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Comment on "Has fire suppression increased the amount of carbon stored in western U.S. forests?" by A. W. Fellows and M. L. Goulden

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[1] *Fellows and Goulden* [2008, hereafter F-G] have recently claimed that fire-suppression, independent of logging, has brought about a decrease in live, aboveground tree carbon via increased mortality of large trees in western U.S. forests over a 60 year span. However the study, restricted for unspecified reasons to part of California, has several problems that I believe collectively invalidate their principal conclusion. I detail these here in increasing order of perceived importance.

[2] Beginning with the interpretation of the literature, the suppression-induced carbon sink rates of 2.3 Mg/ha/yr contested by F-G [from *Houghton et al.*, 1999], apply only to the highly fire-prone western ponderosa pine woodlands, as stated by *Houghton et al.* [1999, Table 2]. *Houghton et al.* [1999] were also clear that their estimate was [*Houghton et al.*, 1999, p. 575] "an upper limit for the sink strength of U.S. ecosystems." Ponderosa pine forests occur generally at low to mid elevations, but F-G analyzed data only from California wilderness areas, which on the whole occupy the higher elevations and contain large areas of other forest types, such as true fir forests and subalpine woodlands [*Barbour and Minnich*, 2000]. A significant fraction of their plots were from above 1830 m (6000 ft), or even 2438 m (8000 ft), beyond the primary range of ponderosa pine forests in California. The effects of fire suppression in western US forests are well known to vary strongly with environment and forest type [e.g., *Agee*, 1993].

[3] Both the 1930s (Vegetation Type Mapping Project (VTM)) and 1990s (Forest Inventory Analysis (FIA)) data reportedly used by F-G are potentially problematic, based on specific knowledge of their purposes and methods, and the claims made by F-G [*Bouldin*, 1999; *Keeley*, 2004; *Waddell and Hiserote*, 2005] (see also United States Forest Service, Forest Inventory and Analysis National Program, data and tools, http://fia.fs.fed.us/tools-data/default.asp, 2009, PNW-FIA data, http://www.fs.fed.us/pnw/fia/publications/data/index.shtml#1a, 2009, and Pacific Southwest Region, Remote Sensing Laboratory Vegetation Inventory Data, http://www.fs.fed.us/r5/rsl/projects/inventory/designs.shtml, 2009 and VTM, http://vtm.berkeley.edu/, 2009). Regarding the FIA data, F-G indicate in their Table 1 that they use 140 wilderness FIA plots sampled between 1990 and 1994 in northern California and/or the Sierra Nevada. The only FIA plots installed in wilderness areas in that region and at that time were in the Sierra Nevada and far northwestern California. Since almost no VTM plots were collected in the latter for the necessary comparisons, this implies that all 140 FIA plots must have been located in eastern northern California (ENC: Sierra-Nevada, Cascades and Modoc Plateau), but this exceeds the number ($\sim$106) actually collected there. Of these, 87 (83%) were located on the Inyo National Forest, an area dominated by cold and/or dry alpine/subalpine or woodland ecosystems above 2438 m (8000 ft) elevation. Conversely, most VTM plots in ENC were established on the much more productive west side of the Sierra Nevada (VTM, http://vtm.berkeley.edu/, 2009). It would not be at all surprising to find an apparent decrease in carbon if this was in fact the comparison made. If, on the other hand, the authors only used that minority of VTM plots from the colder Inyo NF high elevations, one could well question how this represents the effect of fire reduction on carbon accrual in California forests as a whole, much less the entire western United States.

[4] There is also a definitional issue relating to the plot selection criterion. The authors implicitly defined forested areas as those having a minimum of 1 tree per plot ($\sim$12 trees/ha for the 0.08 ha VTM plots). Given that much of the California landscape was responding to fire reduction policies over the 20th century [*Skinner and Chang*, 1996], including upper montane forests where the evidence of catastrophic fires in the 19th century is strong [e.g., *Leiberg*, 1902, pp. 37, 41, 106, and 117], the area meeting this criterion may well have increased over time. This would affect both the area of the landscape sampled, and the demographic character of the plots included in the sample, changes which must be accounted for in region-wide estimates of forest carbon dynamics.

[5] Relevant empirical studies bearing on the topic are scarce, as it is not trivial to separate out fire suppression effects from confounding factors such as logging, climate change and other human impacts. However, the available studies do not support F-G's conclusion. Although climate change [e.g., *Pierce et al.*, 2008] is indeed likely causing increased tree mortality in old growth forests in the western United States in recent decades [*van Mantgem et al.*, 2009] this does not mean that fire reduction over the last 100 to 150 years has not had a much greater, opposing carbon impact. For example, *Leiberg* [1902], in a thorough early survey, noting the strong effect of fire on tree demography throughout the northern Sierra Nevada, stated [*Leiberg*, 1902, p. 85] "...this region does not contain more than 35 percent of the timber it is capable of carrying, and the deficiency is wholly due to forest fires...", and *Gruell* [2001] has provided long-term photographic evidence of both forest expansion and increased density and canopy cover in many locations in the Sierra since the 19th century.

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North et al. [2007] report an increase in timber volume in the southern Sierra despite a probable drop in large tree density since 1865, while *Ansley and Battles* [1998] have documented a 15 percent increase in forest basal area (the total cross sectional area of tree stems) over the latter 20th century in an unlogged northern Sierra Nevada forest. Elsewhere, *Tilman et al.* [2000] report a ca. 3.1 Mg C ha^{-1} yr^{-1} increase in aboveground tree carbon over 31 years in an experimentally manipulated oak savanna in Minnesota, although these changes will likely have less relevance than studies in California old growth. For comparison, I estimate an increase of ca.1.25 Mg C ha^{-1} yr^{-1} over 93 years in ponderosa pine and mixed conifer forests of Yosemite National Park [*Bouldin*, 2008a], about 40 percent of Tilman et al.'s annual rate, but the Yosemite starting biomass was four to five times higher.

[6] Perhaps most importantly, the possibility that the 1930s VTM data were a biased sample of forest conditions at the time must be carefully evaluated. (The FIA data are less problematic in this regard because they are collected under a statistically rigorous sampling design that minimizes bias). The authors state that the VTM data constituted a "forest inventory" this statement is incorrect. Rather, the VTM plot data were collected as part of a statewide vegetation mapping project (VTM, http://vtm.berkeley.edu/, 2009), to help characterize mapped units for their community composition, not to estimate timber volume or biomass. This is apparent from the fact that the largest VTM diameter class is open ended, which would never be the case if timber volume estimates were the goal. It is thus entirely possible that VTM plots were biased with respect to forest structural conditions, given their location in montane, fire-influenced environments, where vegetation structure often varies radically over short distances. If the goal of the VTM effort was to characterize late successional, or "potential", natural vegetation (as it likely was, see below), then such bias is almost guaranteed.

[7] Both published data, and recent analyses of unpublished data strongly suggest that VTM plot are in fact highly biased. For example, *Weeks et al.* [1942] provide demographic summaries of 555 0.08 ha plots in old growth forests in the northern Sierra Nevada. Sampling at the same time as the VTM project, these plots were gridded 0.4 km apart along parallel lines 3.2 km apart, making them minimally biased with respect to vegetation conditions within the 645 km^2 area they comprise. Comparison of these data with VTM data from the same VTM data in the same area (the Bidwell Bar and northern half of the Downieville 30 minute quadrangles, n = 452), shows large differences in size class distributions. Densities of large (>60 cm dbh) VTM trees are 2.6 times those of Weeks et al.'s values (treeless VTM plots excluded as per F-G). Including the differences in smaller trees gives an estimated VTM live tree aboveground carbon bias factor of 2.09. This is a conservative value since not all VTM plots in this non-wilderness location are assured of having been uncut at the time, as they would be in F-G's sample.

[8] These results are supported by comparisons of a set of 91 VTM plots with a co-located sample of 670 large timber inventory plots (mean sampling date, 1922), in two largely to entirely uncut ponderosa pine and mixed conifer landscapes of the Sierra Nevada (J. Bouldin, unpublished data, 2008). Each plot was 40 m by 400 m (1.6 ha) representing a 10 percent sample spanning a 16 ha parcel, and spanning it, either through the middle or at the 1/3 and 2/3 distance points along a side. Results show that mean large tree densities in VTM plots were 2.8 times the timber inventory plot means, and small trees were also over-estimated, leading to an aboveground tree carbon bias factor of 2.7. Applying these two bias estimates to F-G's reported results (F-G, Table 1; northern California and Sierra Nevada area), live tree carbon would more likely have ranged from 51 to 66 MgC/ha in the 1930s, compared to their reported value of 138. The corresponding carbon increases over the $\sim$60 years would range from 34 to 49 MgC/ha, rather than their reported decrease of 38 MgC/ha, a change equal or greater magnitude, but opposite in sign.

[9] These evaluations support statements to me in 1997 by one of the VTM field workers (the now deceased Daniel Axelrod, UC Davis Professor Emeritus of Botany), that the sampling locations were subjectively chosen to represent mature forest conditions, not to produce unbiased estimates of landscape scale forest structures. The authors, and others who have used the data, are not faulted for not knowing of this bias, since the data of *Weeks et al.* [1942], though published, are somewhat obscure. Nevertheless, these results indicate that VTM data cannot be considered an unbiased estimate of forest structure and carbon in the 1930s, directly answering *Keeley*'s [2004] rhetorical question, at least for such variables.

[10] Finally, even if the large tree declines reported by F-G were correct, a full aboveground carbon accounting must make some attempt to estimate detrital carbon, especially in snags and down logs, which can be substantial where trees reach such large sizes. Since the proposed mechanism for the carbon decline is the death of large trees in response to increasing competitive stress, this stress—and the consequent mortality—should increase with time, and be further compounded by recent climatic changes [e.g., *Pierce et al.*, 2008; *van Mantgem et al.*, 2009]. Consequently, there should be many large snags and down logs in early stages of decomposition that need to be accounted for, not to mention forest floor debris, shrub biomass, etc. The authors' contention that much of their estimated live tree carbon decline has already decomposed is not supported by either empirical data or reasonable expectation.

[11] The analysis of historical forest data sets has many potential pitfalls [*Bourdo*, 1956; *Bouldin*, 2008b], because the data are often not well suited for the purposes for which they are later used. I believe that is the case here. The suite of available evidence indicates that the data used by Fellows and Goulden is inappropriate to the task they have set, and that fire reduction has very likely increased, not decreased, live tree carbon in fire prone forests. Catastrophic fires may turn these forests into atmospheric carbon sources in the future, but to date, fire suppression has helped slow the rate of atmospheric carbon dioxide increase over the last 150 years.

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