NERRED+) at the 95% confidence level. Where this precision level is met then no deduction should result for uncertainty. Where uncertainty exceeds 15% of NERREDD+ at the 95% confidence level then the deduction must be equal to the amount that the uncertainty exceeds the allowable level. **Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities. Project description must include set of requirements to expand on project additionality • **Leakage:** quantified using an activity-shifting leakage area(s) and a market leakage area(s), which may or may not overlap with the reference area. Methodology includes a Leakage Emissions Model (LEM) which accounts for emissions from activity-shifting leakage. • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** Determined through equation F.57 included in methodology. Constant 1.64 is the Z value at the 90% confidence level. **Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using the VCS AFOLU Non-Permanence Risk Tool • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage:** Accounts for Activity Shifting Leakage (can be 0) and leakage due to market effects. The leakage factor is determined by considering where in the country logging will be increased as a result of the decreased timber supply caused by the project. The geographic boundaries for leakage from market effects are those of the country in which the project area is located. • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification

	• **Uncertainty:** defined at the 95% confidence interval where the estimated variance exceeds +/- 15 percent from the mean. Procedures including stratification and the allocation of sufficient measurement plots will help ensure that low uncertainty results and ultimately full crediting can result. **Verra VM0011 Methodology for Calculating GHG Benefits from Preventing Planned Degradation, v1.0** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using methodological equation • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities • **Leakage:** Accounts for Carbon from degradation due to shifting of the baseline activity and Carbon from market leakage due to shifts in supply and demand of the products and services affected by the project activity, which in this case is the supply and demand of timber • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** In accordance with IPCC best practice, the methodology requires the use of 95% confidence interval for quantification of random errors (IPCC, 2006, Volume 1, Chapter 3, p. 3.6 and 3.9). A simple approach to determine the uncertainty value of the overall emission reductions from the uncertainties of the individual components, is based on the basic error propagation rule set outlined in the methodology. **Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1** • **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using methodological equation • **Additionality:** The project must use the most recent version of the VCS Tool for the Demonstration and Assessment of Additionality in AFOLU Project Activities noting that the earliest start date of the proposed AUD project activity is January 1st, 2002. However, the start date can be earlier than January 1st, 2002, provided the requirements for projects with a start date prior to 2002, as set out in the most recent version of the VCS Standard, are met. • **Leakage:** Accounts for emissions from increased grazing activities, increased emission from displaced forest fires, decrease in carbon stocks due to displaced deforestation; see leakage calculation section of methodology which details the calculation process. If the project area is located within a jurisdictional program the most recent VCS JNR Requirements must be applied to determine whether a leakage belt is required. In all other cases, a leakage belt is required. • **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification • **Uncertainty:** If the uncertainty of the total average carbon stock of a class is less than 10% of the average value, the average carbon stock value can be used. If the uncertainty is higher than 10%, the lower boundary of the 90% confidence interval must be considered in the

	calculations if the class is an initial forest class in the project area or a final non-forest class in the leakage belt, and the higher boundary of the 90% confidence interval if the class is an initial forest class in the leakage belt or a final non-forest class in the project area. **VM0029 Methodology for Avoided Forest Degradation through Fire Management, v1.0** ● **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using methodological equation ● **Additionality:** The project proponent must apply the latest version of VT0001 Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities. ● **Leakage:** Account for activity shifting leakage which takes into account all fire driving activities. Leakage calculation must be done every year. Total estimated leakage that is equal to or higher than 5 percent of the project's overall emission reductions and removals must be subtracted in the final calculation of net emission reductions and removal. ● **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. ● **Uncertainty:** A confidence interval must be calculated for the mean biomass across the entire map using multiple random samples of calibration data to bootstrap the classification with the remainder used to assess accuracy. The 95 percent confidence interval must be no wider than 30 percent of the mean estimate. For the distribution of fire monitoring checkpoints, at least 86 checkpoints are required across the entire project area so as to ensure the 95 percent confidence interval is no wider than 15 percent. **Verra VM0035 Methodology for Improved Forest Management through Reduced Impact Logging v1.0** ● **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using methodological equation ● **Additionality:** This methodology uses a performance method for the demonstration of additionality. Projects must demonstrate a regulatory surplus and that they exceed the region-specific performance benchmark for each impact parameter for reduced impact logging detailed in the methodology. ● **Leakage:** Since the applicability conditions do not allow for changes in harvest levels, it can be conservatively assumed that leakage is zero because there is no difference in harvest levels between the baseline and project scenarios. ● **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification ● **Uncertainty:** no uncertainty deduction necessary as the two sources of uncertainty (uncertainty include uncertainty with respect to the calculation of emission reductions from impact parameters, and uncertainty with respect to estimates of impact parameters) are addressed by setting demonstrably conservative emission reductions associated with each impact parameter and through imposed minimum sampling intensity requirements for estimation of impact parameters, all established in the applicable region-specific RIL-C performance method module.

	Verra VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0 ● **Permanence:** Requirement of 100 years, with risk of non-permanence calculated using methodological equation ● **Additionality:** 2 step additionality test: projects must demonstrate a regulatory surplus and then also the project proponent must determine additionality by applying the latest version of VCS tool VT0001 Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities. ● **Leakage:** methodology uses Leakage Management Zone (LMZ) to account for leakage and to manage potential leakage. An LMZ must be developed for all project areas where the same amount of goods and services from forests will be extracted in the project scenario as compared to the baseline scenario. Leakage occurring outside the host country are not required to be accounted for. ● **Reversals:** A percentage of credits goes to buffer pool. Buffer credits are calculated via the VCS Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Buffers can be drawn upon over time as project's longevity is established and risks shown to be effectively mitigated. 15% of project's buffer is released every 5 years at re-verification ● **Uncertainty:** The project proponent must clearly state the uncertainty associated with the project activity and describe how much uncertainty must be addressed at what confidence level and must use the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, AFOLU for uncertainty analysis. **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** ● **Permanence**: Minimum project term varies with the type of project; Project generating net C sequestration (or GHG removals) have a minimum project term of 30 years; Project generating net emission reductions have a minimum project term of 20 years; Project generating net irreversible net GHG emission reductions have a minimum project term of 5 years. Project Proponents must conduct a risk assessment using the Panda Standard Risk Analysis Tool. The result of the Risk Assessment is an overall risk category for the Project, translating into a percentage or number of PS Credits that must be deposited into the Panda Buffer Pool. ● **Additionality**: Additionality can be demonstrated using 2 approaches: o **Three-prong approach**: The project activity must meet the following criteria: a. Complies with regulatory requirements b. Exceeds common practice c. Faces investment, technological or institutional barriers); o **Performance standard approach** CDM A/R Additionality Tool required. Procedure is composed of 4 steps (Identification of alternative land use scenarios, Investment analysis (to show that the project activity is not the most attractive financially speaking), Barrier Analysis (Identify barriers that prevent project activities) and Common Practice analysis (demonstrating that the adoption of the of proposed project activities is not common practice)). ● **Leakage:** Accounting for activity shifting required. Any leakage identified must be quantified and subtracted from the net emission reduction/removal benefits except when leakage arises from the creation of poles and fencing to implement Project Activities • Fossil fuel combustion resulting from ground transportation. Leakage accounting might also be omitted if the following criteria are met: Displacement

	of baseline activities occurs on less than an average of 5% of the land area for a given project activity during the crediting period • Total quantity of a given good/commodity (e.g. lumber, crop, fuelwood, grazing animal) supplied to market in the project scenario for a given project activity is reduced by less than 20% of in comparison to the Baseline during the crediting period • All Leakage emissions are estimated to be below the de minimis threshold on average during the crediting period ○ Accounting for market leakage is not required if the following conditions are satisfied: ▪ Average quantity of a given good/commodity supplied to market in the with-Project Scenario for a given Project Activity is reduced by less than 20% in comparison to the Baseline. ▪ Average quantity of a given good/commodity in the Baseline per year supplied to market is less than 5% of total commodity produced per year within the PRC Prefecture (s) where the Project is taking place. ● **Reversals:** A percentage of credits go to a buffer pool (Panda buffer pool). 2 options to mitigate risk: ○ **Option 1**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, this percentage of offsets from the Project itself for deposit to the Panda Buffer Pool"; ○ **Option 2**- "Project Proponents may set aside at each Verification and issuance of new PS Credits, the number of PS credits of any type and vintage that equates to the percentage drawn from the risk assessment". Percentage of contribution to buffer pool is not explicitly stated. ● **Uncertainty:** If the 90% confidence interval is greater than 10% of the mean the reportable amount must include an uncertainty deduction. The uncertainty deduction shall be equal to the calculated % of the mean represented by the confidence interval minus the allowable 10% **Plan Vivo Small-holder Agriculture Mitigation Benefit Assessment (SHAMBA)** ● **Eligible Activities:** tree planting, agroforestry, and conservation agriculture ● **Permanence:** Projects are reimbursed for sequestration activities for 5-15 years, yet carbon benefits are calculated over much longer time periods of up to 150 years. Other permanence requirements including land tenure and tree planting requirements and long-term sale agreements. ● **Additionality:** Project based test: Step 1: Regulatory Surplus (activities not required by legislation); Step 2: Barriers analysis (the project must enable existing barriers to be overcome that otherwise would prevent the desired project activities from taking place.). ● **Leakage:** assessed for each land-use activity in the technical specifications, considering the local and regional trends, identifying potential leakage risks and mechanisms for controlling them. Where leakage is likely to be significant, i.e. likely to reduce climate services by more than 5%, an approved approach must be used to monitor leakage and subtract actual leakage from climate services claimed, or as a minimum, make a conservative estimation of likely leakage and deduct this from the climate services claimed ● **Reversals:** Each project maintains an unsold reserve of carbon credits called a risk buffer. The level of the risk buffer is set by the Plan Vivo Foundation according to its risk assessment of the project (normally 10 – 20%)

	• **Uncertainty:** Projects must identify and describe where uncertainty exists in quantifications of ecosystem services and estimate the approximate level or range of uncertainty. The level of uncertainty must be factored into the level of conservativeness applied in the accounting method for quantifying ecosystem services **Plan Vivo Reducing Locally Driven Deforestation** • **Permanence:** Projects are reimbursed for sequestration activities for 5-15 years, yet carbon benefits are calculated over much longer time periods of up to 150 years. Other permanence requirements including land tenure and tree planting requirements and long-term sale agreements. • **Additionality:** Project based test: Step 1: Regulatory Surplus (activities not required by legislation); Step 2: Barriers analysis (the project must enable existing barriers to be overcome that otherwise would prevent the desired project activities from taking place). • **Leakage:** assessed for each land-use activity in the technical specifications, considering the local and regional trends, identifying potential leakage risks and mechanisms for controlling them. Where leakage is likely to be significant, i.e. likely to reduce climate services by more than 5%, an approved approach must be used to monitor leakage and subtract actual leakage from climate services claimed, or as a minimum, make a conservative estimation of likely leakage and deduct this from the climate services claimed • **Reversals:** Each project maintains an unsold reserve of carbon credits called a risk buffer. The level of the risk buffer is set by the Plan Vivo Foundation according to a three-step risk assessment of the project. Where credits are issued 'ex-ante' there should be a risk buffer of minimum 20% for community based-REDD type projects and for 'ex-post' issuance a minimum of 10%. • **Uncertainty:** Projects must identify and describe where uncertainty exists in quantifications of ecosystem services and estimate the approximate level or range of uncertainty. The level of uncertainty must be factored into the level of conservativeness applied in the accounting method for quantifying ecosystem services **Plan Vivo Estimation of climate benefits from REDD in community managed forests** • **Permanence:** Projects are reimbursed for sequestration activities for 5-15 years, yet carbon benefits are calculated over much longer time periods of up to 150 years. Other permanence requirements including land tenure and tree planting requirements and long-term sale agreements. • **Additionality:** Project based test: Step 1: Regulatory Surplus (activities not required by legislation); Step 2: Barriers analysis (the project must enable existing barriers to be overcome that otherwise would prevent the desired project activities from taking place). • **Leakage:** Estimated at the start of the project period and verified at the end of the project period. Leakage is estimated through two possible approaches: income data approach (based on assumptions relating to displacement of deforestation and forest degradation by stakeholders whose income (including cash and non-cash income, and food production) could be negatively affected by project activities) or the expected leakage approach (based on a conservative estimate of the proportion of climate benefits that could be lost through leakage). • **Reversals:** Each project maintains an unsold reserve of carbon credits called a risk buffer. The level of the risk buffer is set by the Plan Vivo Foundation according to its risk assessment of the project (normally 10 – 20%)

	• **Uncertainty:** Projects must identify and describe where uncertainty exists in quantifications of ecosystem services and estimate the approximate level or range of uncertainty. The level of uncertainty must be factored into the level of conservativeness applied in the accounting method for quantifying ecosystem services
If there are protocols, have there been any registered projects or credits generated? If so, where?	A multitude of credits have been generated via REDD+ projects. It is important to note that REDD+ seems to be tilting towards new jurisdictional programs and grandfathering in projects via nesting approaches. EDF strongly supports the jurisdictional approach for the larger scale of its impact and higher environmental and social integrity (with proper safeguards). *Jurisdictional* **ART TREES** • No credits generated yet • Thirteen jurisdictions are currently listed in the ART Directory, completing the first step of registering a program with ART **ACR Nested REDD+ Standard** • No credits generated yet **CARB Tropical Forest Standard** • No credits generated yet • CARB will still need to approve usage of any generated credits in the California compliance market **FCPF Carbon Fund** • No credits generated yet • Forty-seven developing countries have been selected to join the FCPF (18 in Africa, 18 in Latin America, and 11 in the Asia-Pacific region) **Verra Jurisdictional Nested REDD+** • No credits issued yet **Germany's REDD+ Early Movers – not market; bilateral initiative** • While not a market, this results-based payment initiative funded verified emissions reductions at a jurisdictional scale in Acre and Mato Grosso (Brazil)

	Project Based **American Carbon Registry** ● 3 reforestation projects registered (2 Madagascar, 1 Brazil) ○ Total Credits issued: 3,674,586 ● 2 Avoided Forest Conversion projects registered (2 United States- Florida) ○ Total credits issued: 1,390,048 ● 2 Improved Forest Management projects registered (2 United States-Florida) ○ Total credits issued: 34,662 Note: Fewer details provided for American Carbon Registry due to the inability to search the registry by methodology. The registry can be searched for "forest carbon" and methodologies are not distinguished in the results. **CDM AR-ACM0003: Afforestation and reforestation of lands except wetlands, v2.0** ● 7 projects registered **CDM AR-AMS0003: Afforestation and reforestation project activities implemented on wetlands, v 3.0** ● No project registered **CDM AR-AMS0007: Afforestation and reforestation project activities implemented on lands other than wetlands V3.1** ● 10 projects registered **Climate Action Reserve Mexico Forest Protocol** ● 63 projects registered ○ Total credits issued: 240,059 **Gold Standard's Afforestation/Reforestation (A/R) GHG Emissions Reduction & Sequestration Methodology, v1.0** ● 24 projects registered ○ Total credits issued: 4,897,962 *Note: This is not the number of credits specific to tropical forest system, but rather the total number of credits listed under the methodology* **Verra VM0003 Methodology for Improved Forest Management through Extension of Rotation Age (IFM ERA) Version 1.2** ● 3 projects registered in the U.S. (non-tropical), 2 projects going through validation in the U.S. (non-tropical), Uganda, and Mexico, 2 under development in Mexico

	Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests, v1.0 ● 1 project registered in Indonesia **Revision to Verra VM0004 Methodology for Conservation Projects that Avoid Planned Land Use Conversion in Peat Swamp Forests (Under development)** ● No projects registered **Verra VM0005 Methodology for Conversion of Low-productive Forest to High-productive Forest, v1.2** ● 2 projects registered (Malaysia and Colombia), 2 projects undergoing validation in Spain and Argentina (non-tropical), 2 under development in Brazil **Verra VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.2** ● 13 projects registered (Peru, Colombia, Cambodia, Malawi), 3 projects under development (Colombia and Tanzania), 3 projects undergoing validation (Peru and Myanmar) **Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6** ● 33 projects registered, 9 under validation, 18 under development in Latin America, SE Asia and Africa **Verra VM0009 Methodology for Avoided Ecosystem Conversion, v3.0** ● 14 projects registered, 3 under validation in Africa , 1 under development in Brazil ○ Total credits issued: 76,508,225 *Note: This is not the number of credits specific to tropical forest system, but rather the total number of credits listed under the methodology* **Verra VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest, v1.3** ● 20 projects either registered or under development mostly in China (10). Several in Australia (4). One each in Peru, Colombia, Bolivia and Russia. ○ Total credits issued: 3,801,652 *Note: This is not the number of credits specific to tropical forest system, but rather the total number of credits listed under the methodology* **Verra VM0011 Methodology for Calculating GHG Benefits from Preventing Planned Degradation, v1.0** ● 2 projects registered (Congo and Brazil) ○ Total credits issued: 238,556

	Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1 ● 44 total projects (29 registered, 15 underdevelopment or registration requested), majority in Latin America ○ Total credits issued: 65,395,171 **Verra VM0029 Methodology for Avoided Forest Degradation through Fire Management, v1.0** ● No project registered **Verra VM0035 Methodology for Improved Forest Management through Reduced Impact Logging v1.0** ● No project registered **Verra VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0** ● 7 projects under development India, 1 requesting registration and verification approcal in Colombia **Panda Standard Sectoral Specifications for Agriculture, Forestry and Other Land Use (PS-AFOLU)** ● Unable to locate registry Plan Vivo Small-holder Agriculture Mitigation Benefit Assessment (SHAMBA) ● 8 projects registered ○ Hiniduma Biolink Project (Sri-Lanka) ▪ PVCs issued: 2,767 ○ Trees for Global Benefits (Uganda) ▪ PVCs issued: 647,915 ○ Chalo Verde Timor Community Forest C (Philippines) ▪ PVCs issued: 18,015 ○ Rehabilitation and sustainable management by AGED of degraded pastures in the Sahel region of Burkina Faso (Burkina Faso) ▪ PVCs issued: 6,717 ○ Pasture Conservation and Climate Action , Mongolia ▪ PVCs issued: 40,015 ○ Halo Verde Timor Community Forest Carbon ▪ PVCs issued: 18,015 ○ Rehabilitation and sustainable management by REACH Italia of degraded pastures in the Sahel region of Burkina Faso ▪ PVCs issued: 1,667

	○ The CommuniTree Carbon Program (formerly Limay Community Carbon Project) ▪ PVCs issued: 782,471 Plan Vivo Reducing Locally-Driven Deforestation ● No project registered Plan Vivo Estimation of climate benefits from REDD in community managed forests ● 6 projects registered ○ Bujang Raba Community PES Project ▪ PVCs issued: 125,820 ○ Durian Rambun ▪ PVCs issued: 16,110 ○ Khasi Hills Community REDD+ Project: Restoring and Conserving Meghalaya's Hill Forests Through Community Action ○ Loru Forest Project ▪ PVCs issued: 21,203 ○ Reducing Emissions from Deforestation and Forest Degradation in the Yaeda Valley, Northern Tanzania ▪ PVCs issued: 151,088 ○ Rimbak Pakai Pengidup Project ▪ PVCs issued: 3,488 *Note: The Plan Vivo registry lists projects that use protocols developed by Plan Vivo standard, in addition to protocols that are recognized by Plan Vivo standard, but not developed by the organization. Plan Vivo standard projects that are listed in this table are only those that use protocols specifically developed by Plan Vivo, in order to avoid double listing projects. Additionally, the registry does not list all registered projects but only those that the account holder has requested be publicly available.*
Are there mechanisms for a jurisdictional approach and for aggregation of projects for better addressing leakage,	*Note: Due to the large number of protocols that apply to tropical forests, only those listed in this row allow for aggregation. Unlisted protocols and methodologies do not provide jurisdictional approaches, nor do they permit for aggregation.* *While the jurisdictional approaches have not yet been tested in practice, they provide important frameworks within which REDD+ projects can be developed at a jurisdictional scale. Several project level protocols and methodologies permit for project aggregation, nesting (aligning project accounting with jurisdictional strategies) or, in the case of several project level Verra methodologies, projects using VCS methodologies can seek registration under a jurisdictional REDD+ program. Unlisted protocols and methodologies do not provide jurisdictional approaches, nor do they permit for aggregation.*

additionality, etc. within any existing or proposed market?	*Jurisdictional* **ART TREES** ● The Architecture for REDD+ Transactions (ART) is an independent program that sets standardized procedures which aim to achieve the environmental integrity needed for REDD+ emission reductions and removals (ERRs) at national and jurisdictional scale. ART developed and uses The REDD+ Environmental Excellence Standard (TREES). **ACR Nested REDD+ Standard** ● Provides technical guidance for registration on ACR of REDD+ projects nested within a jurisdictional accounting framework **CARB Tropical Forest Standard** ● Jurisdictional/nested focused approach ● Establishes pathway for national or subnational jurisdictions to link forestry offsets to California's Cap-and-Trade program **FCPF** ● FCPF is a mechanism for performance-based payments for the successful implementation of jurisdictional emission reductions programs ● As of August 2021, Mozambique became the first FCPF country to successfully verify emissions reductions, becoming the first-ever accredited verification of JREDD+ ERs **Verra's Verified Carbon Standard: Jurisdictional Nested REDD+ framework** ● Has three possible scenarios through which projects can be "nested" based on differing jurisdictional decisions and/or market structures. "Nesting" refers to a set of provisions aimed at ensuring project-level accounting is aligned with jurisdictional (e.g., national) strategies and methods. It includes criteria and requirements to ensure the alignment of baselines, monitored data, emission reductions and/or removals estimates and carbon accounting across levels, i.e., projects, subnational programs, and national programs. *Project Based* **ACR** ● Allows aggregation but does not provide specific guidance on how aggregation is to be accomplished **CDM** ● Currently does not allow REDD projects ● Allows stacking of project activities **Climate Action Reserve Mexico Forest Protocol**

	• Aggregation allowed — must consist of two or more forest owners. In Aggregates formed by three or more Forest Projects, no single Forest Project may comprise more than 50 percent of the total combined area in an Aggregate, based on the hectares included in the Activity Areas for each Forest Project **Gold Standard** • Supports a landscape approach but has stated that REDD+ approaches have many challenges **Verra VM0003 Methodology for Improved Forest Management through Extension of Rotation Age (IFM ERA) Version 1.2** • Aggregation of forest properties with multiple landowners is permitted under the methodology with aggregated areas treated as a single project area **Verra VM0006 Methodology for Carbon Accounting for Mosaic and Landscape-scale REDD Projects, v2.2** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements **Verra VM0007 REDD+ Methodology Framework (REDD+MF), v1.6** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements **Verra VM0015 Methodology for Avoided Unplanned Deforestation, v1.1** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements **Verra VM0037 Methodology for Implementation of REDD+ Activities in Landscapes Affected by Mosaic Deforestation and Degradation, v1.0** • Where projects applying this methodology seek registration under a jurisdictional REDD+ program, the project must follow the requirements specified in the latest version of the VCS Jurisdictional and Nested REDD+ (JNR) Requirements

Is there controversy surrounding the markets or credits for the NCS pathway? Why?	*Concerns with project-scale REDD+* • **Permanence concerns***:* As projects cover smaller parcels of land than jurisdictional, there are concerns around the permanence of emissions reductions in the event of extreme weather events or wildfires – although now most high-quality methodologies have buffer pools set aside in the event of reversals. Nevertheless, projects are more vulnerable than jurisdictions to reversal risk. There are also some common misconceptions around how permanence plays out re: flow reductions over a fixed time frame versus preserving the same parcels of trees – this misconception has led to pushback / quality doubts surrounding REDD+ credits. • **Additionality concerns***:* A "self-selection" effect can play out in projects, whereby areas with low deforestation pressures versus those with high deforestation pressures are selected for inclusion as projects. This can pose additionality concerns with project-scale credits. • **Land tenure and rights concerns***:* There have been reported instances of older REDD+ projects being implemented at the exclusion of local communities or Indigenous peoples, leading to land tenure conflicts or local communities being "locked-out" of rights to carbon compensation. Responding to these concerns, most newer REDD+ initiatives require respecting the Cancun safeguards, but we have not evaluated the extent to which safeguards have been respected in practice for projects. • **High transaction costs:** Full implementation of restoration and/or reforestation projects with direct payments to communities can result in high transaction costs (Brancalion et al, 2019; Fiorini et al, 2020). The potentially high cost of required intervention may be underestimated when initiating tropical forest carbon projects. *Concerns with jurisdictional-scale REDD+* • Jurisdictional programs offer advantages over project-scale programs by aggregating reversal risk over a larger land area, mitigating additionality concerns by including deforestation from both high- and low-pressure areas under a historical baseline, and being able to generate more durable transformation in the large-scale drivers of deforestation by integrating incentive schemes with government-led enforcement efforts. Nevertheless, some concerns remain. • **Baselines**. Baselines can be set using either using historical average emissions or projected baselines. Projected baselines, while potentially suitable for areas with rapidly rising deforestation rates (i.e. recognizing that setting a baseline on the basis of historically low deforestation rates will be challenging to reduce emissions below, thus incentives for further reductions can be compromised), can also lead to "hot air" for regions whose deforestation pressures do not match the rate of change presented in the projected baseline. Crediting for High Forest, Low Deforestation (HFLD) regions is also similarly challenging – the possibility has been floated to increase crediting levels by a percentage of carbon stocks protected. There is some dialogue around whether such an approach has additionality concerns, or whether it is a viable way to reward historic forest protectors for their ongoing efforts. • **Benefit Sharing challenges***:* Once a jurisdiction receives finance for reducing emissions below baseline, it is up to the administrative bodies that have applied for credits, such as a state or national government, to decide how to allocate the funding among local stakeholders on the ground. There are many approaches suggested for this, but Indigenous groups have raised concerns that they will not receive adequate representation in benefit sharing negotiations, or that implementation efforts could compromise their land titles or autonomy over their lands. Again, the Cancun safeguards are a requirement for most jurisdictional standards, but their application may vary across regions. The version

	of ART's TREES includes text that allows Indigenous groups to apply as participants and / or a coalition, provided the submission is endorsed at the national level. ● **Administration challenges***:* Ultimately, the implementation of a jurisdictional program lies in effective operation of a jurisdictional authority or Indigenous coalition. The success of this program will depend on the extent to which the jurisdictional authority effectively implements deforestation reduction programs, and how local actors on the ground can expect to be compensated for their efforts. Participation could be affected by political turnover / political instability. In addition, the equity of the programs is also dependent on the benefit sharing arrangements implemented by the overseeing administration, although if they are found to be non-compliant with safeguards, funding for the generated credits could be compromised / withdrawn. Nevertheless, if jurisdictions fail to implement reductions at scale after signing up for a jurisdictional crediting program, they simply will not receive funding – thus, a built-in disincentive is in place for non-compliance. *<u>General concerns with REDD+ as offsets</u>* ● Some stakeholder groups and advocates believe that offering NCS offsets to corporations may disincentivize them from implementing meaningful industrial / energy use transitions in their own operations or supply chains. Others have concerns around local environmental impacts being preserved through the option to "export" environmental goods abroad through the purchase of offsets. EDF in general has taken the position that there are ways to remedy this, such as incorporating moderate use of offsets into a robust net-zero target which includes other transformations over time, such that offsets overall provide a net service to the globe while also offering a vital source of forest finance to tropical countries / Indigenous lands. Even so, messaging around this point is an ongoing effort. *Note: not a controversy, but there is a challenge around quantifying and incorporating emissions from degradation. This is currently a technical limitation that is expected to improve over time. It is relevant to the marketplace because an intact tropical forest stores more carbon than a degraded one, but the level of degradation and change is difficult to accurately represent (and thus capture as a meaningful carbon credit unit) via existing methods.*

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