California Air Resources Board

Quantification Methodology

Riparian Conservation and Restoration

California Climate Investments

FINAL

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List of Acronyms and Abbreviations

Acronym	Term
C	carbon
CARB	California Air Resources Board
CCI	California Climate Investments
CO	carbon monoxide
CO_2	carbon dioxide
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
lb	pounds
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	oxides of nitrogen
O_3	ozone
$PM_{2.5}$	particulate matter with a diameter less than 2.5 micrometers
ROG	reactive organic gases
SO_2	sulfur dioxide
USDA	United States Department of Agriculture
USFS	United States Forest Service
yr	year

List of Definitions

Term	Definition
Air pollution	Term used to describe undesirable amounts of particulate or gaseous matter in atmosphere.
Co-benefit	A social, economic, or environmental benefit as a result of the proposed project in addition to the GHG benefit.
Existing vegetation type	General description of the existing vegetation at the site before project implementation.
Land-use	Land use refers to the most recent use of land before implementing a riparian restoration, including crops (annual or perennial), grazing, and degraded or invaded areas, such as abandoned, urban, or wildland sites requiring restoration due to poor habitat quality. Land-use only applies to natural regeneration and planted communities project types.
Net GHG benefit	Estimated as the sum of soil C stocks, N_2O, and CH_4 production.
Project area	Riparian area designated for conservation or restoration, including the stream's active channel and floodplain.
Project lifetime	Number of years that a project type could be expected to provide GHG benefits. If the project's lifetime is uncertain, a minimum duration of 15 years may be assumed, in accordance with NRCS CPS 391 recommendations.

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (GHG) emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the net GHG benefit and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project types eligible for funding by each administering agency, as reflected in the program expenditure records.

CARB staff developed this Riparian Conservation and Restoration Quantification Methodology to provide guidance for estimating the net GHG benefit and selected co-benefits of each proposed project types. This methodology uses calculations based on the Carbon in Riparian Ecosystems Estimator for California (CREEC) web-based tool to estimate carbon sequestration from riparian conservation and restoration projects. Additional co-benefits from riparian conservation and restoration projects include increase in pollinator diversity and abundance, improved soil stability and resilience to erosion, flood attenuation, reduction of water pollutants, corridors for wildlife passage, regulate local climate. Programs that this QM may be used for include, but are not limited to the following:

- Wetland Restoration by the California Department of Fish and Wildlife (CDFW)
- Climate Adaptation Resiliency Program by the Wildlife Conservation Board (WCB)
- California Conservation Corps

The Riparian Conservation and Restoration Benefits Calculator Tool automates methods described in this document. A step-by-step project examples are included in Appendix B. Projects will report the total project GHG benefits and co-benefits estimated using the Riparian Restoration Benefits Calculator Tool as well as the total project GHG benefit per dollar of GGRF funds awarded. The Riparian Conservation and Restoration Benefits Calculator Tool is available for download on the California Climate Investments resources webpage.

Using many of the same inputs required to estimate net GHG benefit, the Riparian Conservation and Restoration Benefits Calculator Tool estimates key variables and co-benefits from Riparian Conservation and Restoration projects. Key variables are project characteristics that contribute to a project's net GHG benefit ($MTCO_2e$) and signal an additional benefit, including trees planted (number of trees), land conserved (acres) and land restored/treated (acres). Project co-benefit include nitrogen oxides (NO_x) reductions (lbs), fine particulate matter ($PM_{2.5}$) reductions (lbs), reactive organic gases (ROG) reductions (lbs), sulfur dioxide (SO_2) reductions (lbs), and ozone (O_3) reductions (lbs). Additional co-benefits for which CARB assessment methodologies were not incorporated into the Riparian Conservation and Restoration Benefits Calculator Tool may also be applicable to the project. Applicants should consult the specific program guidelines, solicitation materials, and agreements to ensure they are meeting the specific program requirements. All CARB co-benefit assessment methodologies are available on the California Climate Investments co-benefits webpage.

Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability, per the California Climate Investments Funding Guidelines.
CARB has incorporated the Carbon in Riparian Ecosystems Estimator for California (CREEC) database, which was developed by the Department of Conservation and Virginia Matzek from Santa Clara University. This database is integrated into the Riparian Conservation and Restoration Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven methods;
- Use project-level data, where available and appropriate; and
- Result in net GHG benefit estimates that are conservative and supported by empirical literature.

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the riparian conservation and restoration project types. CARB also consulted with interested agencies such as the Wildlife Conservation Board, California Department of Fish and Wildlife (CDFW), and California Conservation Corps to determine project-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level. Although the CREEC database was developed using a comprehensive set of riparian restoration and conservation studies, there are still limitations in studies and data available that comprehensibly represent riparian systems in California.

CARB released the Riparian Conservation and Restoration Quantification Methodology and Draft Riparian Conservation and Restoration Benefits Calculator Tool for public comment in December 2024. This Final Riparian Conservation and Restoration Methodology and accompanying Riparian Conservation and Restoration Benefits Calculator Tool have been updated to address public comments, where appropriate.

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, lessening the impacts and effects of climate change, and strengthening community engagement. Co-benefit assessment methodologies are posted on the California Climate Investments co-benefits webpage.

Tools

The Riparian Conservation and Restoration Benefits Calculator Tool relies on project-specific outputs from the following tools:

CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available on the California Climate Investments resources webpage. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the Riparian Conservation and Restoration Benefits Calculator Tool to estimate the net GHG benefit and co-benefits of the proposed project. The Riparian Conservation and Restoration Benefits Calculator Tool can be downloaded from the California Climate Investments resources webpage.

Section B. Methods

The following section provides details on the methods supporting emission reductions in the Riparian Conservation and Restoration Benefits Calculator Tool.

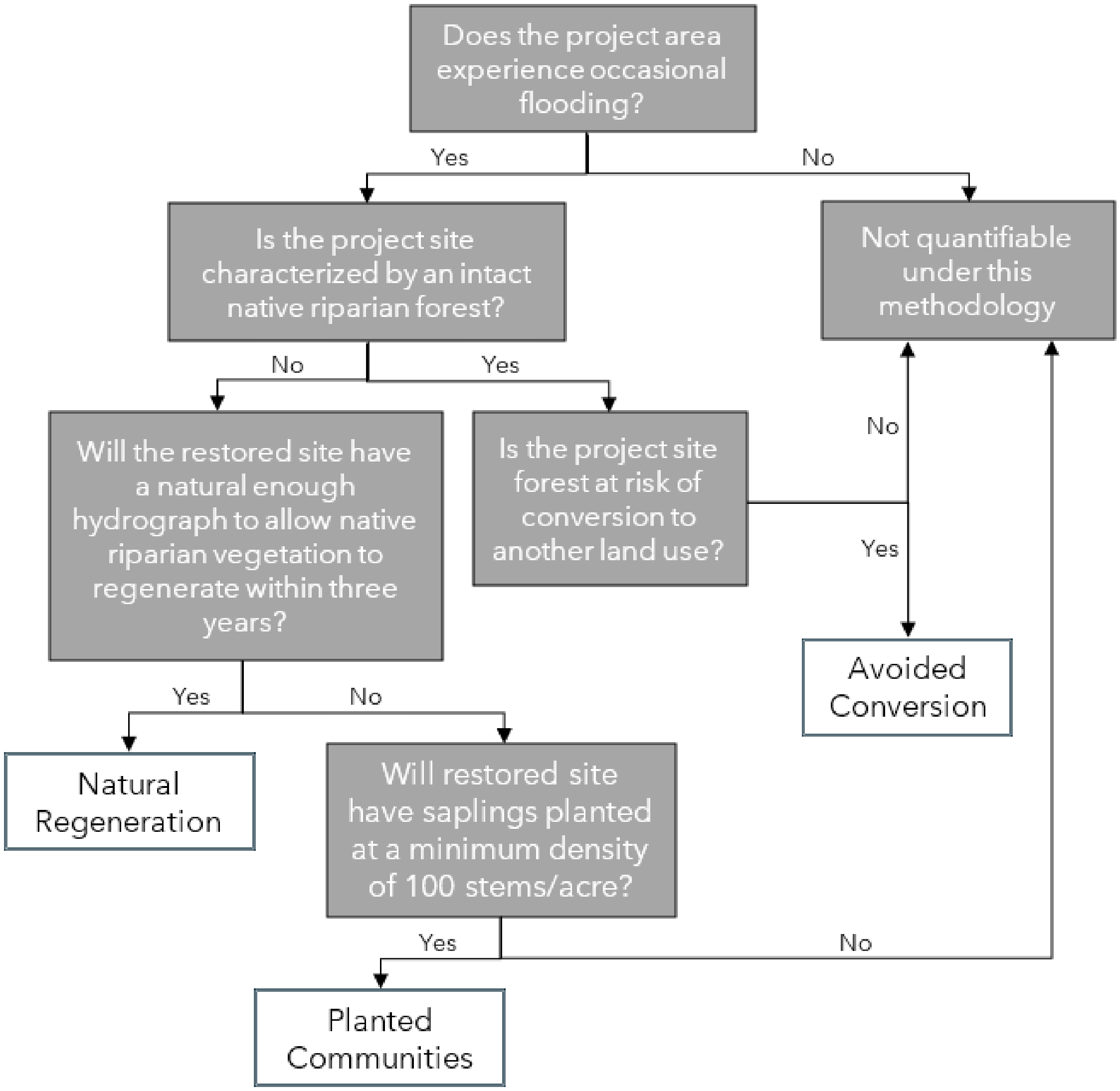
Project Type

The Riparian Conservation and Restoration Quantification Methodology outlines activities that result in a net GHG benefit from natural regeneration, planted communities, and avoided conversion project types. Other project features may be eligible for funding under specific program guidelines. Projects requesting GGRF funding must include at least one of the following:

- Natural Regeneration;
- Planted Communities and;
- Avoided Conversion.

Project applicants can refer to the decision tree in Figure 1 to identify the appropriate project type to quantify. A single site can include multiple project types and benefits are calculated separately for the area allocated to each type. Each project type has specific criteria outlined below. Projects implemented are assumed to be protected by a conservation easement or similar agreement, ensuring that the project area remains as riparian forest habitat for the entire project life.

Figure 1. Decision Tree for Determining Project Type



General Approach

Methods used in the Riparian Conservation and Restoration Benefits Calculator Tool for estimating the net GHG benefit and air pollutant emission co-benefits by activity type are provided in this section. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

These methods estimate the net GHG benefits of riparian conservation and restoration projects, including natural regeneration, planted communities, and avoided land conversion. This approach considers carbon sequestration in both vegetative biomass and soils, assuming that: 1) The community composition will shift from lower-biomass annual grasslands to higher-biomass forests and shrublands; 2) Biomass inputs to soil organic matter will have a higher carbon content when derived from woody plants; and 3) Preventing erosion will help retain soil carbon in the riparian zone. In general, the net GHG benefit is estimated in the Riparian Conservation and Restoration Benefits Calculator Tool using the approaches in Table 1. The Riparian Conservation and Restoration Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate the net GHG benefit.

Figure 2. General Approach to Quantification by Project Type

Natural regeneration and/or Planted Communities
Net GHG Benefits = carbon storage in live and dead trees (above and belowground) + carbon storage in forest floor + carbon storage in understory + carbon storage in soil – carbon loss from vegetation clearing – emissions from site preparation
Avoided Conversion
Net GHG Benefits = carbon storage in live trees+ carbon storage in dead trees + carbon storage in forest floor + carbon storage in understory

A. Net GHG Benefit from Natural Regeneration and Planted Communities Projects

The net GHG benefit from natural regeneration and planted communities project types is estimated using Equation 1. The net GHG benefit is calculated as the balance of the project's carbon sequestration potential over the project lifetime minus the losses due to initial clearing and preparation for the project. These losses include emissions from carbon loss and emissions due to clearing activities.

Equation 1: Net GHG Benefit from Natural Regeneration and Planted Communities Project Types

$$GHG_{net} = GHG_S - GHG_{EV} - GHG_{EC} - GHG_{EE}$$

Where			Units
GHG_{net}	=	Net carbon benefit from planted and natural revegetation over the project life	MT CO_2e
GHG_S	=	On-site carbon stored in planted and natural revegetation over the project lifetime (from Equation 2)	MT CO_2e
GHG_{EV}	=	On-site carbon loss due to initial vegetation clearing in preparation for project implementation (from Equation 3)	MT CO_2e
GHG_{EC}	=	On-site emissions from mobile combustion due to vegetation clearing in preparation for project implementation (from Equation 4)	MT CO_2e
GHG_{EE}	=	On-site emissions from mobile combustion due to earth-moving activities in preparation for project implementation (from Equation 5)	MT CO_2e

B. On-Site Carbon Storage from Natural Regeneration and/or Planted Communities Projects

On-site carbon sequestration from natural regeneration and planted communities is estimated using statistical models that relate age to live tree biomass based on an extensive database of riparian forest measurements in California, with other carbon pools predicted from live tree biomass and forest age. Equation 2 is used to determine the carbon sequestration from natural revegetation and planted communities projects.

Equation 2: GHG Benefit of Carbon Stored in Natural and Planted Revegetation Project Types

$$GHG_S = \sum_i (A_{P_i} \times C_{T_i} \times 1.486)$$

Where,			Units
GHG_S	=	Carbon sequestration from planted and natural revegetation over the project life	MT CO_2e
A_{Pi}	=	Area of a project in the vegetation type *i*	acres
C_{Ti}	=	Total carbon in soil and non-soil components for each vegetation type *i* for the project lifetime	C/ha
1.486	=	Conversion factor from metric tons C/ha to metric tons CO_2e/acre	factor

C. On-Site Emissions from Natural Regeneration and/or Planted Communities Projects

Riparian restoration projects require clearing invasive species or other vegetation prior to restoration. Equation 3 is used to determine carbon loss due to the initial clearing of existing vegetation.

Equation 3: Carbon Loss Due to Vegetation Clearing in Site Preparation for Project Type

$$GHG_{EV} = \sum_i ((A_{P_i} \times C_{R_i}) - (A_{P_i} \times C_{C_i} \times e(-P_L / 19.8)))$$

Where,			Units
GHG_{EV}	=	On-site carbon loss due to initial clearing in preparation for implementing project scenario	MT CO_2e
A_{Pi}	=	Area of a project in the vegetation type *i*	acres
C_{Ri}	=	Average estimated carbon removal for a specific vegetation type in a cleared area *I*, from Table 1	MT CO_2e/ acre
C_{Ci}	=	Chipped biomass factor for cleared area *i* is set to 0 if the removed biomass is not chipped on-site, or a FLi value of if the biomass is chipped on-site	factor
P_L	=	Project lifetime	year
19.8	=	Decay factor for forest-floor material	factor

Table 1. Average Estimated Carbon Removal in Site Preparation for a Specific Vegetation Type

Vegetation Type	**Average Estimated Carbon ($MT\ CO_2e/acre$)** (from Scott and Burgan, 2005)
Grass	3.6
Light to Med Shrubs	13.9
Heavy Shrubs	24.0

Clearing invasive species or other vegetation before restoration may require using heavy equipment such as brush-cutters or chainsaws. The fossil fuel emissions from these activities are estimated in Equation 4.

Equation 4: Emissions from Mobile Combustion for Clearing Activities during Site Preparation

$$GHG_{EC} = \sum_{i} (A_{P_i} \times EF_{V_i})$$

Where,			Units
GHG_{EC}	=	On-site emissions from mobile combustion due to vegetation clearing in preparation for project implementation	$MT\ CO_2e$
A_{Pi}	=	Area of a project in the vegetation type *i*	acres
EF_{Vi}	=	Emission factor for vegetation type in cleared area *i*, from Table 2	factor

Table 2. Emission Factor from Mobile Combustion for Vegetation Clearing during Site Preparation

Vegetation Type	Description	Emission Factor
Light	0-25% brush cover	0.09
Medium	>25-50% brush cover	0.202
Heavy	>50% brush cover, stump removal	0.429

In some cases, riparian restoration requires heavy equipment to implement earth preparation activities such as streambank regrading, culvert removal or placement, riprap, auger-planting, or other excavation work. GHG emissions from earth-moving heavy equipment are estimated in Equation 5. The estimation relies on the number of hours that heavy equipment is used in riparian restoration projects, which is then converted to a volume of fuel consumed based on the equipment's manufacturer-specified fuel-use rate. Fuel-specific emission factors are found in Table 3.

Equation 5: Emissions from Mobile Combustion for Earth-Moving Activities during Site Preparation

$$GHG_{EE} = \sum_i \frac{Fuel_i \times EF_{F_i} \times t_i}{1000}$$

Where,			Units
GHG_{EE}	=	On-site emissions from mobile combustion due to earth-moving activities in preparation for project implementation	MT CO_2e
$Fuel_i$	=	Estimated fuel use for vehicle or equipment *i*	gal/hr
t_i	=	Estimated number of hours that heavy equipment is used in riparian restoration projects	hr
EF_{Fi}	=	Fuel specific emission factor used by vehicle or equipment *i*, from CARB Emission Factor Database	kg CO_2e/gal
1000	=	Conversion factor from kg to MT CO_2e	

D. Net GHG Benefit from Avoided Conversion Projects

The net GHG benefit from the avoided conversion project type is estimated using Equation 6. For these projects, it is assumed that (1) a mature riparian forest with high conservation value remains intact and does not require clearing, and (2) since only non-soil carbon pools are accounted for, the site is presumed to have remained undisturbed by land-use changes or site preparation, with no anticipated recovery from soil carbon depletion.

Equation 6: Carbon Preserved from Avoided Conversion Project Type

$$GHG_A = \sum_i (A_{P_i} \times C_{T_i} \times 1.486)$$

Where,			Units
GHG_A	=	Carbon preserved from the avoided conversion of riparian areas over the project life	MT CO_2e
A_{Pi}	=	Area of a project that avoids conversion in a vegetation type *i*	acres
C_{Ti}	=	Total carbon non-soil components for each vegetation type *i* for the project lifetime	C/ha
1.486	=	Conversion factor from metric tons C/ha to metric tons CO_2e/acre	factor

E. Air Pollutant Co-Benefits from Planted Communities and Avoided Conversions Projects

Riparian conservation and restoration projects can provide co-benefit by increasing the absorption of air pollutants, including O_3, NO_x, SO_2, and $PM_{2.5,}$ improving air quality for communities surrounding the project area. Air pollutant co-benefits are estimated only for planted communities and avoided conversion project types in which species composition is known. Air pollutant co-benefits are calculated as the sum of air pollutant emissions removed from the atmosphere by trees during the project's lifetime. To consider tree species diversity and site variability in tree planting, average air pollutant co-benefits of O_3, NO_x, SO_2, and $PM_{2.5}$ from tree species commonly found in riparian systems were simulated using i-Tree. Tree species were simulated, accounting for a 10% annual tree mortality rate after year 10. A minimum planting density of 100 plants/acre was assumed to convert estimated co-benefits to a project area basis. More details are available on the i-Tree Tool webpage. The O_3, NO_x, SO_2, and $PM_{2.5}$ from the project are estimated using Equation 7.

Equation 7: Air Quality Co-Benefits from Planted Communities and Avoided Conversion Projects

$$Co-benefit\left[O_3 / NO_X / SO_2 / PM_{2.5}\right]_P = Co-benefit\left[O_3 / NO_X / SO_2 / PM_{2.5}\right]_{Avg,i} \times P_L \times 100$$

Where,			Units
Co-benefit [O_3/NO_x/SO_2/ $PM_{2.5}$]$_P$	=	Estimated project co-benefit [O_3/NO_x/SO_2/$PM_{2.5}$] reductions for planted communities and avoided conversion projects	lbs/acre yr
Co-benefit [O_3/NO_x/SO_2/ $PM_{2.5}$]$_{Avg, i}$	=	Average co-benefit [O_3/NO_x/SO_2/$PM_{2.5}$] reduction per year	lbs/yr
P_L	=	Project lifetime	year
100	=	Minimum expected planting density for riparian restoration projects	trees/acre

F. Air Pollutants Emissions from Natural Regeneration and Planted Communities

In addition to the GHG emissions from earth-moving activities that use heavy equipment (calculated in Equation 5), heavy equipment used in natural regeneration and planted communities also produces air pollutants from fossil fuel combustion.

The air pollutant emissions are estimated using the CARB Emission Factor Database, as outlined in Equation 8.

Equation 8: Air Pollutant Emissions from Riparian Conservation and Restoration Projects

$$\mathbf{AirPolutant}\left[ROG / NO_X / PM_{2.5}\right]_P = \frac{\sum EF\left[ROG / NO_X / PM_{2.5}\right]_{\mathbf{AirPollutant},i} \times t_i}{\mathbf{453.6}}$$

Where,			Units
AirPollutant [ROG/NOx/ PM2.5]$_P$	=	On-site emissions from mobile combustion due to earth-moving activities in preparation for project implementation	lbs
$EF_{AirPollutant,i}$	=	Air pollutant specific emission factor for equipment *i*, from CARB Emission Factor Database	g/hr
t_i	=	Estimated number of hours that heavy equipment is used in riparian restoration projects	hr
453.6	=	Conversion factor from grams to pounds	factor

Section C. References

The following references were used in the development of this Quantification Methodology and the Riparian Restoration Benefits Calculator Tool.

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Appendices

APPENDIX A. Carbon in Riparian Ecosystems Estimator for California (CREEC)

The Carbon in Riparian Ecosystems Estimator for California (CREEC) database provides estimates of carbon accumulation in live and dead tree biomass, forest floor, downed dead wood, understory, and soil pools. These estimates are based on project type, location, restoration approach, previous land use, site preparation disturbance, and the species composition of the planned or conserved forest community. CREEC provides estimates in intervals of five or 10 years up to 100 years, and the results are used as inputs for Equations 1 and 4 of this Quantification Methodology.

Methodology
The methodology to estimate carbon stocks in the CREEC database was developed by Matzek et al. (2018). Forest aboveground biomass was modeled based on statistical relationships between forest age and live tree biomass in California riparian forests. Live tree biomass or forest age were estimated following the US National Greenhouse Gas Inventory methodology. Soil carbon accumulation is modeled as recovery from depletion, with the rate influenced by prior land use and site preparation disturbance. The predicted carbon stocks are consistent with published estimates for riparian forests. A brief description of the methodology follows, with additional details available at Matzek et al. (2018).

Riparian Vegetation Types
The database used included over 654 plots that included over 25,000 live and dead individual trees and woody shrubs of diameter at breast height ≥ 2.5 cm. To facilitate the implementation of the riparian conservation quantification methodology, riparian vegetation types were delineated. Species were grouped by habit, genus, and successional status in categories including scrubby willows, pioneer trees, upland shrubs, and shade-tolerant trees. Species' relative density in each of the four groups were used to construct the riparian vegetation associations described in Table 3. These are statistical groups, not formal vegetation classifications, intended to improve the precision of biomass estimates based on species composition.

Table 3. Grouped species composition.

Group acronym	Description
ABS	Ash/boxelder/sycamore group dominant
AlWal	Alder/walnut group dominant
Cot	Cottonwood-dominant
MRF	Diverse; willows/cottonwoods <50%
Shrub	Shrub-dominant

VORF	Diverse; oak dominant
VOW	Oaks>25%, remainder willows & shrubs
WilCot	Willows/cottonwoods together >75%
Wfor	Diverse; willows>25%
Wmix	Diverse; willows>50%
Wscrub	Willows>50% and shrubs>25%
AllW	Willows>90%

Aboveground and belowground biomass
Allometric equations were used to estimate tree aboveground tree biomass from diameter at breast height (Chojnacky et al., 2013) and carbon, assuming 50% of carbon in biomass. Aboveground biomass estimates used equations from Smukler et al. 2010 for woody shrubs. Estimated aboveground biomass was adjusted to ensure conservative estimates of biomass in riparian forests. Belowground biomass was calculated following the US Forest Projects protocol, using the two-parameter equation from Cairns et al. (1997), which predicts belowground biomass based on forest age and aboveground biomass.

Tree carbon stocks
Total tree biomass for ages 0-100 years was estimated by fitting 3-parameter Chapman-Richards growth functions to the empirical data within each of the 12 statistical groups previously identified (Pienaar & Turnbull 1973; Liu & Li 2003), using Equation 9.

$$LiveTree_{biomass} = a(1 - e^{-b(Age)})^c \quad \text{Equation 9.}$$

where a is the maximum stand live tree biomass, b is a growth rate that determines how fast the stand reaches its asymptote, and c determines the shape of the sigmoid curve and the location of its inflection point. The curves were then iteratively fitted using the Levenberg-Marquardt algorithm until an optimal solution was reached. The expected values generated from these equations formed the basis for estimating all other forest biomass components and followed the methodology used in the Carbon Online Estimator (COLE 3.0).

Due to the absence of data from high elevations (above ~3000 feet) and regions from California south of the Transverse Ranges in the source database, carbon estimates for these forests used a different methodology. For high-elevation areas in the Klamath, Cascades, and Sierra, live tree biomass values were derived from COLE 3.0 results, specifically from the Forest Inventory and Analysis (FIA) plots containing riparian indicator species within the following Ecological Subregions-Sections: Klamath Mountains (M261A), Northern California Coast Ranges (M261B), Northern California Interior Coast Ranges (M261C), Southern Cascades (M261D), Sierra Nevada (M261E), Sierra Nevada Foothills (M261F), and Modoc Plateau (M261G)

(Cleland et al., 2007; McNab et al., 2007). Due to the lack of suitable data for southern California in COLE, all forests in that region were classified under the "willow/cottonwood" group.

Additional forest carbon pools
The US National Greenhouse Gas Inventory methods, as outlined in Smith et al. (2013), were used to estimate forest floor, downed dead wood, and understory biomass. *Forest floor carbon* was specifically estimated using the methodology from Smith & Heath (2002), which calculates carbon as a function of stand age, according to Equation 10.

$$Forest_{floor} = \frac{f_1 \times Age}{f_2 + Age} \qquad \text{Equation 10.}$$

where f_1 and f_2 are coefficients appropriate to Western hardwood forests. This equation excludes the decay component, as restored or preserved riparian forests generally do not experience clearcutting that will significantly impact carbon estimates.

Downed dead wood carbon was estimated as a fixed ratio of live tree carbon, with a ratio of 0.062 for elm, ash, cottonwood, willow, and oak-dominated plots, and 0.095 for alder-dominated plots, following the FORCARB2 model (Heath et al., 2010). *Understory carbon* was modeled to initially increase following stand replacement but gradually decline as the canopy closes and understory plants are shaded out. The relationship using Equation 11.

$$Forest_{understory} = LiveTreeC \times e^{c_1 - (c_2 \times \ln(LiveTreeC))} \qquad \text{Equation 11.}$$

where c_1 and c_2 are coefficients specific to Western oak, elm/ash/cottonwood, or alder/maple forests. The equation and coefficients come from Smith et al. (2013), building on the work of Birdsey (1996) and Heath et al. (2010).

Standing dead biomass was initially estimated using field measurements from the CREEC database instead of the National Greenhouse Gas Inventory's volume-based models, which tend to overestimate standing dead wood. Instead, Chapman-Richards growth functions were applied twice: first for combined biomass (live + dead) and then for live-tree biomass alone, providing a more accurate and conservative estimate.

Soil carbon
Soil carbon accumulation is modeled as recovery from depletion to an expected value, with the rate influenced by previous land use and the extent of soil disturbance during site preparation. Using the afforestation approach in COLE v. 3.0, the model

assumes prior land use reduced soil organic carbon, with reforestation or natural regeneration gradually restoring it to an anticipated average level for the region and forest type. Soil carbon at a 1-meter depth for a specific project age is shown in Equation 12.

$$soilC = MeanSoilC \times (p + (1 - p)) \times (1 - e^{-\left(\frac{age}{50}\right)^2})$$ Equation 12.

where p is the proportion of remaining soil carbon after land-use change, and *MeanSoilC* is the expected value. The expected mean soil values in CREEC are derived from tables in Smith et al. (2013), which utilize the methodology of Amichev & Galbraith (2004). This approach integrates forest data from the FIA database with soil data from the STATSGO database (Schwarz & Alexander 1995) to generate regional soil carbon values for different forest types. Values of p were determined based on combinations of previous land use (grazing, orchards, tilled crops, degraded/invaded forest) and the intensity of soil disturbance during site preparation (mechanical or non-mechanical). These values were derived from broad-scale meta-analyses that assess the impact of agricultural activities on soil carbon stocks (Guo & Gifford 2002, Lagani?re et al. 2010, Li et al. 2012). For avoided conversion project types, CREEC does not account for soil carbon accumulation when returning stock tables, as it assumes that soil carbon levels in an intact, healthy riparian forest are not depleted and are expected to remain stable.

Comparison of CREEC to other Riparian Restoration Estimates

CREEC outputs were compared to estimates of riparian forest carbon accumulation from other sources. At 30 years of forest age, total biomass in all non-soil pools from CREEC ranged from 69-161 Mg/ha, with a mean of 108±7.4 Mg/ha. COMET-Planner (Swan et al., undated) predicts 150 Mg/ha for vegetation and soil, based on an annual rate of 5 Mg/ha/yr. Data from the Sacramento River in Matzek et al. (2015) estimate 97.4 Mg/ha for tree carbon and 120.4 Mg/ha for live and dead trees plus soil. COLE 3.0, using 10 California datapoints, predicts 116 Mg/ha for elm/ash/cottonwood forest. CREEC results fall well within the range of these published estimates.

APPENDIX B. Step-by-Step Examples for Riparian Conservation and Restoration Projects

Natural Regeneration

To get started review general instruction in the "Read me" tab before continuing to the "Project Info" tab. In the "Project Info" tab input basic project Information and Identify project type in STEP 1. In this example, the proposed project Is a natural regeneration and applicant will skip STEP 2 and continue to STEP 3.

STEP 1: Input basic project information and identify project type.

Implementation year:	2024
Project ID:	Riparian_Project_123
Applicant:	River Trust
County:	Del Norte
Project location (Region):	Central Valley/Coast Ranges/Foothills (Elevation < 1000 m)
Project type:	Natural regeneration

TIP:
If project type is **planted communities** or **avoided conversion** continue to STEP 2 and then to STEP 3.
If project type is **natural regeneration** skip STEP 2 and continue to STEP 3.

In STEP 3, the applicant must provide detailed project information, including the type of soil preparation, previous land use, project lifetime (years), project area (acres) and a general description of the existing vegetation (e.g., grass, light to medium shrubs, or heavy shrubs). If biomass is cleared, specify whether it will be chipped on-site. Additionally, indicate whether the project will require earth-moving equipment.

For example, in our case, the site preparation method is mechanical, and the project is located on degraded land. The expected project lifetime is 30 years, covering an area of 100 acres. A visual inspection of the site reveals that the current vegetation consists of light to medium shrubs, and biomass will be chipped on-site. The project will also require an excavator for soil preparation, which is expected to operate for approximately 4 hours. The proposed project is expected to provide a GHG benefit 19,993 MT CO_2e.

STEP 3: Input project-specific implementation details

Site Preparation	Mechanical
Land Use	Degraded/Invaded
Project Lifetime (years)	30
Project Area (acres)	100
Existing Vegetation Type	Light to Medium Shrubs
Is Biomass Chipped On-Site? (Y/N)	Yes
Does the Project Require Site Preparation Equipment? (Y/N)	Yes
Equipment 1	Excavator
Time Usage Equipment 1 (hr)	4
Equipment 2	
Time Usage Equipment 2 (hr)	
Equipment 3	
Time Usage Equipment 3 (hr)	
Equipment 4	
Time Usage Equipment 4 (hr)	
Total Project Cost ($):	$ 1,000,000
Project GGRF Funds Awarded ($):	$ 500,000
Project non-GGRF Funds ($):	$ 500,000

Planted Communities

Using the previous project example, let's consider a planted community project type. In the "Project Info" tab input basic project information and identify project type in STEP 1. In this example, the proposed project is a planted communities and applicant will complete STEP 2 and STEP 3.

STEP 1: Input basic project information and identify project type.

Implementation year:	2024
Project ID:	Riparian_Project_123
Applicant:	River Trust
County:	Del Norte
Project location (Region):	Central Valley/Coast Ranges/Foothills (Elevation < 1000 m)
Project type:	Planted communities

TIP:
If project type is **planted communities** or **avoided conversion** continue to STEP 2 and then to STEP 3.
If project type is **natural regeneration** skip STEP 2 and continue to STEP 3.

In STEP 2 select the species to be planted and use percentage to describe this community. Percentage must add up to 100%. In the project example, the species *Baccharis salicifiolia* (40%), *Myrica californica* (30%), and *Salix exigua* (30%) will be planted in the restoration project.

Species	Percentage
Acer negundo	
Acer (other)	
Alnus rhombifolia	
Alnus (other)	
Aesculus californica	
Baccharis pilularis	
Baccharis salicifiolia	40
Cephalanthus occidentalis	
Fraxinus latifolia	
Garrya elliptica	
Heteromeles arbutifolia	
Juglans (sp)	
Laurus nobilis	
Myrica californica	30
Physocarpus capitatus	
Platanus racemosa	
Populus fremontii	
Populus (other)	
Quercus lobata	
Quercus agrifolia	
Quercus (other)	
Rosa californica	
Rubus (sp)	
Salix exigua	30
Salix gooddingii	
Salix laevigata	
Salix lasiolepis	
Salix lucida	
Salix (other)	
Sambucus (sp)	
Symphoricarpos albus	
Toxicodendron diversilobum	

Vitis californicus	
Other canopy tree	
Other understory woody shrub	
TOTAL	**100**

Using the similar project specific information from the natural vegetation project type shown previously, the proposed project Is expected to provide a GHG benefit of 10,872 MT CO_2e.