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Estimating down deadwood from FIA forest inventory variables in Maine

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Abstract

Down deadwood (DDW) is a carbon component important in the function and structure of forest ecosystems, but estimating DDW is problematic because these data are not widely available in forest inventory databases. However, DDW data were collected on USDA Forest Service Forest Inventory and Analysis (FIA) plots during Maine's 1995 inventory. This study examines ways to predict DDW biomass from other FIA variables so that DDW could be estimated without tedious measurement. Our results include a regression model that predicts DDW as a function of stand size class, basal area of dead and cut trees, and dummy variables for forest type and forest industry ownership. We also found DDW similar to FIA's standing-tree mortality at a statewide scale. Published by Elsevier Science Ltd.

Keywords: Coarse woody debris (CWD); Carbon; Nontimber products; CART; MARS

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1. Introduction

Increasing concentration of atmospheric greenhouse gases has led many nations to seek ways to mitigate greenhouse gas emissions. Forest management is one of the few activities that can remove large amounts of a major greenhouse gas, carbon dioxide, from the atmosphere at relatively low cost. In the United States, about 210 Tg $(10^{12}$ g$)$ of carbon—11% of all United States greenhouse gas emissions reported in 1998—is sequestered annually in forests and forest products (Birdsey and Heath, 1995; USEPA, 2000). Therefore, accurate measurement of carbon in forests is essential.

The most reliable and verifiable method of estimating carbon at a national scale in United States forests is conversion of forest inventory data to carbon (Birdsey, 1992) or linking inventory data with additional information from models (Heath and Birdsey, 1993; Plantinga and Birdsey, 1993; Turner et al., 1995). These methods generally partition the forest ecosystem into carbon pools for live trees, down deadwood (DDW), standing dead trees, understory vegetation, forest floor material, and soil carbon.

Estimating the DDW or downed coarse woody debris pool has been particularly problematic. Down deadwood is not consistently available from the largest inventory data source, the US Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program, and there is little data on DDW in the scientific literature. Plantinga and Birdsey (1993) dealt with DDW in a carbon assessment by assuming logging residue immediately decayed and its carbon was emitted into the atmosphere, while Turner et al. (1995) used a modeling approach to estimate DDW that was based on the work of Harmon (1993).

In this study, we investigated methods to predict biomass of DDW from FIA data in Maine, which includes a special collection of DDW. This work will be useful for improving methodology to track DDW in forest carbon budgets and to provide information for other uses of DDW. Besides carbon sequestration, DDW is important in understanding energy flows, nutrient cycling, and soil movement, and for serving as habitat for numerous organisms (McMinn and Crossley, 1996). To appeal to the broadest possible audience, we used measurement units in dry weight biomass, which is about 50% carbon for sound wood.

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2. Materials and methods

2.1. Data collection

Down deadwood data were collected concurrent with the 1995 FIA inventory of Maine (Fig. 1; Griffith and Alerich, 1996). FIA inventories are conducted in two phases in a double sampling for stratification design (Chojnacky, 1998). Field measurements were made on second-phase plots located at roughly 5-km intervals, which subsample about every 25th first-phase point. The first-phase points measure forest cover from remotely sensed data for a "support region" (Campbell, 1994; Moisen et al., 1995) of about 0.4 ha (1 acre) around each point. In Maine, the second-phase field plot measured the support region with one circular 0.08-ha (1/5-acre) plot. The sample included 2491 plots that had DDW measurement, although total sample size for analysis was 2522 because FIA "splits" plots when the sample location straddles more than one forest condition (Hahn et al., 1995).

In addition to DDW, FIA variables used in this analysis included tree measurements for diameter at breast height (dbh), species, and live/dead/cut tree status. All live, dead standing, and cut trees were included. Plot variables included county, ownership, latitude, longitude, aspect, slope, forest type, site index, stand size, stand age, physiographic class, forest stocking, timber management opportunity, stand origin, ground land use, and plot size expansion factors (Hansen et al., 1992).

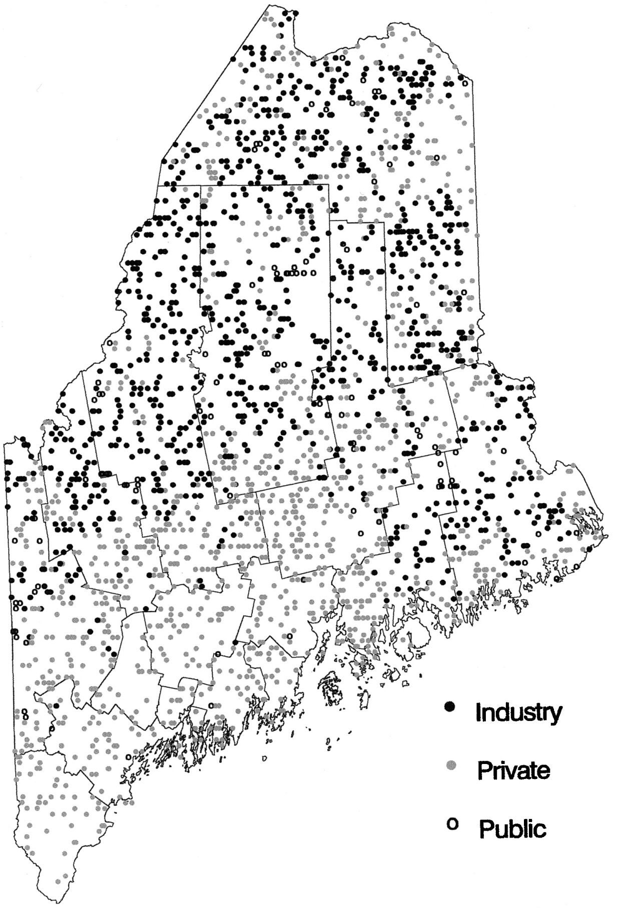

Fig. 1. The 1995 Maine FIA inventory includes 2491 field plots (of 3001 total) where down deadwood (DDW) data were collected on forest industry, other private, and public ownerships for stocked timberlands.

On each plot, DDW was sampled on two transects at 45 and 135° from plot center to plot boundary (Heath and Chojnacky, 2001). All wood pieces that intersected each transect and were at least 7.6-cm diameter at the point of intersection and longer than 0.9 m were tallied. Three decay classes were identified: (1) sound intact logs, (2) partly soft rotten logs with branch stubs firmly attached, and (3) soft, squishy if moist, rotten logs with sloughed or detached bark and missing branch stubs. Logs were not sampled if there was little structural log shape, no evidence of branch stubs, texture was doughy when wet or fluffy when dry, and bark was generally detached or absent (i.e. decay class 4). Decay classes were taken from Cline et al. (1980), and modified based on unpublished data from the Penobscot Experimental Forest, Bradley, Maine. Log volume per unit area was calculated for each piece by using line-intersect sampling theory (deVries, 1986; Heath and Chojnacky, 2001). Down deadwood volume was converted to biomass using specific gravity and was reduced 10, 30, and 60%, for decay classes 1, 2, and 3, respectively. Fifty-one of the plots also had slash piles of DDW but these were excluded from this analysis.

2.2. Data summary

The cut-tree basal area on half of the plots exceeded 10% of live-tree (over 12.6-cm dbh) basal area on the plot, and cut exceeded live basal area by 75% for a quarter of the plots. The 32 forest types and 76 tree species in Maine were too large a number to effectively handle. Therefore, basal area by species within each forest type was used to collapse data into six forest types—sugar maple/beech/birch, aspen/birch, red maple/other hardwoods, pine/oak, northern white cedar/hemlock, and spruce/fir (Table 1).

In previous work, DDW has been modeled as a function of stand age or stand size class (Gore and Patterson, 1986; Harmon et al., 1986; Spies et al., 1988; McCarthy and Bailey, 1994; McGee et al., 1999; Spetich et al., 1999). However, FIA stand age data (Fig. 2) were not particularly suited for this type of model. Twenty-five percent of the plots had missing stand age. The rest included an average age calculated from, at most, three trees per plot, and these trees were primarily selected for site index determination.

More general descriptors of stand structure were sought to complement or replace stand age. FIA data

Table 1
Maine's FIA forest types grouped into 6 categories

Forest type group	FIA forest type and code number
Northern white cedar/eastern hemlock	White pine/hemlock (4), hemlock (5), northern white cedar (14), tamarack (15)
Spruce/fir	Balsam fir (11), black spruce (12), red spruce/fir (13), white spruce (16), Norway spruce (17), red spruce (19)
Pine/oak	Jack pine (1), red pine (2), white pine (3), pitch pine (38), oak/pine (40), white pine/red oak (41), other oak/pine (49), post oak/black oak/bear oak (51), chestnut oak (52), white oak/red oak/hickory (53), white oak (54), northern red oak (55), mixed central hardwoods (59)
Aspen/birch	Aspen (91), paper birch (92), gray birch (93)
Sugar maple/beech/birch	Sugar maple/beech/yellow birch (81), mixed northern hardwoods (89)
Red maple and other hardwood	Sugarberry/American elm/green ash (63), black ash/American elm/red maple (71), willow (74), red maple/lowland (76), black cherry (82), red maple/northern hardwood (84), red maple/upland (87), northern hardwood/old field (88), nonstocked (99)

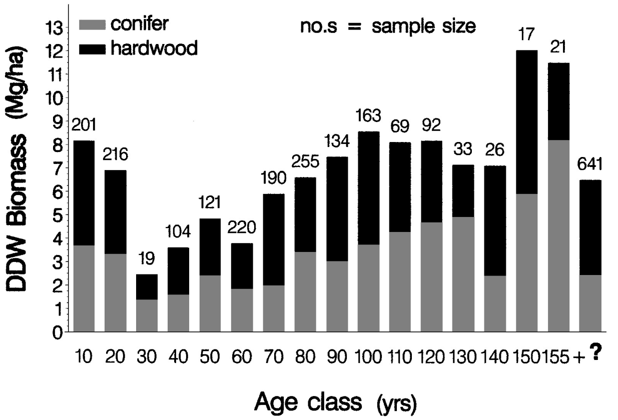

Fig. 2. Slight u-shaped pattern for down deadwood biomass in relation to stand age for Maine FIA plots. Age is missing (?) for 641 plots.

included a stand size class variable for seedling, pole, and saw timber stand sizes, but the basic tree measurements also provided opportunity to calculate more stand structure variables. Tree density, average size, and species composition were estimated by the suite of variables—basal area, trees per area, stand density index (Long, 1998), and quadratic mean diameter—calculated separately for hardwoods and conifers divided into live, dead, and cut classes. Calculations included all trees in each class, and were repeated twice to include trees larger than threshold diameters of 12.7 and 25.4 cm dbh. The smaller threshold corresponded to the plot size for trees less than 12.7 cm dbh, which were sampled on five subplots with a total area 12 times smaller than plot size for larger trees. Overall, the measurements and subsequent calculations provided about 300 variables for analysis.

All variables were evaluated for predicting DDW by using three methods: (1) stepwise regression, (2) classification and regression trees (CART), and (3) multivariate adaptive regression splines (MARS). The stepwise regression analysis was limited to continuous variables and to subsets of more or less independent variables. On the other hand, all variables were examined simultaneously in the nonparametric CART and MARS data mining tools (Salford Systems, 2000). Because the dependent variable (DDW) was continuous, MARS was theoretically more appropriate than CART, but both gave similar results. CART and MARS are classification regression-tree methods where the most important variables identify data splits at the top of dichotomous tree diagrams. These nonparametric methods require few assumptions, but results are somewhat dependent on which options are used in the software. CART and MARS were used in an exploratory mode to find the most important "splitter variables" for a range of options. The regression-tree and stepwise-regression results were compared with select variables consistently important among all methods.

3. Results and discussion

From the variable selection analyses, we found DDW biomass most related to variable functions of dead standing trees and cut tree stumps. For example, basal area, biomass, stand density index, and numbers of standing dead and cut trees were consistently important in CART and MARS data mining results. Live tree variables, on the other hand, showed little relationship to DDW. We chose basal areas of standing dead and cut trees as simple and adequate summary variables of the CART and MARS findings.

None of the procedures showed much value in stand age for estimating DDW. This was contrary to previous findings, but it could have been due to inadequate FIA age measurement procedures. Therefore, a surrogate for age was sought because we wanted to include effects of stand development over time in our model. Stand size class categorized by forest type showed the typical u-shaped pattern others have observed for age data (Fig. 3).

Model refinements on fitting DDW to a function of dead/cut basal area and stand size class showed some value for including some forest types and ownership as dummy variables. Regression was used to parameterize our model:

$$\mathrm{DDW} = 8.9096 + 1.3169 \times d_i + 1.2795 \times d_s + 1.6342 \times d_m - 6.9071 \times X_1 + 1.6361 \times X_1^2 + 0.7042 \times X_2 + 0.2260 \times X_3 \tag{1}$$

where: DDW = down deadwood biomass >7.6 cm diameter (Mg/ha); $d_i = 1$ if forest industry ownership, 0 otherwise; $d_s = 1$ if forest type spruce/fir, 0 otherwise; $d_m = 1$ if forest type sugar maple/beechlbirch, 0 otherwise; X_1 = FIA stand size class (3 = seedling, 2 = poletimber, 1 = sawtimber); X_2 = basal area of standing dead trees 7.6-cm dbh and larger (m^2/ha); X_2 = basal area of standing dead trees 7.6- cm dbh and larger (m^2/ha); X_3 = basal area of recently cut trees 7.6-cm dbh and larger (m^2/ha).

Although the data fit the model rather poorly $\left(R^2 = 0.10\right)$, the large sample size ($n = 2522$) randomly distributed across Maine ensured unbiased predictions for the State. Another way to view the model is as a slight improvement over estimating DDW from a table of mean values within forest type, stand size, and owner.

Because the model is empirical, the Maine forest types are unlikely to extrapolate to other states. Therefore, a less detailed hardwood and conifer forest type version was also fit to the data:

$$\mathrm{DDW} = 10.0666 + 1.6102 \times d_i - 0.4344 \times d_{cr} - 7.1780 \times X_1 + 1.6924 \times X_1^2 + 0.7108 \times X_2 + 0.2190 \times X_3 \tag{2}$$

where $d_{cr} = 1$ if conifer forest type, 0 otherwise.

Validation against similar data for Vermont and New Hampshire showed reasonable results for the Eq. (1) model. Down deadwood for most forest types was underestimated from 3 to 16% but pine and spruce/fir were overestimated by 7 and 1%, respectively (Fig. 4).

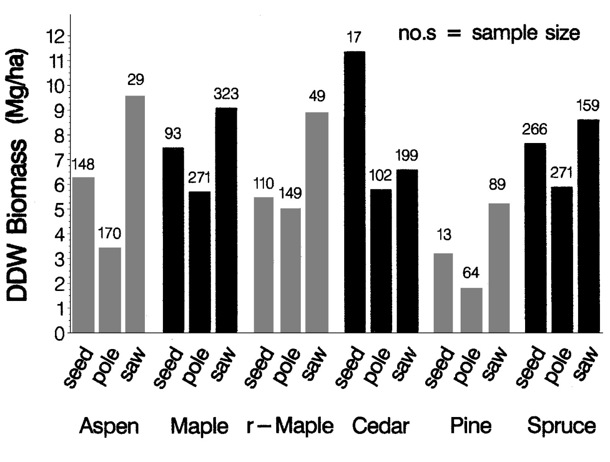

Fig. 3. Down deadwood is related to stand size class (seedling, poletimber, sawtimber) in u-shaped pattern for forest type groups (aspen/birch, maple/beech/birch, red maple/other hardwoods, cedar/hemlock, pine/oak, spruce/fir).

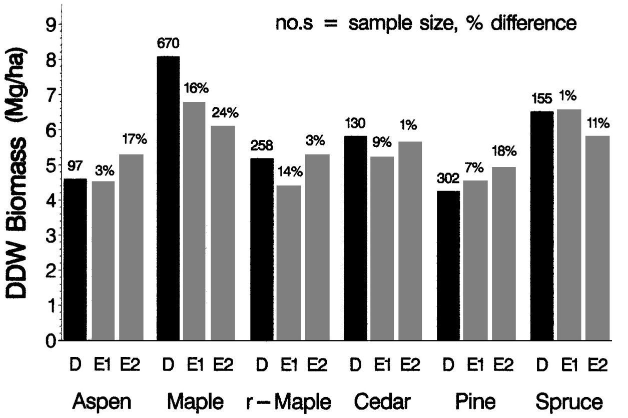

Fig. 4. Down deadwood data (D) from New Hampshire and Vermont compares favorably with predictions from our Eqs. (1) and (2) (E1, E2) for most forest type groups (aspen/birch, maple/beech/birch, red maple/other hardwoods, cedar/hemlock, pine/oak, spruce/fir).

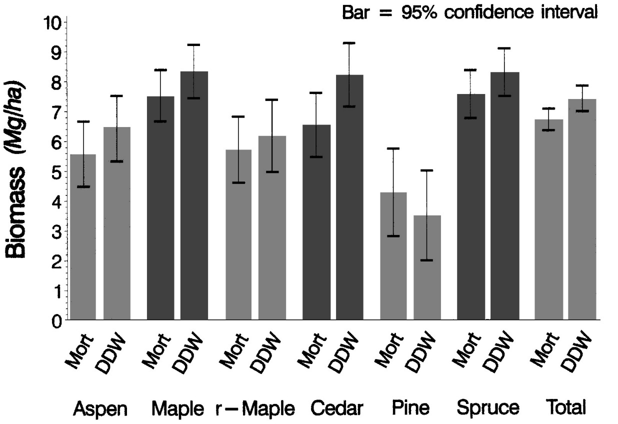

Fig. 5. Biomass of standing mortality trees (Mort) that have died since the last FIA inventory (14 years ago) is comparable with down deadwood (DDW) in Maine for forest type groups (aspen/birch, maple/beech/birch, red maple/other hardwoods, cedar/hemlock, pine/oak, spruce/fir). The 95% confidence interval is based on variance calculation from the double sampling for stratification design. Sample size was reduced to 1848 because FIA does not account for mortality on newly established plots.

The more general Eq. (2), lacking forest type detail, produced similar but slightly more variable results. Because the model is empirical, greater difference should be expected for application to States farther from Maine.

In comparing DDW biomass with other components of forest biomass, we noticed biomass of FIA's mortality trees was closely related to DDW biomass at the Statewide scale for Maine (Fig. 5). FIA mortality included all standing trees (over 12.6-cm dbh) that had died during the 14-year period since the last inventory. This relationship was not evident on a plot-by-plot basis, but only at the State level. Vermont and New Hampshire data also showed the same curious pattern. Although surprising, this warrants further study because standing crop DDW biomass may be in balance with disturbance factors in some manner where DDW could be modeled as a function of dead tree inputs and decay rates in a very general sense at a broad geographic scale.

In summary, DDW can be estimated from FIA variables—dead and cut tree basal area, stand size class, forest type, and ownership. Because our model is empirically derived and lacking theoretical justification for application outside Maine, its best use might be in a regression subsampling strategy where new parameters are estimated for each State inventoried by FIA. Also, biomass of FIA mortality trees is a point of comparison for our model. For Maine, Vermont, and New Hampshire, the DDW biomass and standing mortality biomass were quite similar.

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References

Birdsey, R.A., 1992. Carbon Storage and Accumulation in United States Forest Ecosystems (Gen. Tech. Rep. WO-59). USDA Forest Service, Washington, DC.

Birdsey, R.A., Heath, L.S., 1995. Carbon changes in U.S. forests. In: Joyce, L.A. (Ed.), Climate Change and the Productivity of America's Forests (Gen. Tech. Rep. RM-271). USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, pp. 56–70.

Campbell, K., 1994. Sampling the continuum: the spatial support of environmental data. In: 1993 Proceedings of the American Statistical Association, Statistical Computing Section. Alexandria, VA, pp. 11–19.

Cline, S.P., Berg, A.B., Wight, H.M., 1980. Snag characteristics and dynamics in Douglas-fir forests, Western Oregon. Journal of Wildlife Management 44, 773–786.

Chojnacky, D.C., 1998. Double Sampling for Stratification: A Forest Inventory Application in the Interior West (Res. Pap. RMRS-RP-7). USDA Forest Service, Rocky Mountain Research Station, Ogden, UT.

deVries, P.C., 1986. Sampling Theory for Forest Inventory: A Teach-yourself Course. Springer-Verlag, Berlin.

Gore, J.A., Patterson III., W.A., 1986. Mass of downed wood in northern hardwood forests in New Hampshire: potential effects of forest management. Canadian Journal Forest Research 15, 335–359.

Griffith, D.M., Alerich, C.L., 1996. Forest Statistics of Maine, 1995 (Resour. Bull. NE-135). US Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Hahn, J.T., MacLean, C.D., Arner, S.L., Bechtold, W.A., 1995. Procedures to handle inventory cluster plots that straddle two or more conditions. Forest Science Monograph 31, 12–25.

Hansen, M.H., Frieswyk, T., Glover, J.F., Kelly J.F., 1992. The Eastwide Forest Inventory Database: Users Manual (Gen. Tech. Rep. NC-GTR-151). USDA Forest Service, North Central Forest Experiment Station, St. Paul, MN.

Harmon, M.E., 1993. Woody debris budgets for selected forest types in the US. In: Turner, D.P., Lee, J.J., Koerpner, G.J., Barker, J.R. (Eds.), The Forest Sector Carbon Budget of the United States: Carbon Pools and Flux Under Alternative Policy Options (EPA/600/3-93/093). US Environmental Protection Agency, Corvallis, OR, pp. 51–178.

Harmon, M.E., Franklin, J.F., et al., 1986. Ecology of coarse woody debris in temperate ecosystems. In: Macfadyen, A., Ford, D.E. (Eds.), Advances in Ecological Research, Vol. I5. Academic Press, New York, pp. 133–302.

Heath, L.S., Birdsey, R.A., 1993. Carbon trends of productive temperate forests of the coterminous United States. Water, Air, and Soil Pollution 70, 279–293.

Heath, L.S., Chojnacky, D.C., 2001. Down Dead Wood Statistics for Maine Timberlands, 1995 (Res. Bull. NE-150). USDA Forest Service, Northeastern Research Station, Newtown Square, PA.

Long, J.N., 1998. Multiaged systems in the Central and Southern Rockies. Journal of Forestry 96 (7), 34–36.

McCarthy, B.C., Bailey, R.R., 1994. Distribution and abundance of coarse wood debris in managed forest landscape of the central Appalachians. Canadian Journal of Forest Research 24, 1317–1329.

McGee, G.G., Leopold, D., Nyland, R.D., 1999. Structural characteristics of old-growth, maturing, and partially cut northern hardwood forests. Ecological Applications 9 (4), 1316–1329.

McMinn, J.W., Crossley, D.A. (Eds.), 1996. Biodiversity and Coarse Woody Debris in Southern Forests, Proceedings of the Workshop on Coarse Woody Debris in Southern Forests: Effects on Biodiversity; 18–20 October; Athens, GA (Gen. Tech. Rep. SE-94). USDA Forest Service, Southern Research Station, Asheville, NC.

Moisen, G.G., Stage, A.R., Born, J.D., 1995. Point sampling with disjoint support near population boundaries. Forest Science Monograph 31, 61–82.

Plantinga, A.J., Birdsey, R.A., 1993. Carbon fluxes resulting from US private timberland management. Climatic Change 23, 37–53.

Salford Systems, 2000. CART and MARS Data Mining Software. http://www.salford-systems.com. San Diego, CA.

Spetich, M.A., Shifley, S.R., Parker, G.R., 1999. Regional distribution and dynamics of coarse woody debris in midwestern old-growth forests. Forest Science 45 (2), 302–313.

Spies, T.A., Franklin, J.F., Thomas, T.B., 1988. Coarse woody debris in Douglas-fir forests of western Oregon and Washington. Ecology 96 (6), 1689–1702.

Turner, D.P., Koeper, G.J., Harmon, M.E., Lee, J.J., 1995. Carbon sequestration by forests of the United States. Current status and projections to the year 2040. Tellus 47B, 232–239.

US Environmental Protection Agency, 2000. Inventory of US Greenhouse Gas Emissions and Sinks: 1990–1998 (EPA-236-R-00-001). Office of Policy, Planning, and Evaluation, Washington, DC.