Forests on the Edge: Evaluating Contributions of and Threats to America's Private Forest Lands

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Abstract.—The Forests on the Edge project, sponsored by the U.S. Department of Agriculture Forest Service, uses geographic information systems to construct and analyze maps depicting ecological, social, and economic contributions of America's private forest lands and threats to those contributions. Watersheds across the conterminous United States are ranked relative to the amount of their private forest land, relative to the contributions of their private forest lands to water quality and timber supply, and relative to threats from development, wildfire, and ozone. In addition, development and wildfire threats to private forest land contributions to water quality and timber supply are assessed. The results indicate that private forest lands are concentrated in the Eastern and Southeastern United States and that threats to the contributions of private forest lands are also concentrated in the same regions. Threats also are distributed throughout the North Central, Central Hardwoods, and Pacific Northwest regions. The maps may be used to focus additional studies on watersheds of particular concern.

Introduction

America's forest lands contribute in a myriad of ways to the economic, ecological, and social well-being of the Nation. Increasingly, however, forest lands are threatened from a variety of sources including urbanization, climate change, invasive flora and fauna, wildfire, pollution, fragmentation, and parcelization. The increasing emphasis on sustainable forest management requires quantitative and spatial assessments of the impacts of these threats to forest lands and forest land contributions. The Forests on the Edge (FOTE) project, sponsored by State and Private Forestry, U.S. Department of Agriculture Forest Service, conducts map-based assessments of threats to the Nation's private forest lands using spatial data layers and geographic information systems. The Montreal Process criteria and indicators provide an appropriate context for framing and conducting these assessments (McRoberts *et al.* 2004). For example, Criterion 2, Maintenance of the Productive Capacity of Forest Ecosystems, includes indicators related to forest area and timber production; Criterion 3, Maintenance of Forest Ecosystem Health and Vitality, includes indicators related to fire, wind, disease, and insects; and Criterion 4, Conservation and Maintenance of Soil and Water Resources, includes indicators related to the contributions of forests to water quality.

The objectives of FOTE are threefold: (1) to construct nationally consistent data layers depicting the spatial location of

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private forest lands and their contributions such as water quality and timber supply; (2) to construct similar layers depicting threats to the contributions of private forest land from sources such as conversion to urban and exurban uses, wildfire, and pollution; and (3) to identify watersheds whose private forest lands simultaneously make the most important contributions and face the greatest threats.

Methods

Data Layers

All data layers were obtained as or constructed to be nationally consistent and were summarized at the spatial scale of fourth-level watersheds (Steeves and Nebert 1994). Watersheds were selected as the analytical units because they highlight the important connections between private forests and ecological processes. Only watersheds with at least 10 percent forest cover of which at least 50 percent is in private ownership were considered for the study.

Area of Private Forest Land

A 100-m resolution forest ownership layer was constructed by aggregating the classes of the National Land Cover Dataset (Vogelmann *et al.* 2001) into forest and nonforest classes and using the Protected Areas Database (PAD) (DellaSalla *et al.* 2001) to distinguish ownership and protection categories. The emphasis for this study was private forest land, which includes tribal, forest industry, and nonindustrial ownerships. Stein *et al.* (2005) provide detailed information on this layer.

Water Quality

Private forest lands provide nearly 60 percent of all water flow from forests in the United States and nearly 50 percent of the water flow originating on land in the conterminous 48 States. Water flow from private forests is generally considered clean relative to water flow from other land uses and, therefore, makes a positive contribution to water quality. The water quality layer depicts the contribution of private forest land to the production of clean water and is based on three underlying assumptions: (1) water bodies near the heads of hydrologic networks are more sensitive to the loss of forest buffers than water bodies near the bases of the networks, (2) the presence or absence of upstream forest buffers influences water quality downstream in the networks, and (3) forest land throughout watersheds better indicates the contributions of private forest land to water quality than does forest land only in the immediate vicinity of water bodies (FitzHugh 2001).

The water quality layer was constructed from two underlying layers: the forest ownership layer and the National Hydrography Dataset (USGS 2000), which depicts water bodies in the 48 contiguous States. The layer was constructed in four steps: (1) a 30-m buffer was constructed around all water bodies, (2) the buffers were intersected with the private forest land class of the forest ownership layer to quantify the amount of private forest land in close proximity to water bodies, (3) each buffer segment was assigned to one of four categories based on the relative position of the segment to the head of its hydrologic network, and (4) for each watershed, the percentage of the total buffer area in each of the four categories was determined. Water quality index (WQI) was then calculated for each watershed as

$$WQI = 0.6*(A_1+A_1*A_2)+0.4*(0.53*B_1+0.27*B_2+0.13*B_3 +0.07*B_4)$$

where:

A_1 = percent of watershed in private forest land.

A_2 = percent of total forest land in watershed that is privately owned.

B_1 = percent of private forest land buffer in the first category (nearer head of hydrologic network headwater).

B_2 = percent of buffer in the second category.

B_3 = percent of buffer in third category.

B_4 = percent of buffer in fourth category (farthest downstream from the head of hydrologic network).

The 0.6 and 0.4 weightings of the A and B variable components, respectively, reflect the third assumption above. The relative weightings of the B variables among themselves reflect the assumption that each category of buffer is twice as important as the following category.

Timber Supply Layer

Private forest lands make a substantial contribution to America's timber resources, accounting for 92 percent of all timber harvested in the United States in 2001 (Smith *et al.* 2004). The timber supply layer depicts the ranking of watersheds relative to an index of their private forest land contributions to timber supplies and is based on Forest Inventory and Analysis (FIA) plot data (http://ncrs2.fs.fed.us/4801/fiadb/) and Timber Products Output data (http://www.ncrs.fs.fed.us/4801/regional-programs/tpo/). The timber supply index (TSI) is based on four subindexes of timber contributions of the timberland component of private forest land. Timberland is defined by the FIA program as forest land that has not been withdrawn from production and that is capable of producing 20 ft^3/yr of industrial wood. For each watershed, the four subindexes are calculated as follows: (1) growth index (GI) is the average growing stock volume growth rate on private timberland in the watershed relative to the average for private timberland in all watersheds, (2) volume index (VI) is the average net growing stock volume per acre on private timberland in the watershed relative to the net volume for private timberland in all watersheds, (3) area index (AI) is the ratio of private timberland and total private land for the watershed relative to the same ratio for all watersheds, and (4) private area index (PI) is the ratio of private timberland area and total area in the watershed. TSI was calculated for each watershed as

$$TSI = PI*(GI+VI+AI).$$

Development

The development layer depicts predicted threats to private forest lands resulting from conversion to urban or exurban uses. The layer is based on estimates of current population and housing density data obtained from the 2000 Census and predictions of housing density increases. A spatially explicit model was used to predict the full urban-to-rural spectrum of housing densities (Theobald 2005). The model uses a supply-demand-allocation approach and is based on the assumption that future growth patterns will be similar to those in the past decade. Future patterns are forecast on a decadal basis in four steps: (1) the number of new housing units in the next decade was forced to meet the demands of the predicted populations; (2) a location-specific average population growth rate from the previous to current time step was computed for each of three density classes: urban, exurban, and rural; (3) the spatial distribution of predicted new housing units was adjusted with respect to accessibility to the nearest urban core area; and (4) predicted new housing density was added to the current housing density under the assumption that housing densities do not decline over time. For these analyses, predicted new housing was not permitted to occur on protected private land as indicated by PAD (DellaSalla *et al.* 2001). The spatially explicit housing density predictions were combined with the forest ownership layer to identify watersheds with the greatest predicted conversion of private forest land to urban and exurban uses. Stein *et al.* (2005) provide detailed information on this layer.

Wildfire

Although wildfire is one of the most compelling threats to forest land, particularly in the Western United States, predicting wildfire risk is extremely complex and relies on a variety of regional models using regional variables. Further, even if the models could be readily used to construct a national layer, the geographic consistency of the layer would be questionable. Therefore, as a surrogate for wildfire risk, FOTE used the 1-km by 1-km resolution current fire condition class (CFCC) data which depict deviations of fire incidence from historic natural fire regimes and estimated efforts necessary to restore stands to historic regimes (Schmidt *et al.* 2002). All private forest lands in each watershed were assigned to one of three CFCC classes: (1) $CFCC_1$, forest lands with fire regimes that are within or near historical ranges and that can be maintained by treatments such as prescribed fire or fire use; (2) $CFCC_2$, forest lands with fire regimes that have been moderately altered from historical ranges and that may require moderate levels of prescribed fire, fire use, hand or mechanical treatment, or a combination to be restore the historical fire regime; and (3) $CFCC_3$, forest lands with fire regimes that have been substantially altered from historical ranges and that may need high levels of hand or mechanical treatment before fire is used to restore historical fire regimes. For each watershed, an index was calculated as

$$CC = CC_1 + 2*CC_2 + 4*CC_3$$

where CC_i is the area of private forest land in class $CFCC_i$. The weights associated with each class in the calculation of CC reflect the assumption that each class is twice as important as the next class. The wildfire layer depicts the ranking of watersheds relative to their CC index values.

Ozone

Ozone affects forest ecosystems by causing foliar lesions and rapid leaf aging, altering species compositions, and weakening pest resistance (Chappelka *et al.* 1997, Miller 1996). It is the only gaseous air pollutant that has been measured at known phytotoxic levels at both remote and urbanized forest locations (EPA 1996). The ozone layer depicts private forest land threatened by ground level ozone and was based on late summer observations by FIA field crews of ozone damage to bioindicator species known to be sensitive to ground level ozone. Data for more than 2,500 FIA plots were available for the study. Each plot was assigned a biosite value based on a subjective assessment by trained observers of the quantity and severity of damages (Coulston *et al.* 2003, Smith *et al.* 2003). Inverse distance weighted interpolation was used to create a map of ozone damage. This map was then combined with the forest ownership layer to identify private forest land with elevated levels of ozone damage. For each watershed, the percentage of private forest land in moderate or high damage categories was calculated.

Analyses

For each contribution and threat layer, with the exception of ozone, the distribution of watershed values was determined, and a percentile ranking was assigned to each watershed. Because only approximately 10 percent of watersheds satisfying the 10 percent forest cover and 50 percent private ownership criteria had elevated levels of ozone damage, no percentile ranking was constructed. For each watershed, development and wildfire threats to water quality and timber supply contributions were assessed using the average of the watershed's percentile rankings for the contribution and the threat. The results are depicted using percentile-based categories of the average of the contribution and threat percentiles.

Results

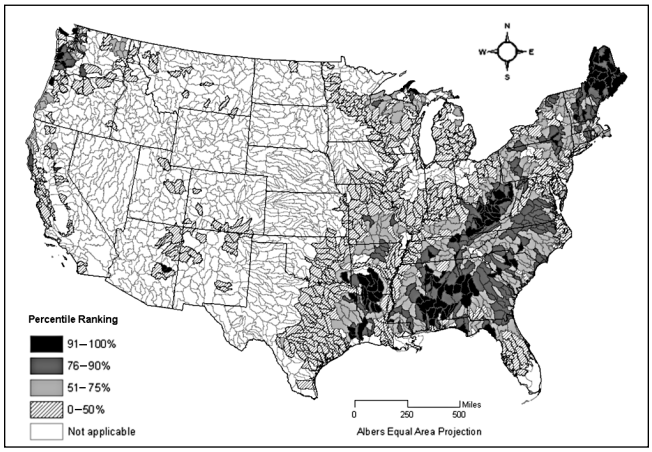
The results are briefly discussed and maps are presented for percent private forest land area, water quality and timber supply contributions, and development, wildfire, and ozone threats. Maps of the threats from development and wildfire to water quality and timber supply are also presented and discussed. No assessments of threats of ozone to water quality or timber supply were made, because so few watersheds had elevated levels of ozone damage.

Watersheds with the greatest percentage of private forest land are generally in New England, the Southeast, and the Pacific Northwest (fig. 1). The concentration in the East is not surprising, because much of the forest land in the West is in public ownership. Watersheds whose private forests make the greatest contributions to water quality and timber supply align closely with the watersheds with greatest amounts of private forest land (figs. 2 and 3).

Development threats to private forest land area are concentrated in southern New England and the Southeast, although some are also found in the Pacific Northwest (fig. 4). Wildfire threats to private forest land, as indicated by the surrogate CC layer, are primarily in the northeastern quadrant of the country (fig. 5). The two Midwestern areas in this northeastern quadrant, however, are characterized by low percentages of private forest land (fig. 1). With only a few exceptions, watersheds with elevated levels of ozone damage were in the east-central portion of the country (fig. 6).

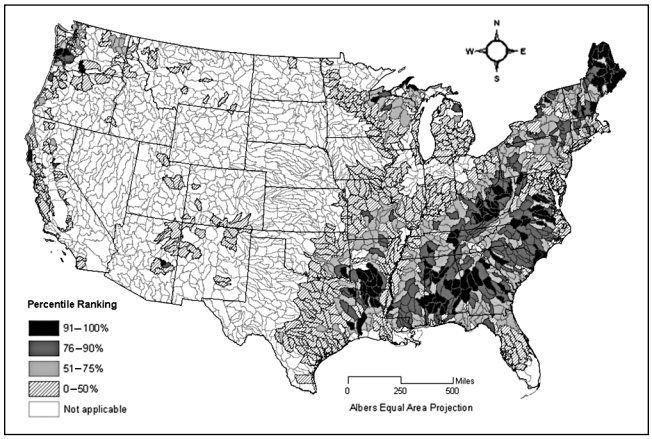
Development threats to the contributions of private forest land to both water quality and timber supply are concentrated in southern New England and the Southeast (figs. 7 and 8). These results are as expected, because higher percentile watersheds for all three underlying layers are also in southern New England and the Southeast. Wildfire threats, as indicated by the surrogate CC layer, to both water quality and timber supply contributions are distributed throughout the East and Southeast, the Lakes States, the Central Hardwoods region, and the Pacific Northwest (figs. 9 and 10).

Figure 1.—*Percentile rankings of watersheds with respect to percent of private forest land.*



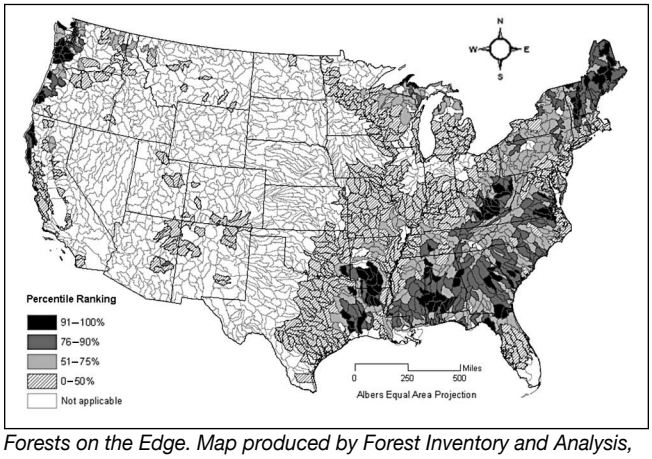
Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 2.—*Percentile rankings of watersheds with respect to contribution of private forest land to water quality.*



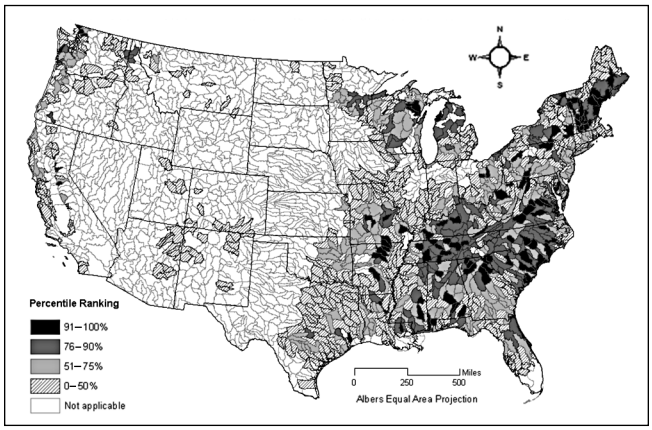
Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 3.—*Percentile rankings of watersheds with respect to contributions of private forest land to timber supply.*



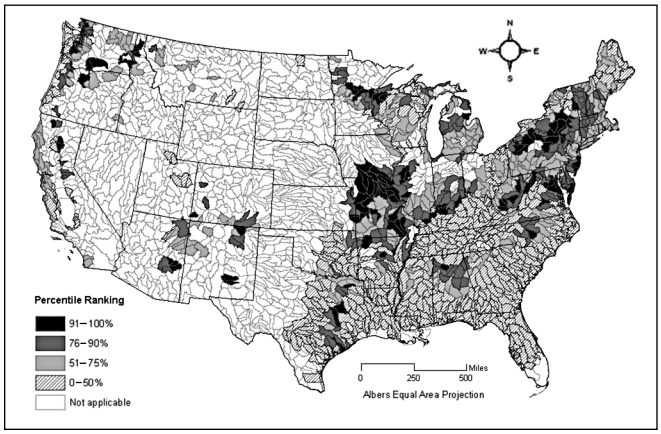
Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 4.—*Percentile rankings of watersheds with respect to percent of private forest land predicted to convert to exurban or urban uses by 2030.*



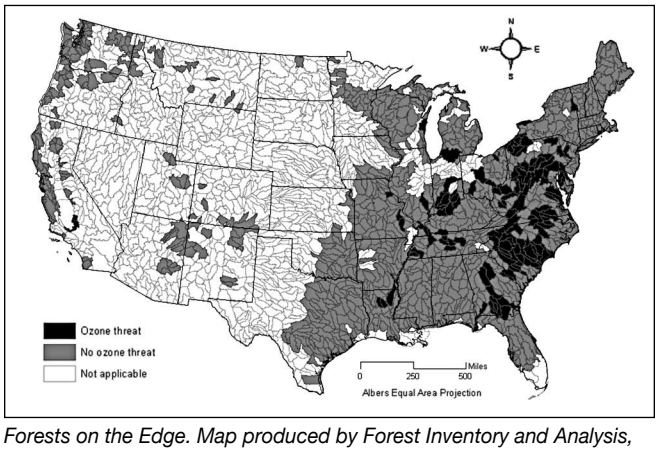
Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 5.—*Percentile rankings of watersheds with respect to wildfire threat to private forest land.*



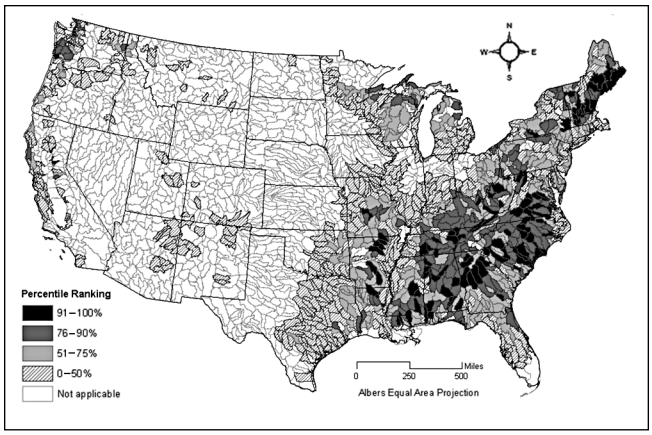
Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 6.—*Watersheds with detectable ozone threats.*



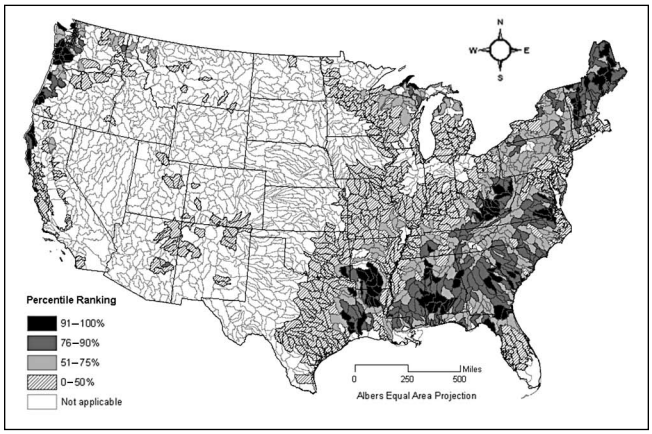
Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 7.—*Percentile rankings of watersheds with respect to development threat to the contributions of private forest land to water quality.*



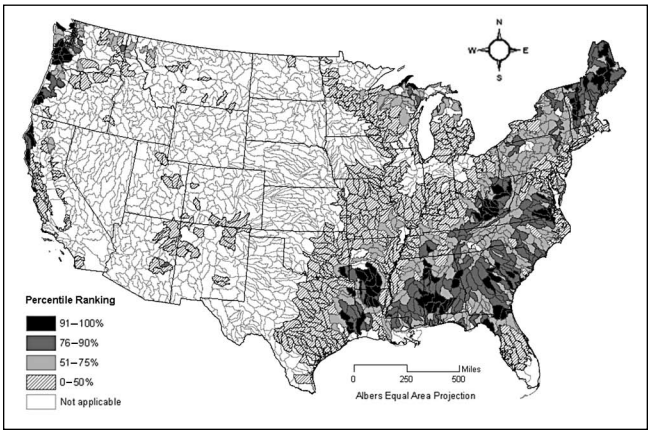
Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 8.—*Percentile rankings of watersheds with respect to development threat to contribution of private forest land to timber supply.*



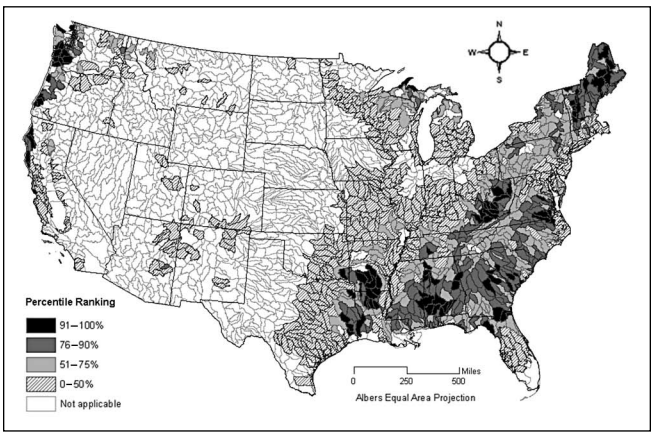
Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 9.—*Percentile rankings of watersheds with respect to wildfire threat to contribution of private forest land to water quality.*



Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Figure 10.—*Percentile rankings of watersheds with respect to wildfire threat to contribution of private forest land to timber supply.*



Forests on the Edge. Map produced by Forest Inventory and Analysis, Northern Research Station, USDA Forest Service.

Conclusions

Several conclusions may be drawn from this study. First, private forest land is located mostly in the Eastern United States, particularly New England and the Southeast, although there are also concentrations in the Pacific Northwest. Second, the watersheds making the greatest private forest contributions to water quality and timber supply are generally the watersheds with the greatest percentages of private forest land. Third, the watersheds with the greatest private forest land contributions to water quality and timber supply are also the watersheds most threatened by development. Fourth, the CC surrogate for wildfire depicts the greatest threats to watersheds in the central part of the Eastern United States and the Pacific Northwest. Watersheds depicted by this layer in the central part of the United States have relatively small percentages of private forest land. Fifth, the FOTE spatial approach to assessing threats to the contributions of private forest lands produces useful, visual information that is relatively easy to obtain and interpret. The only serious impediment associated with this approach is the

difficulty in obtaining or constructing nationally consistent data layers that depict the contributions and threats of interest.

Future work will include assessment of additional contributions such as at-risk species and interior forest and threats such as insects, disease, and additional pollutants. In addition, work has begun on construction of an Internet-based system that permits users to select particular contribution and threat layers, options for combining them, and options for depicting the results.

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