University of California
Agriculture and Natural Resources | California Institute for Water Resources

# Creek Carbon - Dynamics of Carbon and Nitrogen in Restored Mediterranean Riparian Zones

*Principal Investigators*:

**David Lewis**
**Director Cooperative Extension Marin County, UC ANR**

**Technical Completion Report for project: NIWR 2012CA294B**
**Project period: March 1, 2011 – February 28, 2013**

## Project Summary

The objectives of our project include:

• Document the potential to store carbon and nitrogen pools in soil and vegetation across a chrono-sequence of riparian restoration projects;

• Measure carbon pool fractions within riparian soils to document long term carbon sequestration potential within these systems;

• Understand the characteristics of riparian restoration (age, biodiversity, stream characteristics) that affect processes of carbon and nitrogen storage in order to maximize these ecosystem services for future efforts; and

• Make the research information available to restoration practitioners, funders, and permitting agencies for integration of carbon sequestration and nitrogen storage into stream restoration objectives.

A. If needed, note and justify any revisions made to the original objectives and/or timetable.

We have not completed the estimate of above-ground carbon storage. This task has taken longer than expected because of the extensive literature, new methods available guiding allometric equation protocols and collaboration with other UC researchers. For example, the Manual for building tree volume and biomass allometric equations (FAO 2013) is now available and we are capitalizing on work by previous studies (e.g. Williams et al. 2011).

B. Note any other problems encountered and steps taken to resolve them.

Another challenge has been the laboratory enumeration of recalcitrant forms of carbon. Numerous methods are being used in the literature to quantify the most stable humic and fumic acids. This study is providing feedback regarding the effectiveness of protocols.

Land managers have restored river and stream banks using revegetation technologies with native plant material for over four decades in coastal California, achieving multiple ecosystem functions and natural resource management objectives. The number of river and stream restoration projects in the U.S. has steadily increased since the 1980s with over $2 billion spent on river restoration in California. In Marin County alone, 25 miles of stream has been restored since the 1960s.

Despite the increase in stewardship effort and funds expended, there has been limited documentation of improvements in water quality, watershed functions, and ecosystem services. Though evidence of improved wildlife habitat is abundant, the current knowledge base is lacking an understanding of the biophysical relationships between soil properties, flooding, riparian forests, and the temporal vs. spatial variability controlling how conservation practices have restored watershed functions.

In addition to wildlife habitat and water quality, watershed restoration appears to have also improved air quality. Total and labile carbon increase over time as project age increases. The upperbank locations have consistently higher amounts than floodplains; however, the rate of carbon sequestration appears greater in floodplain soil and correlates to the rapid increase in canopy cover and root density as sites transition from grassland to riparian forest. Multivariate analysis is in progress to ascertain if keystone species or certain functional groups maximize long-term carbon storage. The conservation partnership, including most importantly its farmers and ranchers, have a fuller appreciation for what they have accomplished and are applying our results towards options to improve long-term agricultural viability.

Understanding long term carbon sequestration potential within coastal California streams provides a foundation of knowledge to maximize these ecosystem services. In doing so, the researchers are adding to the growing body of knowledge validating the outcomes from ecological restoration and conservation practices. The information is timely for policies and programs to mitigate greenhouse gas emissions and develop market driven incentives for carbon sequestration. It is also needed by restoration planners for optimizing revegetation project design and setting realistic objectives. Lastly, the funding community will utilize this research to guide the allocation of financial resources and document long term project effectiveness.

**Figure 1** - 30 year old stream restoration site (left) and aggrading soil in a floodplain plot (left) depicting layers of annual leaf litter and sediment deposition (right).

## Information Transfer/Outreach Program

### *Changes in Knowledge*

The above ground component of carbon sequestration has been well understood and justifies revegetation with woody species as a mitigation tool for climate change. However, research into the below ground storage is showing the importance of recalcitrant carbon forms to long-term sequestration. Understanding the recovery processes of riparian forest systems offers pragmatic applications to riparian buffer management and maximizing ecosystem services over multiple decades.

*Changes in Skill/Behavior/Practice*

The effectiveness of existing conservation practices to impact new societal concerns offers the feedback needed to improve and fine-tune approaches for maximizing environmental returns. Stream restoration can now target watershed locations and soil types that provide the greatest potential for long-term carbon sequestration. Landowners are prioritizing new sites for conservation and restoration projects in addition to organizing old ranch photos that document pre-project conditions of previously restored sites.

*Changes in Conditions*

The conceptual relationships between vegetation and ecosystem functions provides the foundation for impacting communities' approach to stewardship. Local Resource Conservation Districts are implementing water quality trading credits and grant funds are being leveraged to install new stream restoration projects. Policies encouraging ecosystem services have also utilized our results to validate how conservation practices have improved numerous ecological attributes and functions.

*Creating or strengthening partnerships with stakeholders*

The on-farm conservation partnership working across Marin, Sonoma, Napa and Mendocino counties has directly benefited by this project in addition to numerous local programs such as the Marin Carbon Project. For example, the Natural Resource Conservation Service, local Resource Conservation Districts, university researchers and private consultants are incorporating the concepts and preliminary results from this project into their assessments of conservation practice effectiveness and plans to compensate landowners for providing ecosystem services.

Our research finding are being disseminated on multiple levels to local partners, regional programs and international disciplines. The interest is very high in our results in part because of the critical reviews watershed restoration has received in recent years after spending over $2 billion dollars across the US. In addition, on-farm conservation practices are existing stewardship systems hungry for evidence supporting or refuting effectiveness to mitigate climate change that are reviewed by applied scientists in economics, agriculture, engineering and many others with international exposure.

## TECHNICAL REPORT

### An evaluation of soil carbon sequestered at stream restoration sites

The conservation practices related to stream restoration often target vegetation establishment. As sites mature over multiple decades, greater atmospheric carbon may be sequestered into the soil profile reducing available greenhouse gases.  This has been well documented for agroforestry systems by quantifying the carbon sequestered in living trees. Stream and river corridors on California's farms and ranches are hot spots for tree and woody species growth because of available water in the soil profile to support plant growth.  For example, in response to this potential more than 25 miles of streams have restored in Marin County since the 1960s.  By sampling soil and vegetation at restored sites, our project explored the interactions that riparian conservation has with soil carbon and nitrogen dynamics.

The temporal gradient of stream restoration project sites surveyed (n=42) ranged from 0 to 45 years since restoration was initiated. The robust sample size spanning multiple decades was critical to investigate multiple stages of forest development because we expected changes in soil chemistry may lag behind the rapid response in vegetation trajectories. Our trajectory analysis of soil carbon and nitrogen following 45 years of riparian forest succession used a retrospective, cross-sectional study design. Site selection focused on subwatershed locations where comparable stream reaches of different project age (i.e. years since project implementation) were adjacent to each other with similar soil and stream morphology.

Preliminary results of total, labile and recalcitrant forms of soil carbon are summarized by age group categories. Further analyses will utilize statistical modeling to compare linear and polynomial relationships with project age as a continuous variable.  Results indicate trends in below ground values of total carbon and labile forms with higher amounts in the upperbank landform and greater magnitude of change over time occurring in floodplain landforms (Figure 2). In contrast, preliminary analysis of the stable recalcitrant humic and fumic acid analyzed carbon components were variable in response to restoration project age.  Similarly, total soil nitrogen did not indicate a trajectory over time in this preliminary analysis (Figure 3).

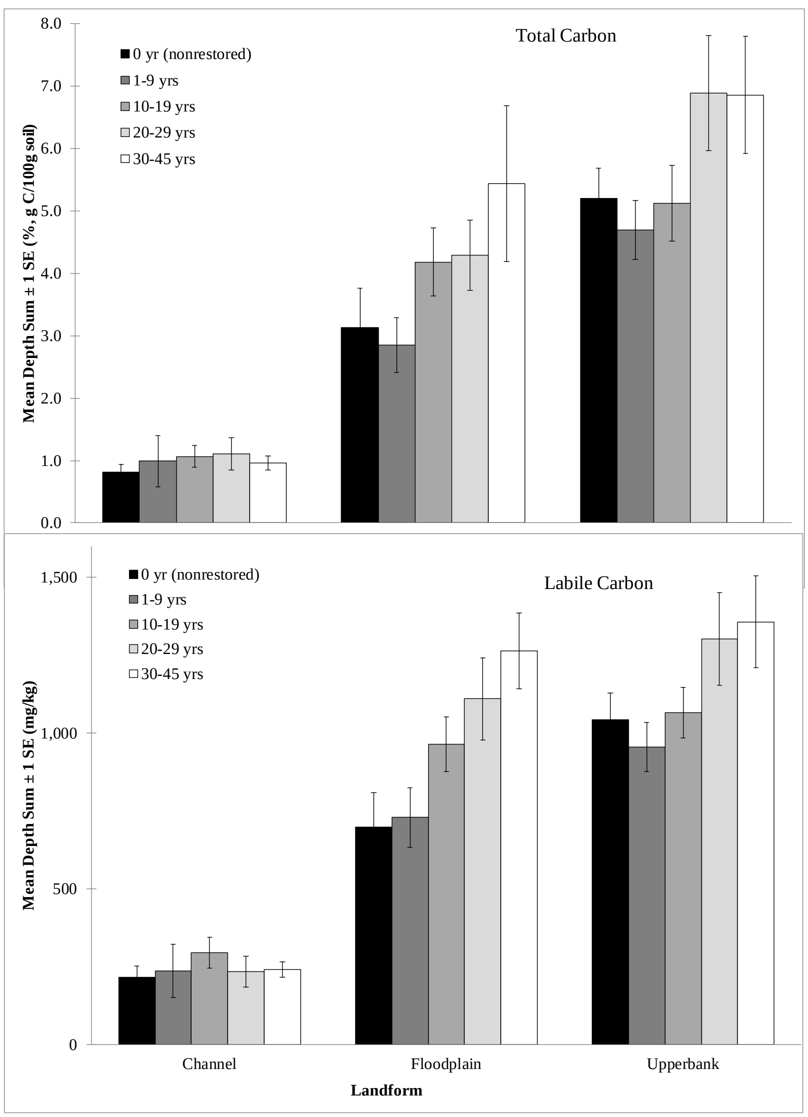


**Figure 2** - Carbon results from soil pits as a function of project age and landform class for total carbon (top) and labile carbon (bottom). Channel data is not directly comparable to floodplain or upperbank landforms because of the soil pit depth variation.

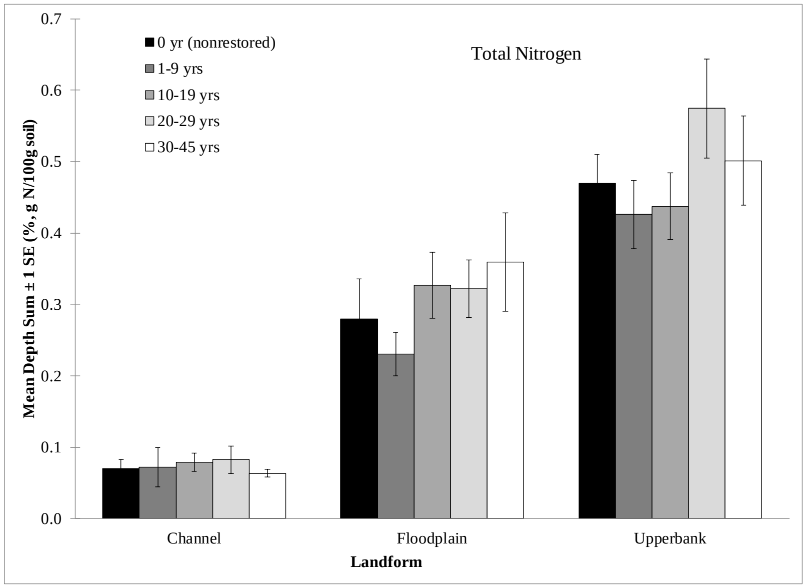
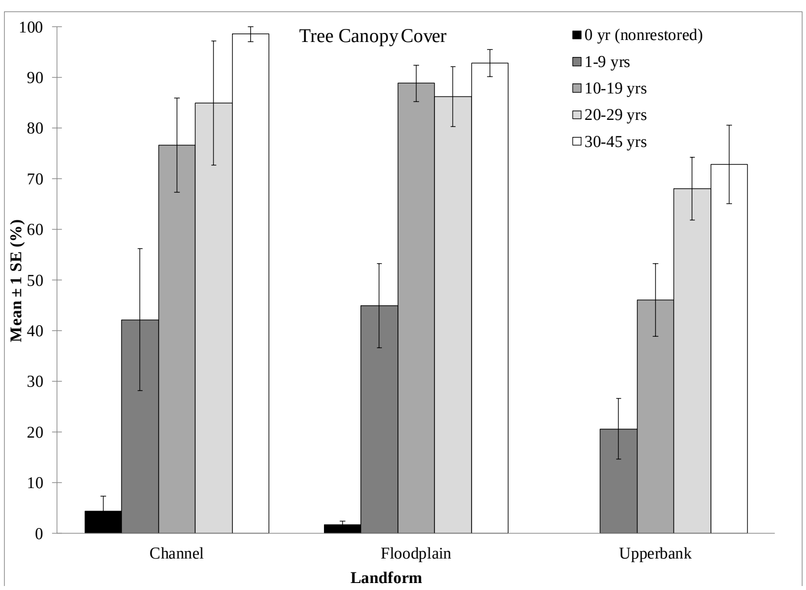



**Figure 3** - Total nitrogen as a function of project age group by landform. Channel data is not directly comparable to floodplain or upperbank landforms because of the variation in soil pit depth.

Vegetation trajectories observed were similar to previous research by the project team (i.e. Lennox et al. 2009). Restored steam sites rapidly developed tree canopy within 20 years while root abundance within soil pits continued to increase over 40 years (Figure 4). These attribute trajectories indicate the successional changes occurring at the restored sites surveyed as they transition from full-sun grassland to closed-canopy sites with increasing shrub and tree cover over time.  In contrast, the perennial herbaceous vegetation does not indicate a clear trajectory showing a temporary increase in cover that decrease back to non-restored values after 20 years. The annual species clearly reduce in cover over 40 years from 45 to 0 percent and 60 to less than five percent for floodplain and upperbank landforms, respectively.



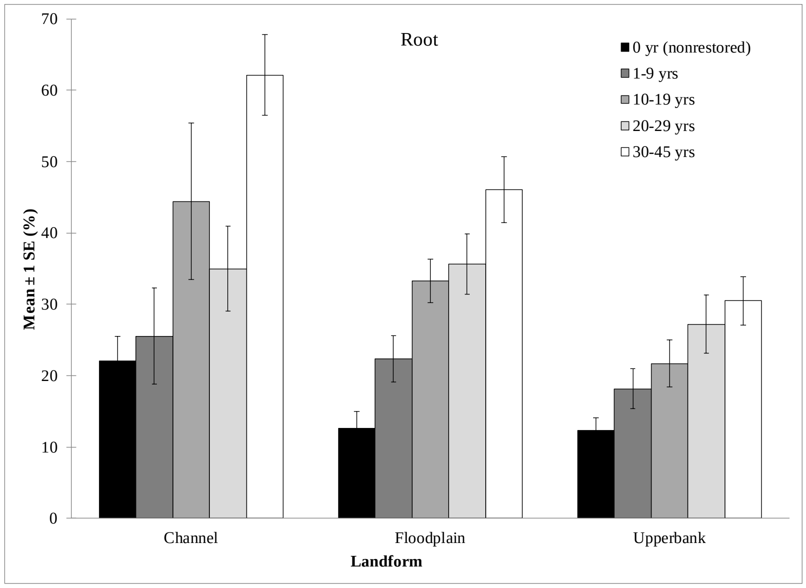



**Figure 4** - Vegetation attributes as a function of project age and landform for percent tree canopy cover (top) and roots in soil pit (bottom).

In summary, we documented the variation of carbon trajectories in streamside soil and vegetation from watershed restoration programs and the associated conservation practices. The information provides a data-driven quantification of actual outcomes for potential inclusion in market-based payments for ecosystem services and carbon or water quality credits. The conservation partnership, including most importantly its farmers and ranchers, have a fuller appreciation for what they have accomplished and greater options to improve long-term working landscape viability.