Peat Accumulation in Mountain Fens of the Western USA

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Fen Definition (USA)

Fens are wetlands:
1) Primarily supported by groundwater (=GDEs);
2) Have organic soils meeting USDA NRCS definition of a histosol or a histic epipedon in at least some part of the contiguous wetland.

Hydrologic Regime:
Saturated for >30 days / year

Horizon Thickness:
Histosol (or Histel):
≥ 40 cm of the upper 80 cm composed of organic soil material. Organic soil materials are comprised of ≥ 12-18 % of organic-carbon contents:

1) Peat (fibric soil material)- Undecomposed or weakly decomposed organic material; plant remains are distinct and identifiable;

2) Mucky peat (hemic soil material)- Moderately to well-decomposed organic material; plant remains recognizable but may be indistinct & difficult to identify;

3) Muck (sapric soil material) – Strongly to completely decomposed organic material; plant remains indistinct to unrecognizable.

Examples of peat – fibric soil material

Drepanoclados moss fibers

Sedge roots & rhizomes

Photos by D. Cooper

Photo by D. D’Amore
Examples of peat – hemic soil material

Willow roots; sedge roots & rhizomes + some hemic soil material

Photo by D. Cooper
Composition of Soil Material:

Organic soil materials are comprised of ≥ 12-18% of organic-carbon contents, depending on clay content.

- 12% organic carbon if 0% clay;
- ≥ 18% organic carbon if ≥ 60% clay;
- 12% + (0.1* % clay): so if soil contains 20% clay, need 14% organic carbon.

What is “peat”? Different cut-offs for:

% organic matter (OM)
% mineral (ash content)

Global Distribution of Peatlands
Ecosystem Services of Fens

Support species (many rare species), including plants, waterfowl, amphibians, invertebrates; high proportion of regional biodiversity.

Peat profiles are archives, containing records of temporal changes in microfossils (e.g. pollen, spores) & macrofossils (plant parts, wood, animal remains). Provide insights into past climates and peatland development.

Water storage; fens can behave hydrologically like unregulated, shallow reservoirs; can influence water, sediment and nutrient movement in watersheds.

Carbon storage; peat contains 5-65% carbon; potentially huge belowground C stores. Assessment of carbon stocks on NFS lands mandated by the 2012 Planning Rule.
Peatland Studies/Inventories in Mountains of the Western USA
Photos by D. Cooper
### Inventory Results: National Forests

<table>
<thead>
<tr>
<th></th>
<th>Medicine Bow NF, WY</th>
<th>Bighorn NF, WY</th>
<th>Grand Mesa &amp; Gunnison NFs, CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Wetlands Visited</td>
<td>104</td>
<td>168</td>
<td>308</td>
</tr>
<tr>
<td>Peat &lt; 20 cm (not fens)</td>
<td>23</td>
<td>85</td>
<td>144</td>
</tr>
<tr>
<td>Peat 20 - 40 cm</td>
<td>11</td>
<td>36</td>
<td>11</td>
</tr>
<tr>
<td>Peat ≥ 40 cm</td>
<td>70</td>
<td>47</td>
<td>153</td>
</tr>
</tbody>
</table>

Peat < 20 cm (not fens) includes dry meadows and upland vegetation.

Peat ≥ 40 cm includes peat bogs and fens.
Mountain Fens: Small and Numerous


Sierra Nevada, CA
n=79 fens
Range: 0.0045-20 ha
Median: 0.17 ha

San Juan Mtns., CO
n=624 fens
Range: 0.2 to 20.5 ha
Mean: 1.2 ha
Median: 0.8 ha
(Chimner et al. 2010. Wetlands 30: 763-771.)
Occurrence of Mountain Peatlands

San Juan Mountains, CO
Peatlands occur:
- Over wide elevational range
- In basins to steep hillslopes
- Over wide range of pH

Challenges of Measuring Peat Thickness

1) Difficult to extract a representative core (augers);
2) For deeper peat beds, rarely reach maximum peat depth;
3) Natural variability; variable peat thickness, depending on location of auger core;
4) Profiles can be altered by land use (grazing, water extraction);
5) Probing can provide good estimates in some fens (Chimner et al. 2014).
Estimation of Peat Thickness: Limits of Probing

Stratigraphy of augered cores at Dry Fen & Johnson Fen, Fremont-Winema NF, OR

Initiation of fen development linked to eruption of Mt. Mazama (7700 years ago); Variable peat depth, depending on location of auger core AND fen location; Probing could not differentiate peat from pumice.

High variability within & between wetland-fen complexes
- Vegetation
- Subsurface conditions
- Peat thickness

<table>
<thead>
<tr>
<th>CT</th>
<th>%</th>
<th>Dominant Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25</td>
<td>ELAC-DREPA2</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
<td>SAPL2</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>CAUT-CAAQ</td>
</tr>
<tr>
<td>D</td>
<td>5</td>
<td>ABBI3-SAPL2-DECE</td>
</tr>
<tr>
<td>E</td>
<td>5</td>
<td>ELAC-DREPA3-CAUT</td>
</tr>
<tr>
<td>F</td>
<td>5</td>
<td>CAAQ-ELAC-DREPA3</td>
</tr>
<tr>
<td>G</td>
<td>10</td>
<td>CACA4-VETE4-SETR</td>
</tr>
<tr>
<td>H</td>
<td>10</td>
<td>CAJO-CACA4-CAPR5-CAAQ</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
<td>DECE-CASA10</td>
</tr>
</tbody>
</table>

Fen-wetland complex, Grand Mesa, CO
Mineral Soil Material Input from Hillslopes
Methods: Augering Soils

Methods: Describing Soils

By Horizon:
- peat type
- Von Post value
- % rock
- % roots
- matrix color
- redoxi-morphic features
Methods: Ashing Soil Samples

Soil Processing:
1. Stored cold;
2. Dried at 105°C for \(\approx 48\) hours;
3. Ground using mortar & pestle;
4. Ashed in muffle furnace for minimum of 3 hrs;
5. % OM calculated as loss on ignition (LOI).

Relation between % organic matter and % carbon (n=107; Chimner, unpublished data)

Fraser Experimental Forest, CO
Toeslope wetland that drains directly to stream (=GDE);
Elevation 2850 m;
~ 14 % of wetlands sampled ≠ fens.

How does this wetland differ in function?
Percent Organic Matter with Depth

<table>
<thead>
<tr>
<th>Depth</th>
<th>n</th>
<th>Median %OM/ %C</th>
<th>Range %OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>60</td>
<td>70/ 35</td>
<td>31-100</td>
</tr>
<tr>
<td>10-20</td>
<td>60</td>
<td>66/ 33</td>
<td>31-96</td>
</tr>
<tr>
<td>20-30</td>
<td>60</td>
<td>65/ 32</td>
<td>30-96</td>
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<tr>
<td>30-40</td>
<td>58</td>
<td>68/ 34</td>
<td>31-91</td>
</tr>
<tr>
<td>40-50</td>
<td>48</td>
<td>48/ 24</td>
<td>5-94</td>
</tr>
<tr>
<td>50-60</td>
<td>46</td>
<td>37/ 18</td>
<td>4-87</td>
</tr>
<tr>
<td>60-70</td>
<td>45</td>
<td>22/ 11</td>
<td>3-85</td>
</tr>
<tr>
<td>70-80</td>
<td>45</td>
<td>22/ 11</td>
<td>3-81</td>
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<tr>
<td>80-90</td>
<td>44</td>
<td>16/ 8</td>
<td>2-78</td>
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<tr>
<td>90-100</td>
<td>34</td>
<td>14/ 7</td>
<td>2-76</td>
</tr>
<tr>
<td>100-110</td>
<td>29</td>
<td>13/ 6</td>
<td>2-72</td>
</tr>
<tr>
<td>110-120</td>
<td>22</td>
<td>12/ 6</td>
<td>2-72</td>
</tr>
<tr>
<td>120-130</td>
<td>17</td>
<td>8/ 4</td>
<td>2-78</td>
</tr>
<tr>
<td>130-140</td>
<td>13</td>
<td>8/ 4</td>
<td>2-78</td>
</tr>
<tr>
<td>140-150</td>
<td>11</td>
<td>6/ 3</td>
<td>0-78</td>
</tr>
<tr>
<td>&gt;150</td>
<td>10</td>
<td>6/ 3</td>
<td>2-82</td>
</tr>
</tbody>
</table>
Variation in Peat Thickness

San Juan Mountains, CO

Elevation: 2690 – 3870 m;
Surveys at 182 fens; estimated 2000 fens
in San Juan Mountains.

Elk Mountains, West Elk Mountains, Grand Mesa, CO

Elevation: 2530 – 3810 m;
Surveys at 147 fens; estimated 1700 fens on Grand Mesa, Uncompahgre, & Gunnison National Forests


Variation in Peat Thickness

Sierra Nevada, CA
n=79 fens

A) Increase in peat thickness with increase in catchment area

B) Thickest peat bodies occur on gentlest slopes

C) Thicker peat bodies have higher organic matter content

Gunnison NF, CO
n=128 fens

Weak relationship:
slight increase in
depth with
elevation;

Deepest peat at
mid-elevations?

Johnston et al. 2012. Inventory of fens in a large landscape of west-central Colorado;
Grand Mesa, Uncompahgre, and Gunnison National Forests. 198 pages.
Peat Thickness by Geomorphic Landform

- **Toeslope Fens**: 
  - $n=282$
  - Median = 100 cm

- **Basin Fens**: 
  - $n=147$
  - Median = 115 cm

- **Fens on Steep Slopes**: 
  - $n=41$
  - Median = 80 cm

- **Spring Mound Fens**: 
  - $n=16$
  - Median = 120 cm

Peat Thickness by Underlying Lithology

- **Rhyolite**
  - $n = 267$
  - Median = 100 cm

- **Glacial Till**
  - $n = 114$
  - Median = 120 cm

- **Andesite**
  - $n = 27$
  - Median = 100 cm

- **Geothermal**
  - $n = 33$
  - Median = 165 cm

- **Basalt**
  - $n = 35$
  - Median = 120 cm

Relevance of Peat Thickness

**Carbon storage:** contributes to assignment of conservation and restoration priorities

**Origin and development of fens:** Provide insights into past climates and peatland development.

**Deep peat profiles:** Provide paleo-ecological archives for surrounding region.

**Water storage:** deeper peat beds can potentially store more water
## Age of Colorado Fens

<table>
<thead>
<tr>
<th>Location</th>
<th>Elevation (m)</th>
<th>Basal Date YBP</th>
<th>Peat Depth (m)</th>
<th>Accumulation Rate (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>South Park, CO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sacramento Creek (Cooper 1990b)</td>
<td>3,100</td>
<td>9,820 ± 150</td>
<td>2.13</td>
<td>0.22</td>
</tr>
<tr>
<td>Carpenter’s Fen (Cooper 1990b)</td>
<td>3,150</td>
<td>9,280 ± 180</td>
<td>3.20</td>
<td>0.34</td>
</tr>
<tr>
<td>McMaster’s Fen (Cooper 1990b)</td>
<td>3,175</td>
<td>9,220 ± 110</td>
<td>3.33</td>
<td>0.36</td>
</tr>
<tr>
<td>East Lost Park Fen (Cooper 1990b)</td>
<td>3,100</td>
<td>10,080 ± 150</td>
<td>2.64</td>
<td>0.26</td>
</tr>
<tr>
<td>High Creek Windmill Fen (Cooper 1990b)</td>
<td>3,010</td>
<td>8,270 ± 140</td>
<td>0.90</td>
<td>0.11</td>
</tr>
<tr>
<td>Lost Park Fen (Vierling 1992)</td>
<td>3,079</td>
<td>11,820 ± 100</td>
<td>3.30</td>
<td>0.28</td>
</tr>
<tr>
<td><strong>Gore Range, CO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dome Creek Meadow (Feiler and Anderson 1997)</td>
<td>3,146</td>
<td>7,800 ± 100</td>
<td>3.62</td>
<td>0.46</td>
</tr>
<tr>
<td>Buffalo Pass (Madole 1980)</td>
<td>3,146</td>
<td>7,730 ± 250</td>
<td>1.93</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Front Range, CO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Mt. Pond (Cooper 1990)</td>
<td>2,865</td>
<td>11,820 ± 170</td>
<td>1.50</td>
<td>0.13</td>
</tr>
<tr>
<td>Big Meadows (Cooper 1990)</td>
<td>2,865</td>
<td>11,230 ± 170</td>
<td>1.50</td>
<td>0.13</td>
</tr>
<tr>
<td>Winding River Kettle (Madole 1976)</td>
<td>2,640</td>
<td>10,320 ± 200</td>
<td>1.75</td>
<td>0.28</td>
</tr>
<tr>
<td>Silver Lake Bog (Pennak 1963)</td>
<td>2,979</td>
<td>6,190 ± 300</td>
<td>1.25</td>
<td>0.51</td>
</tr>
<tr>
<td>Albion Bog (Pennak 1963)</td>
<td>3,247</td>
<td>2,470 ± 200</td>
<td>1.90</td>
<td>0.18</td>
</tr>
<tr>
<td>Caribou Fen (Benedict and Maher, unpublished data)</td>
<td>3,400</td>
<td>10,500 ± 70</td>
<td>1.32</td>
<td>0.26</td>
</tr>
<tr>
<td>Zapf’s Fen (Benedict and Maher, unpublished data)</td>
<td>2,725</td>
<td>5,000 ± 140</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>La Poudre Pass (Madole 1980)</td>
<td>3,103</td>
<td>9,800 ± 400</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>San Juan Mountains, CO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eureka Gulch Bog (Carrara et al. 1991)</td>
<td>3,665</td>
<td>6,180 ± 160</td>
<td>2.40</td>
<td>0.29</td>
</tr>
<tr>
<td>California Gulch Bog (Carrara et al. 1991)</td>
<td>3,165</td>
<td>7,860 ± 40</td>
<td>1.55</td>
<td>0.20</td>
</tr>
<tr>
<td>Placer Gulch Bog (Carrara et al. 1991)</td>
<td>3,600</td>
<td>8,790 ± 260</td>
<td>0.85</td>
<td>0.10</td>
</tr>
<tr>
<td>Picayne Gulch Bog (Carrara et al. 1991)</td>
<td>3,750</td>
<td>8,350 ± 250</td>
<td>1.30</td>
<td>0.16</td>
</tr>
<tr>
<td>Hurricane Basin Bog (Carrara et al. 1991)</td>
<td>3,660</td>
<td>8,420 ± 750</td>
<td>2.05</td>
<td>0.24</td>
</tr>
<tr>
<td>Cottongrass Fen (Cooper – Telluride)</td>
<td>3600</td>
<td>10,300</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td><strong>Gunnison County, CO</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red Lady Fen (Fall 1997)</td>
<td>3,350</td>
<td>4,675 ± 155</td>
<td>0.95</td>
<td>0.20</td>
</tr>
<tr>
<td>Red Well (Fall 1997)</td>
<td>3,290</td>
<td>2,805 ± 160</td>
<td>1.00</td>
<td>0.36</td>
</tr>
<tr>
<td>Iron Bog (Fall 1997)</td>
<td>2,290</td>
<td>8,260 ± 220</td>
<td>2.20</td>
<td>0.27</td>
</tr>
<tr>
<td>Splains Gulch Meadow (Fall 1997)</td>
<td>3,150</td>
<td>8,560 ± 600</td>
<td>2.00</td>
<td>0.23</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
<td>8,190</td>
<td>1.99</td>
</tr>
</tbody>
</table>
More Questions (and next steps):

What is the correct thickness for identifying fens? How do we manage ‘shallow-peat’ wetlands?

What are the key drivers in regulating peat thickness? At local, regional, & larger scales?

How does water storage change with increasing peat thickness? In fens in different geomorphic/landscape positions?

Differences in C storage in fens located in different geomorphic positions?
THANKS to collaborators & field crews!

Wikipedia:
The word "fen" is derived from Old Greek *bogg Old Norse *fen (quagmire), Gothic *fani (mud), Dutch *ven, German Fenn (fen, bog), from Proto-Germanic *fanja. Cognates include Gothic (fani), Old Frisian (fenne), Dutch (veen, ven) and German (Fenn(e), Venn, Vehn, Feen, Fehn).[11]