Climate Change Mitigation Potential of California’s Rangeland Ecosystems

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Rangelands are geographically expansive

30% of global land surface area
30-50% of US land area
23 million hectares in California
**Rangeland systems**: land on which plant cover (climax, sub-climax, or potential) is composed principally of grasses, grass-like plants, forbs or shrubs suitable for grazing and browsing, including both native and introduced plant species *(USDA, 2009a).*
There are approximately 23 million hectares of rangeland in California.
Livestock raised on rangelands are an important contributor to California’s agricultural economy.

Table 1. Economic value of rangeland-supported industries in California (USDA, 2009b).

<table>
<thead>
<tr>
<th>Livestock category</th>
<th>2002</th>
<th>2007</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle and calves (excludes dairy products, includes animals on feed)</td>
<td>1,582,334</td>
<td>2,536,571</td>
<td>2,068,412</td>
<td>2,825,125</td>
</tr>
<tr>
<td>Sheep, goats, and their products</td>
<td>52,418</td>
<td>71,890</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horses, ponies, mules, burros, and donkeys</td>
<td>32,397</td>
<td></td>
<td>72,433</td>
<td></td>
</tr>
</tbody>
</table>
Conceptual model of carbon and greenhouse gas dynamics on California rangelands

- Photosynthesis (CO₂ uptake)
- C in plant biomass
- Litterfall
- Root exudates and death
- Woody plants
- Manure decomposition
- Manure deposition
- Compaction
- Soil C and N
- Respiration (CO₂), enteric fermentation (CH₄, N₂O)
- CO₂, CH₄ and N₂O emitted, N volatilized
- Irrigation, N fertilization
- Increased N₂O production
- Warmer soil – stimulates decomposition
- Soil erosion – physical loss of C and N
- Overgrazing – decreased plant growth
- Plant growth
- Irrigation, N fertilization
- Irrigation, N fertilization
Plant production (a.k.a. forage production) is the primary mechanism for carbon sequestration in rangelands.
Net Ecosystem Exchange
-1.4 to +1.9 Mg C ha\(^{-1}\) y\(^{-1}\)

0.2-70 kg CH\(_4\) head\(^{-1}\) y\(^{-1}\)
Up to 175 g N\(_2\)O head\(^{-1}\) y\(^{-1}\)

30-230 Mg C ha\(^{-1}\)
Annual grasses and sensitive to climate
Rainfall in California is naturally highly variable and is likely to get more variable in the future.
Eddy covariance provides an estimate of net ecosystem exchange of CO$_2$
These data highlight the sensitivity of rangeland C fluxes to rainfall.
The more rainfall, the more likely these ecosystems will be a carbon sink.
Annual grasslands may be losing carbon under current management and conditions.
Can rangeland management help mitigate climate change?
Grasslands store one-third of the world’s soil carbon

Grasses allocate a large portion of photosynthate belowground to roots
California Rangelands:
Wide range in soil carbon pool size
High soil carbon storage capacity

From Silver et al. 2010
We can detect changes in rangeland soil carbon pools with management.

Soils sampled from 35 grazed rangeland sites in Marin and Sonoma Counties.

From Silver et al. In prep.
California Rangelands and Carbon Sequestration

23 million hectares of rangeland statewide
Assume 50% available for C sequestration projects

Units:
Mg = Metric ton
MMT= Million metric tons
CO₂e = CO₂ equivalents

Emissions data: CA GHG Inventory 2010
California Rangelands and Carbon Sequestration

23 million hectares of rangeland statewide
Assume 50% available for C sequestration projects

At a rate of 0.5 Mg C ha\(^{-1}\) y\(^{-1}\)
= 21 MMT CO\(_2\)e/y

Units:
Mg = Metric ton
MMT= Million metric tons
CO\(_2\)e = CO\(_2\) equivalents

Emissions data: CA GHG Inventory 2010
California Rangelands and Carbon Sequestration

23 million hectares of rangeland statewide
Assume 50% available for C sequestration projects

At a rate of 0.5 Mg C ha\(^{-1}\) y\(^{-1}\)
= 21 MMT CO\(_2\)e/y

At a rate of 1 Mg C ha\(^{-1}\) y\(^{-1}\)
= 42 MMT CO\(_2\)e/y

Units:
Mg = Metric ton
MMT = Million metric tons
CO\(_2\)e = CO\(_2\) equivalents

Emissions data: CA GHG Inventory 2010
At a rate of 0.5 Mg C ha\(^{-1}\) y\(^{-1}\) = 21 MMT CO\(_2\)e y\(^{-1}\)

At a rate of 1 Mg C ha\(^{-1}\) y\(^{-1}\) = 42 MMT CO\(_2\)e y\(^{-1}\)

• Livestock
  \(\sim 15\) MMT CO\(_2\)e y\(^{-1}\)

• Commercial/residential
  \(\sim 42\) MMT CO\(_2\)e y\(^{-1}\)

• Electrical generation
  \(\sim 112\) MMT CO\(_2\)e y\(^{-1}\)

Emissions data: CA GHG Inventory 2010
The potential for grazing to increase carbon sequestration
Rangeland soils appear to be adapted to grazing (not overgrazing)

![Graph showing soil C content (Mg ha⁻¹) for grazed and not grazed conditions. The graph indicates higher soil C content in grazed conditions.]

Silver et al. 2010
Improved grazing practices can sequester soil carbon
Carbon sequestration potential from improved grazing practices:

1.3 to 3.2 Mg CO$_2$e ha$^{-1}$ y$^{-1}$ (Eagle et al. 2011)

*Scaled to 50% of California rangelands: 15-37 Tg CO$_2$e y$^{-1}$*

1 Mg C ha$^{-1}$ y$^{-1}$ (Conant et al. 2001)

*Scaled to 50% of California rangelands: 42 Tg CO$_2$e y$^{-1}$*
Organic matter amendments increased soil carbon by 50 Mg C ha$^{-1}$ in the top meter of soil

Analysis of 35 fields (1050 samples) from Marin and Sonoma Counties

From Silver et al. In prep
Manure applications have the potential to increase nitrous oxide emissions
Organic matter amendments to rangelands can increase carbon sequestration
Plant production (aka forage) has increased every year following a one-time compost application.

Aboveground Net Primary Production (g m\(^{-2}\))

<table>
<thead>
<tr>
<th>Year</th>
<th>Control</th>
<th>Compost</th>
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<tbody>
<tr>
<td>2009</td>
<td>450</td>
<td>650</td>
</tr>
<tr>
<td>2010</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td>2011</td>
<td>550</td>
<td>850</td>
</tr>
<tr>
<td>2012</td>
<td>400</td>
<td>600</td>
</tr>
</tbody>
</table>

Ryals and Silver 2012, Ryals and Silver in prep.
Net Ecosystem Production

Compost increase net C storage by 0.5 to 1.2 Mg C ha\(^{-1}\) y\(^{-1}\)

Partitioning of Total Soil Respiration (% Rh)

- 30%
- 50%
- 60%

Valley

Coastal

Ryals and Silver 2012 Ecological Application
Organic matter amendments increase soil C pools

![Bar graph showing the change in soil organic carbon (g C/m²) from pre-treatment to 2009, 2010, and 2011. The graph indicates a significant increase in 2009 and 2010 compared to pre-treatment and 2011.](image)
Compost added an average of 3 Mg C/ha to the soil over three years.
Organic matter amendments can be stored in pools with long turnover times

Analysis of $^{14}$C in soil carbon fractions

Silver et al. in prep.
Model results suggest that C persists in soil for > 100 years

Ryals et al. in prep
Scalability
Scalability

One quarter of the rangeland area in California:

\[ = 23 \text{ Tg of CO}_2\text{e y}^{-1} \text{ (without including compost C)} \]

\[ = 337 \text{ Tg of CO}_2\text{e y}^{-1} \text{ (with compost C additions)} \]
Availability of compost

Potential compost production: 27 to 33 MMT yr\(^{-1}\)

Enough to reapply to 25% of California’s rangelands every 17-40 years
Life cycle assessment suggests much higher climate change mitigation potential

Applied to 5% of CA Rangeland

Global warming potential (MMT CO$_2$e)

- Emissions from commercial sector (2008)
- Emissions from Ag and forestry sector (2008)

Redrawn from DeLonge et al. 2013
Gaps in knowledge

Compost quality and greenhouse gas emissions

Arid and semi-arid systems
Key Findings:

California’s rangelands are extensive and diverse. Even small rates of C sequestration and emissions reduction across these landscapes have the potential to make significant contributions to the State’s climate change mitigation goals.

Differences in the life history strategy of annual grasslands compared to perennial systems are likely to lead to significant differences in management outcomes for climate change mitigation.

A large proportion of California’s rangelands are likely to be degraded with regard to soil C pools, and thus have significant potential for increased C sequestration in soils through management.

Organic matter amendments, and particularly composted organic wastes, are a viable strategy for C sequestration on rangelands in California’s Mediterranean climate. This management approach has the added benefit of greenhouse mitigation in other sectors (i.e. waste management, confined livestock operations).

Well managed, rotational grazing is not likely to decrease soil C pools on rangelands, and could increase C storage. Identification and testing of sustainable grazing practices will be particularly important to meeting growing demands for meat and dairy products with population growth in the State.

Climate change is posing new challenges to rangeland management in California.
Research Priorities

- Carbon and greenhouse gas dynamics of California’s diverse rangelands
- Grazing management to reduce greenhouse gas emissions and increase C storage.
- The use of organic matter amendments for climate change mitigation
- The interactions of grazing and fire management
- Modeling the effects of management alternatives (including those outlined above) under changing climate