# Decline of Forest Interior Conditions in the Conterminous United States:

# Supplementary Information

Kurt H. Riitters[1] & James D. Wickham[2]

[1]Southern Research Station, United States Department of Agriculture, Forest Service, Research Triangle Park, NC 27709, USA

[2]National Exposure Research Laboratory, United States Environmental Protection Agency, Research Triangle Park, NC 27711, USA

The Supplementary Information includes:

1. Supplementary Text.
2. Supplementary Table (Table S1).
3. Supplementary Analyses of 36 Ecological Provinces.
4. Supplementary References.

# 1. Supplementary Text.

**Natural versus anthropogenic fragmentation**

Our analysis did not distinguish between natural and anthropogenic disturbance and recovery, nor did it compare conditions in 2001 with the patterns of potential natural vegetation absent human influences. Knowledge of potential natural vegetation is helpful for understanding specific impacts of fragmentation on ecological attributes and functions, but it is not essential when evaluating trends of forest interior area within the human dominated era. The generalized nonforest class included water and permanently barren land cover, and fragmentation by those types of land cover is arguably a natural condition. While the initial conditions of forest interior were affected by water and barren land in a neighborhood, the net change of forest interior was largely unaffected because those two types of land cover tend to persist over time. At the other extreme, fragmentation by the nonforest land cover classes of agriculture and development (infrastructure, urban) is clearly anthropogenic and usually permanent (with a few exceptions such as road closure and reversion of agricultural land to forest). In the western United States, agriculture and development do not often occur in the most heavily forested areas because most of that area is publicly owned, remote, or otherwise unsuitable. In the eastern United States, development on privately owned land is a major driver of forest fragmentation[S1].

It is more difficult to evaluate the importance of fragmentation by the semi-natural land cover classes of grassland and shrubland. Whether those classes are considered natural depends on actual land use, for example whether grassland is artificially maintained for grazing, which cannot be inferred from land cover alone. Forest fragmentation associated with those types of land covers may be a natural condition, particularly at natural ecotones between forest and nonforest vegetation in mountainous regions and savanna forests. Like water and barren land, the net change of forest interior was unaffected to the extent grassland and shrubland were originally present and persisted. The problem is that both natural disturbances (e.g., fire, insects, etc.) and temporary anthropogenic disturbances (e.g., harvest) are often followed by the appearance of grassland or shrubland before forest replaces them. Transitions among land cover classes observed on the NLCD land cover maps indicate that the total area of forest converted to grassland and shrubland was more than twice the area of forest gained from both of those land cover classes (Table S1).

**Causes of fragmentation**

More information is needed to evaluate quantitatively the relative importance of the causes of fragmentation in different parts of the United States. Here we provide brief summaries of available national information for abiotic disturbances, insects and diseases, forest harvest, and urbanization, which are considered to be the main current drivers of forest fragmentation.

Abiotic disturbances. Nine unusually severe fires and fire complexes larger than 100 $km^2$ burned a total of approximately 7,500 $km^2$ in the western United States between 2001 and 2006. Assuming all burned area was forest interior area, all forest was lost when burned, and all burned area did not recover, then those nine wildfires would account for a maximum of approximately 15% to 25% of the observed net loss of forest interior area depending on spatial scale. Actual percentages are lower because the assumptions are not strictly true. In comparison, in 2007 alone six named fires and fire complexes larger than 100 $km^2$ burned a total of 9,485 $km^2$, contributing to a report of 11,024 $km^2$ of "high severity" burned forest area from 2003 to 2007[S2]. Blowdown from severe storms (hurricanes, tornados, etc.) is another locally important and usually temporary cause of forest loss.

Insects and diseases. A recent national compilation of aerial survey data showed that the annual mapped area of "forest mortality" from all causes ranged from approximately 12,000 $km^2$ to 44,000 $km^2$ between 2001 and 2006[S2]. While these statistics provide some information about the magnitude of insect and disease activity, they are not comparable to total forest interior change estimates from NLCD land cover data because "forest mortality" does not imply forest loss, and because some of the same "forest mortality" area was mapped in more than one year.

Forest harvest. Normal silvicultural operations include periodic harvest and regeneration of forest area balanced over time frames of 20 to 200 years corresponding to forest rotation ages in different regions. Recent statistics indicate that total forest harvest (roundwood and fuelwood) volume declined by 10% to 15% from peak values in the 1990's and was relatively stable from 2001 to 2006[S2]. While conversions of harvest volume estimates to harvest area estimates are problematic, it is unlikely that total forest area loss from harvest was higher after 2001 than before 2001. If the reduction of forest interior area over the five-year study period is inflated by a temporary imbalance of harvest over regeneration, the imbalance is more likely due to lower regeneration rates than to higher harvest rates. In any case, most of the impact of silvicultural operations would probably have been in the South region which provided most (62%) of the harvest volume in 2006 compared to the North (18%), Pacific Coast (16%), and Rocky Mountain (3%) regions[S2].

Urbanization. Using the same NLCD maps that were used in this study, urban area (including roads) increased by 11,710 $km^2$ from 2001 to 2006 for the conterminous United States[S3]. Included are approximately 3,100 $km^2$ of forest converted to urban land cover, which represents approximately 11% of total net forest loss. New urban area was concentrated near existing urban area where forest interior is not common, but dispersed urbanization including road construction within privately owned forests is a major driver of the loss of forest interior area in the eastern United States[S1].

## 2. Supplementary Table.

Table S1. Transitions between forest and the grassland or shrubland land cover classes from 2001 to 2006[S3].

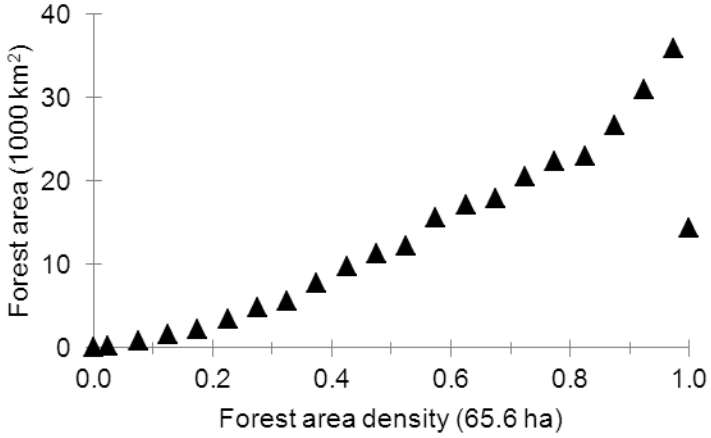
| | To or from: | |
|---|---|---|
| | Grassland Thousand $km^2$ | Shrubland Thousand $km^2$ |
| From forest in 2001 | 20.1 | 21.5 |
| To forest in 2006 | 11.9 | 6.0 |

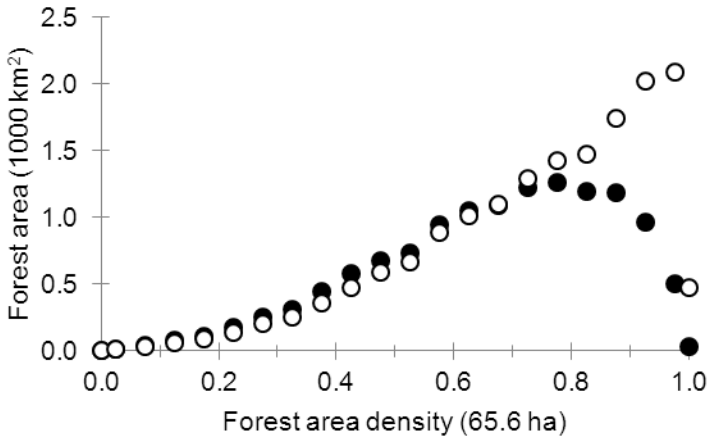
## 3. Supplementary Analyses of 36 Ecological Provinces.

This supplement summarizes forest area change and forest interior change at 65.6-ha scale for each of the 36 ecological provinces[S4] of the conterminous United States. Provinces appear in order of decreasing total forest area in 2001. The format includes the province name and data code[S5], a map showing the location of the province[S6], a table showing total forest area and forest area change from 2001 to 2006, and two figures illustrating the spatial patterns of forest, forest gains, and forest losses. The figures are comparable to Figs. 1b and 1e in the main text, which show the aggregate results for the conterminous United States. In the first figure, triangles show the distribution of all forest area in 2001 in relation to forest area density in 2001. The second figure shows gross forest area lost in relation to forest area density in 2001 (open circles) and gross forest area gained in relation to forest area density in 2006 (closed circles). The regional analyses show that the aggregate trend statistics shown in the main text were typical of a wide range of original forest conditions as indicated by ecological provinces.

Outer Coastal Plain Mixed Forest (232)

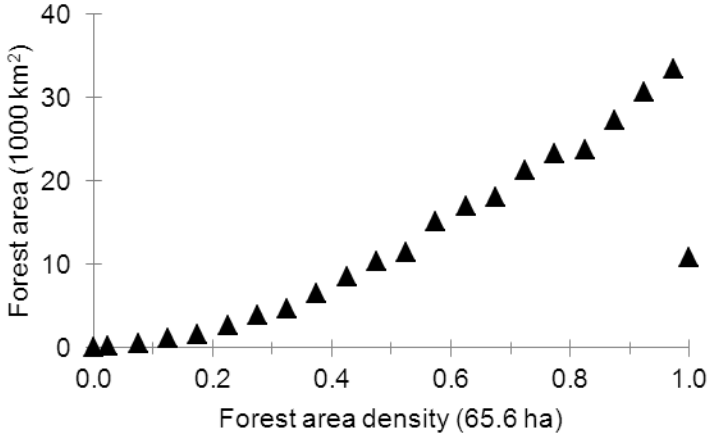
| | | |
|---|---|---|
| Forest in 2001 | 284.07 | thousand km$^2$ |
| Forest loss | 16.43 | thousand km$^2$ |
| Forest gain | 12.89 | thousand km$^2$ |
| Net change | -3.53 | thousand km$^2$ |
| Forest in 2006 | 280.53 | thousand km$^2$ |

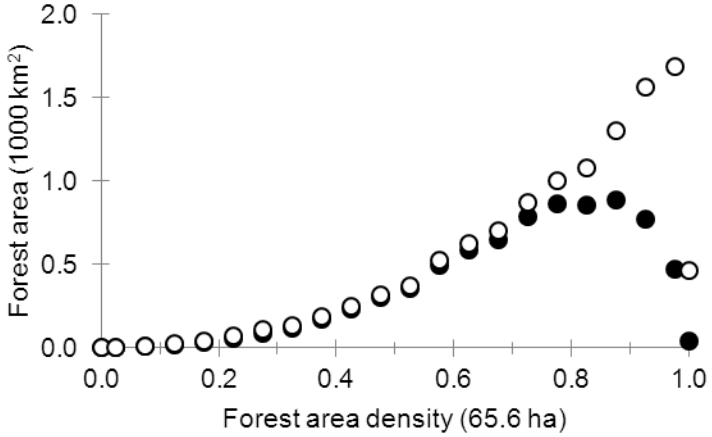


Southeastern Mixed Forest (231)

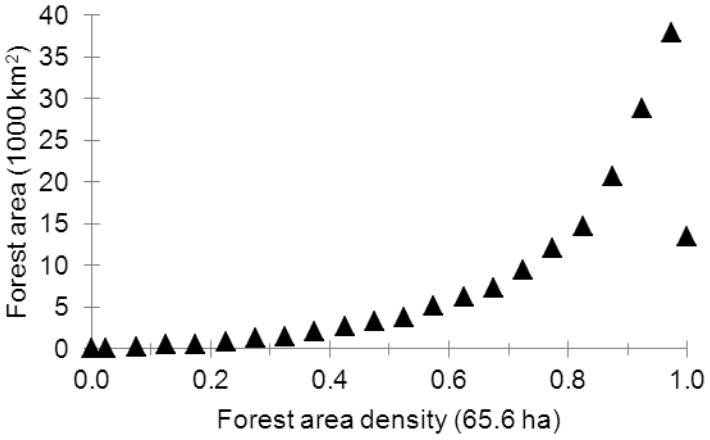
| | | |
|---|---|---|
| Forest in 2001 | 272.40 | thousand km$^2$ |
| Forest loss | 11.37 | thousand km$^2$ |
| Forest gain | 7.81 | thousand km$^2$ |
| Net change | -3.56 | thousand km$^2$ |
| Forest in 2006 | 268.84 | thousand km$^2$ |

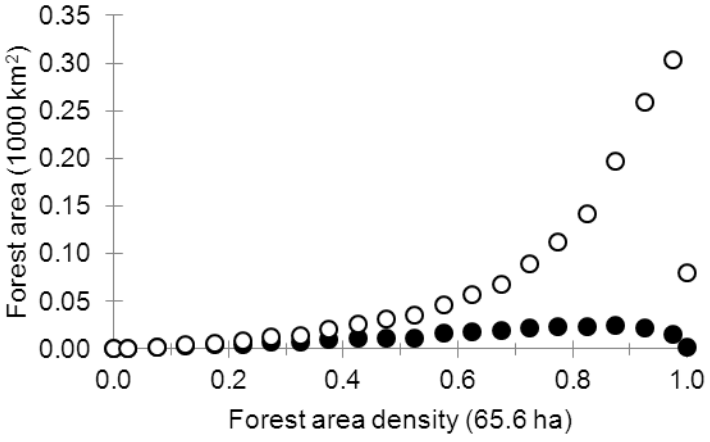


Laurentian Mixed Forest (212)

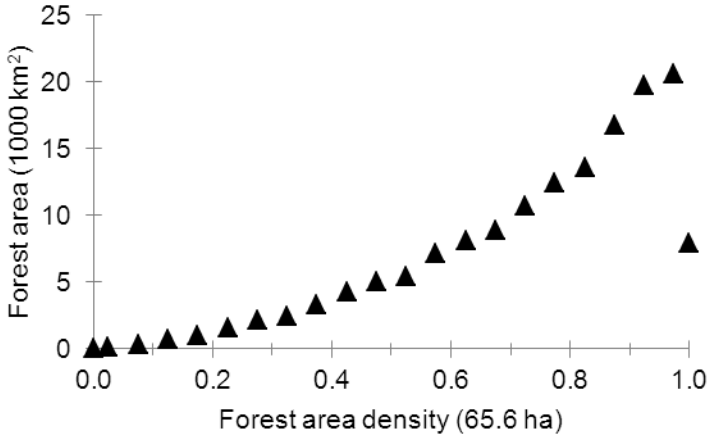
| | | |
|---|---|---|
| Forest in 2001 | 172.58 | thousand km$^2$ |
| Forest loss | 1.52 | thousand km$^2$ |
| Forest gain | 0.26 | thousand km$^2$ |
| Net change | -1.26 | thousand km$^2$ |
| Forest in 2006 | 171.32 | thousand km$^2$ |

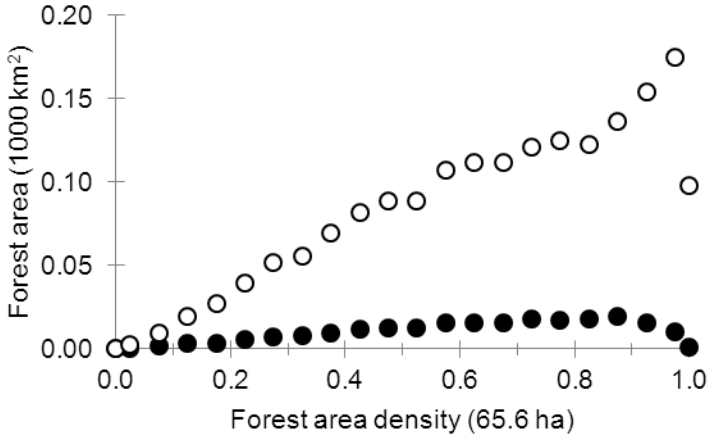


Eastern Broadleaf Forest (221)

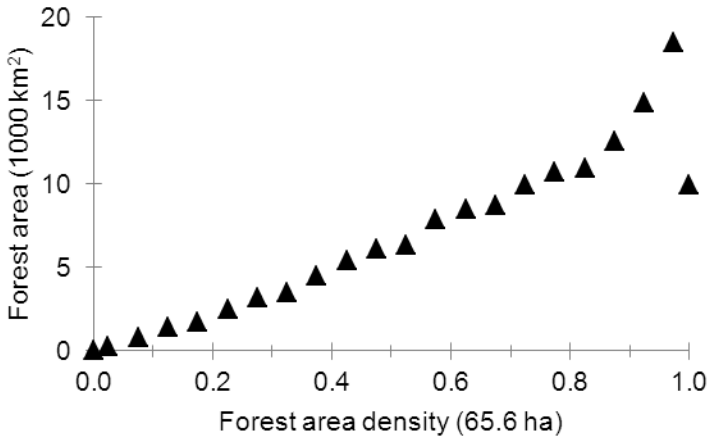
| | | |
|---|---|---|
| Forest in 2001 | 152.43 | thousand km$^2$ |
| Forest loss | 1.80 | thousand km$^2$ |
| Forest gain | 0.22 | thousand km$^2$ |
| Net change | -1.58 | thousand km$^2$ |
| Forest in 2006 | 150.85 | thousand km$^2$ |

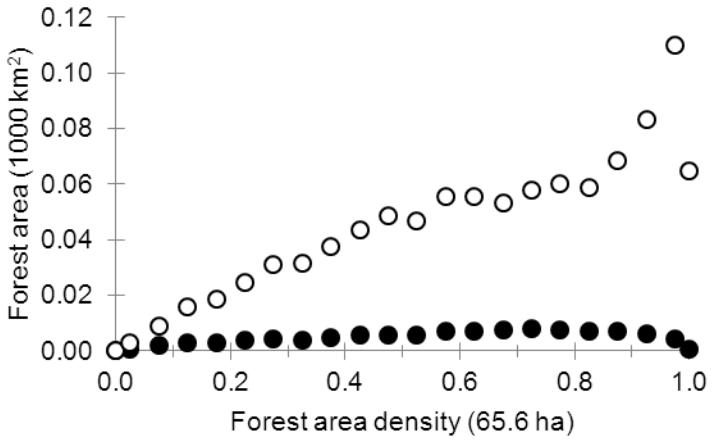


Central Interior Broadleaf Forest (223)

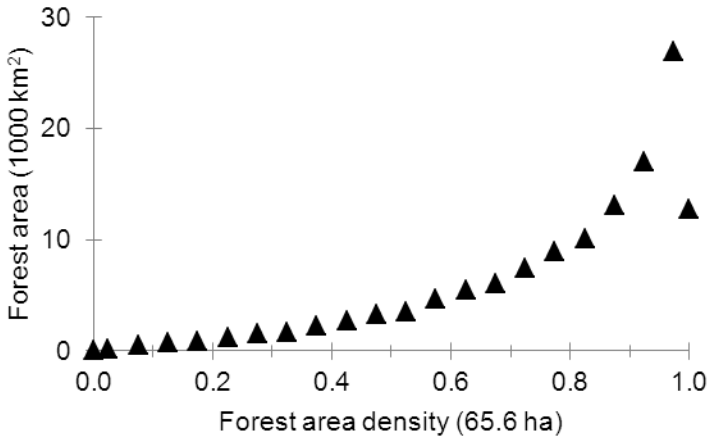
| | | |
|---|---|---|
| Forest in 2001 | 148.39 | thousand km$^2$ |
| Forest loss | 0.98 | thousand km$^2$ |
| Forest gain | 0.10 | thousand km$^2$ |
| Net change | -0.87 | thousand km$^2$ |
| Forest in 2006 | 147.52 | thousand km$^2$ |

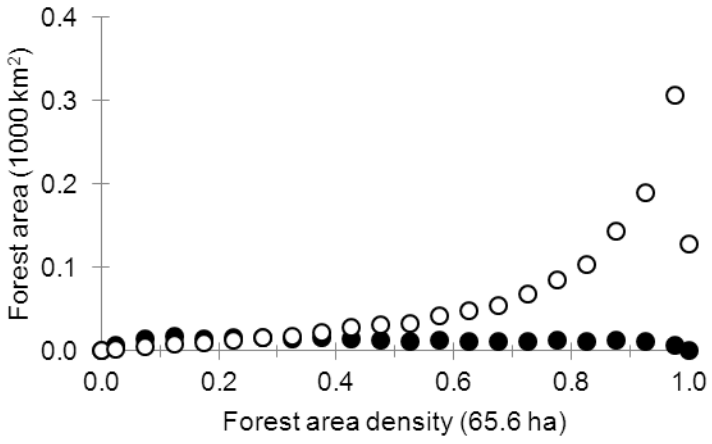


Southern Rocky Mountain Steppe - Open Woodland - Coniferous Forest - Alpine Meadow (M331)

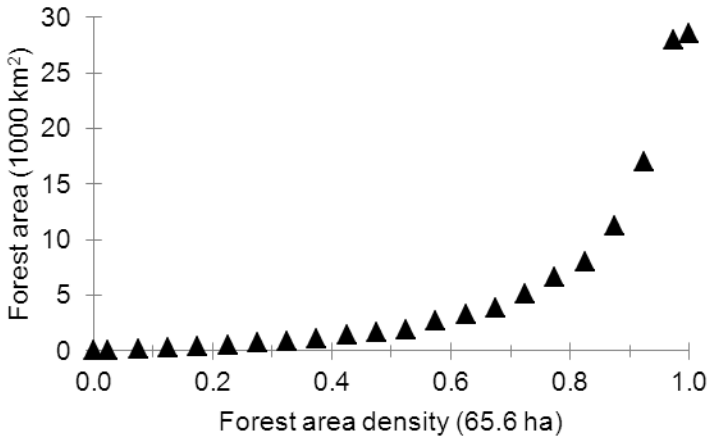
| | | |
|---|---|---|
| Forest in 2001 | 130.66 | thousand km$^2$ |
| Forest loss | 1.36 | thousand km$^2$ |
| Forest gain | 0.26 | thousand km$^2$ |
| Net change | -1.10 | thousand km$^2$ |
| Forest in 2006 | 129.56 | thousand km$^2$ |

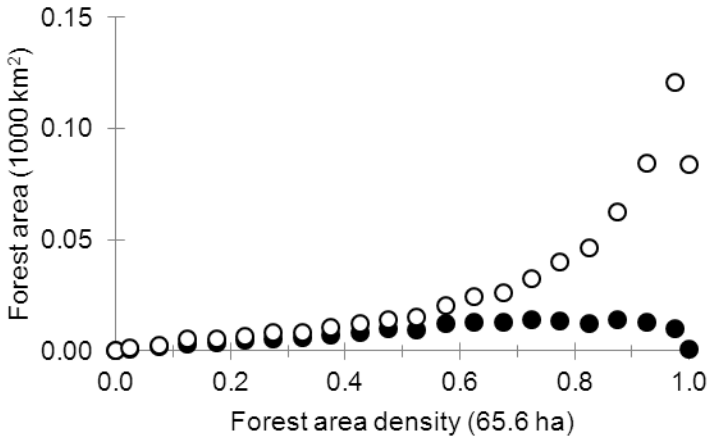


Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow (M221)

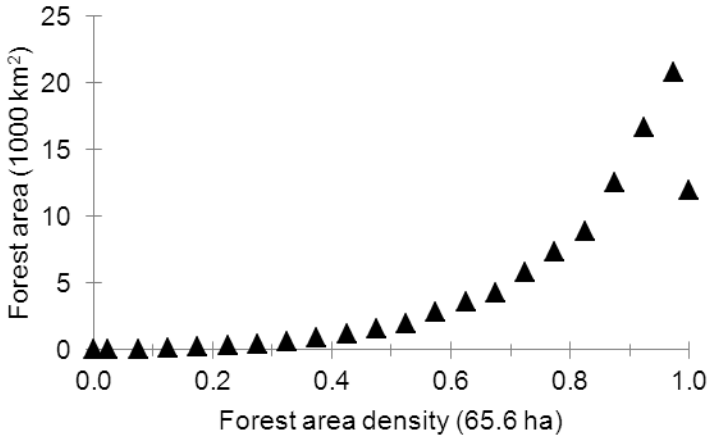
| | | |
|---|---|---|
| Forest in 2001 | 123.48 | thousand km$^2$ |
| Forest loss | 0.63 | thousand km$^2$ |
| Forest gain | 0.18 | thousand km$^2$ |
| Net change | -0.46 | thousand km$^2$ |
| Forest in 2006 | 123.02 | thousand km$^2$ |

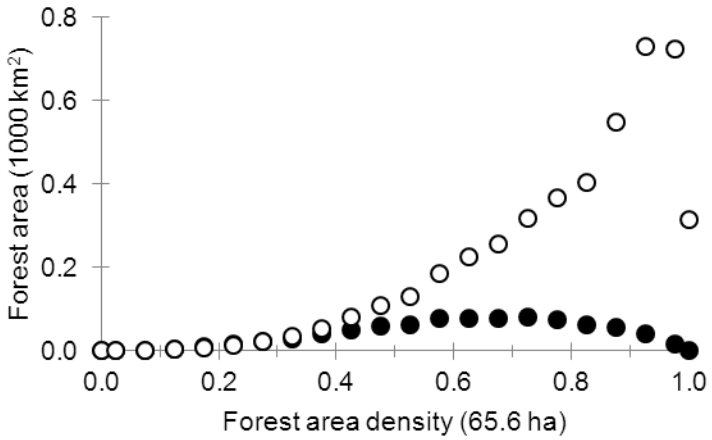


Cascade Mixed Forest - Coniferous Forest - Alpine Meadow (M242)

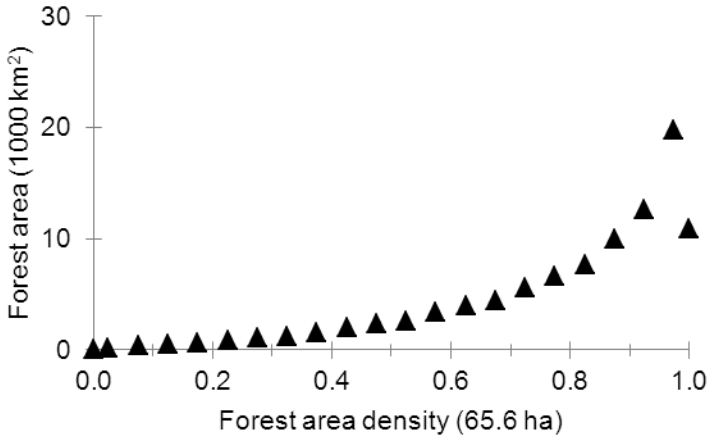
| | | |
|---|---|---|
| Forest in 2001 | 102.11 | thousand km$^2$ |
| Forest loss | 4.53 | thousand km$^2$ |
| Forest gain | 0.87 | thousand km$^2$ |
| Net change | -3.67 | thousand km$^2$ |
| Forest in 2006 | 98.44 | thousand km$^2$ |

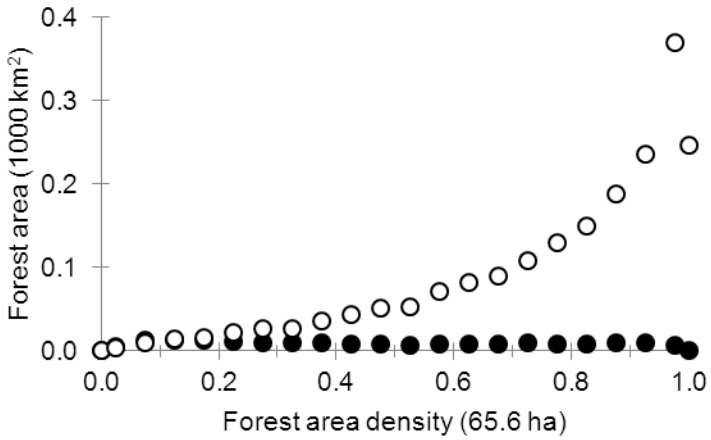


Middle Rocky Mountain Steppe - Coniferous Forest - Alpine Meadow (M332)

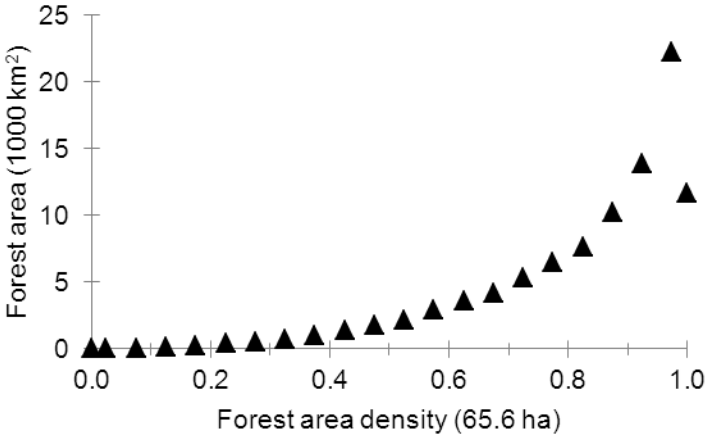
| | | |
|---|---|---|
| Forest in 2001 | 97.96 | thousand km$^2$ |
| Forest loss | 1.97 | thousand km$^2$ |
| Forest gain | 0.19 | thousand km$^2$ |
| Net change | -1.79 | thousand km$^2$ |
| Forest in 2006 | 96.18 | thousand km$^2$ |

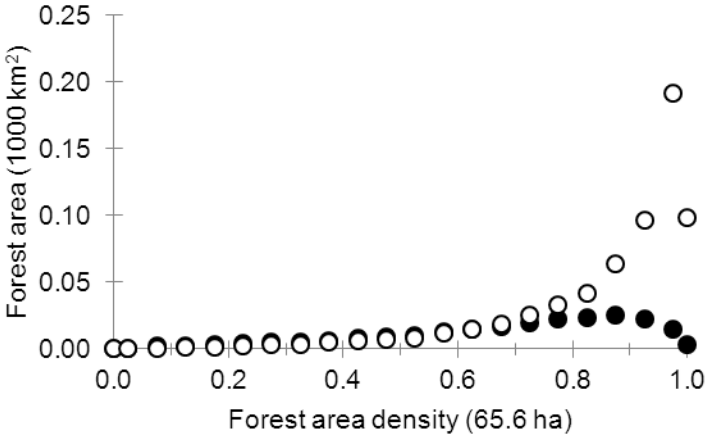


Northeastern Mixed Forest (211)

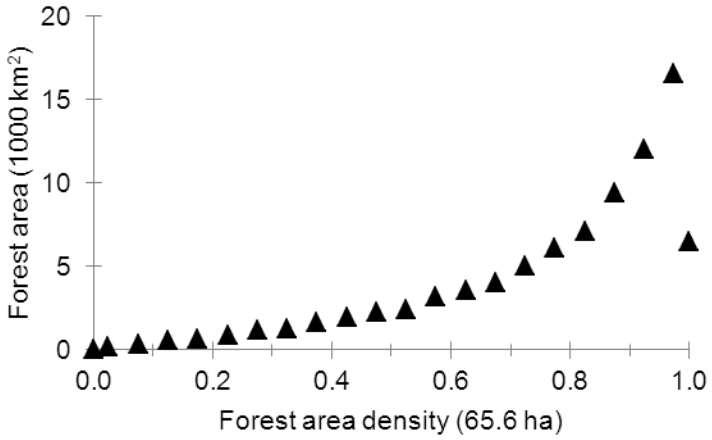
| | | |
|---|---|---|
| Forest in 2001 | 96.53 | thousand km$^2$ |
| Forest loss | 0.63 | thousand km$^2$ |
| Forest gain | 0.23 | thousand km$^2$ |
| Net change | -0.40 | thousand km$^2$ |
| Forest in 2006 | 96.12 | thousand km$^2$ |

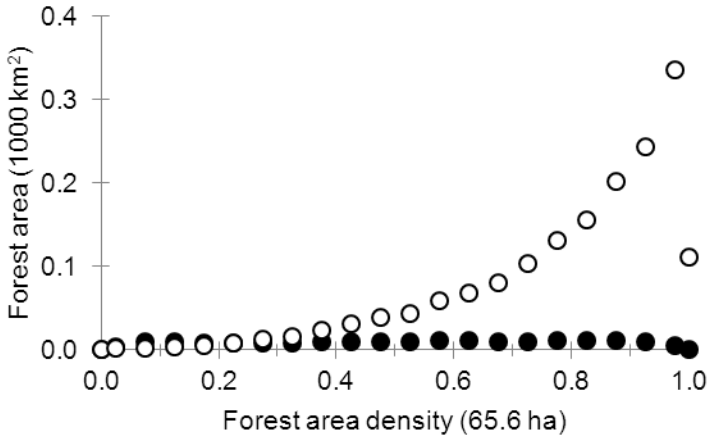


Sierran Steppe - Mixed Forest - Coniferous Forest - Alpine Meadow (M261)

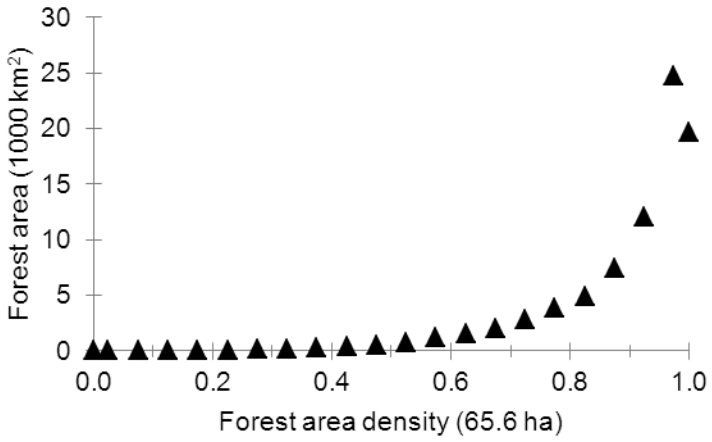
| | | |
|---|---|---|
| Forest in 2001 | 86.84 | thousand km$^2$ |
| Forest loss | 1.68 | thousand km$^2$ |
| Forest gain | 0.19 | thousand km$^2$ |
| Net change | -1.50 | thousand km$^2$ |
| Forest in 2006 | 85.35 | thousand km$^2$ |

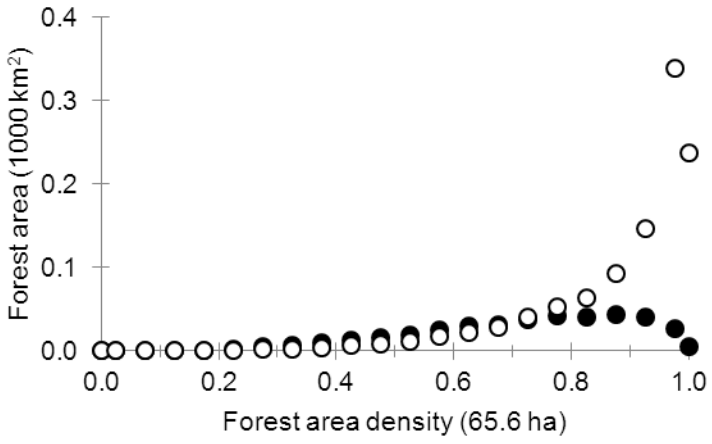


Adirondack-New England Mixed Forest--Coniferous Forest--Alpine Meadow (M211)

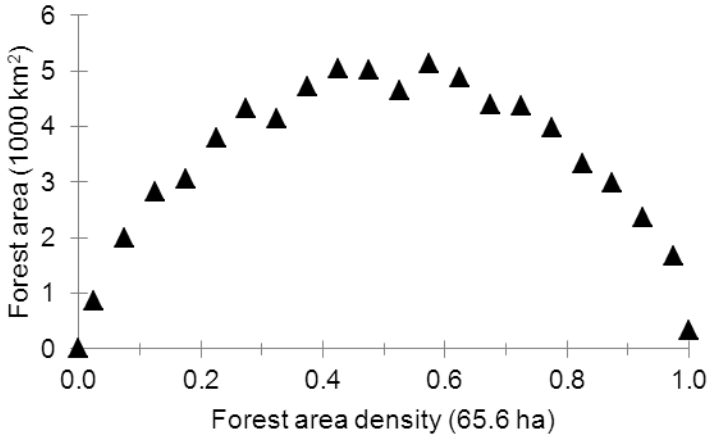
| | | |
|---|---|---|
| Forest in 2001 | 82.53 | thousand km$^2$ |
| Forest loss | 1.08 | thousand km$^2$ |
| Forest gain | 0.40 | thousand km$^2$ |
| Net change | -0.68 | thousand km$^2$ |
| Forest in 2006 | 81.85 | thousand km$^2$ |

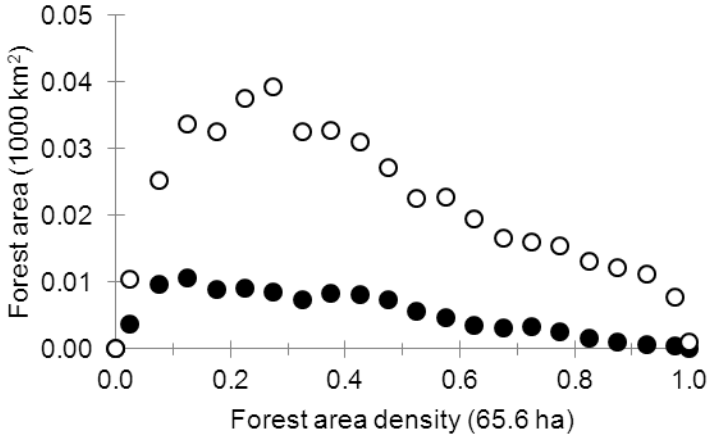


Midwest Broadleaf Forest (222)

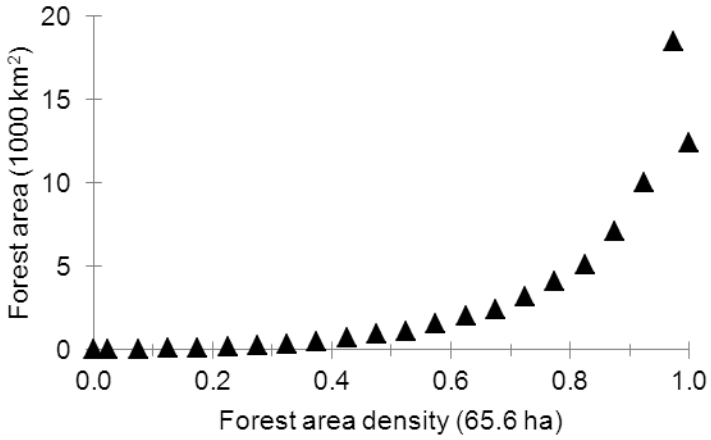
| | | |
|---|---|---|
| Forest in 2001 | 73.85 | thousand km$^2$ |
| Forest loss | 0.46 | thousand km$^2$ |
| Forest gain | 0.11 | thousand km$^2$ |
| Net change | -0.35 | thousand km$^2$ |
| Forest in 2006 | 73.50 | thousand km$^2$ |

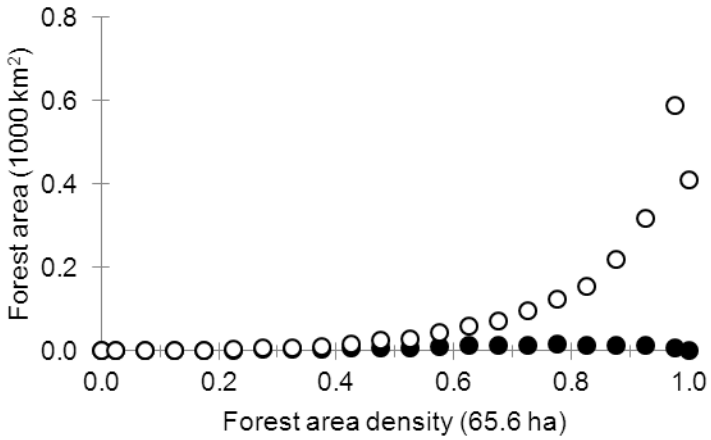


Northern Rocky Mountain Forest-Steppe - Coniferous Forest - Alpine Meadow (M333)

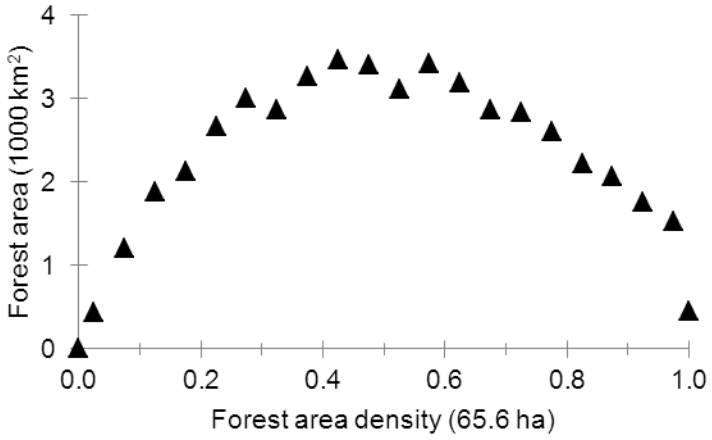
| | | |
|---|---|---|
| Forest in 2001 | 70.93 | thousand km$^2$ |
| Forest loss | 2.20 | thousand km$^2$ |
| Forest gain | 0.16 | thousand km$^2$ |
| Net change | -2.03 | thousand km$^2$ |
| Forest in 2006 | 68.90 | thousand km$^2$ |

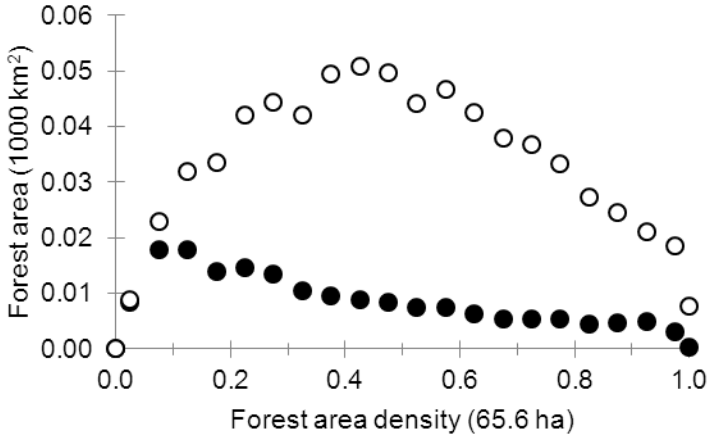


Prairie Parkland (Subtropical) (255)

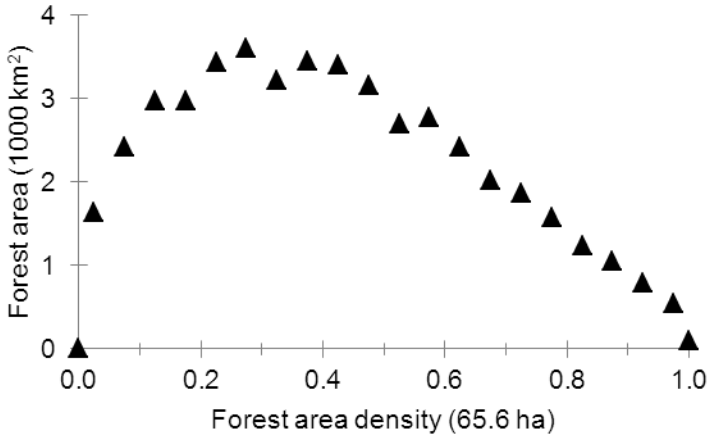
| | | |
|---|---|---|
| Forest in 2001 | 50.39 | thousand km$^2$ |
| Forest loss | 0.72 | thousand km$^2$ |
| Forest gain | 0.18 | thousand km$^2$ |
| Net change | -0.54 | thousand km$^2$ |
| Forest in 2006 | 49.85 | thousand km$^2$ |

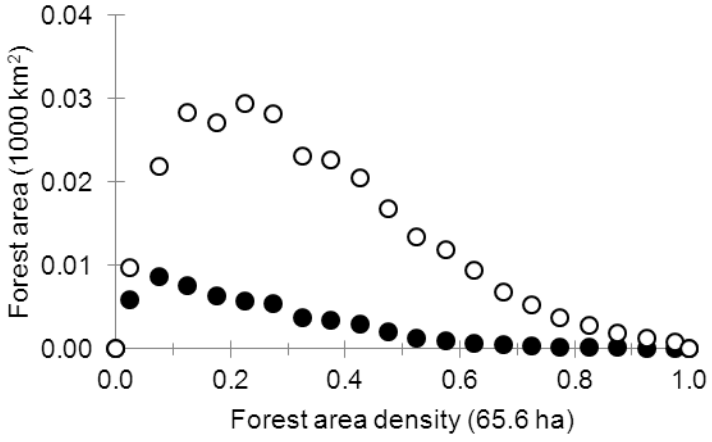


Prairie Parkland (Temperate) (251)

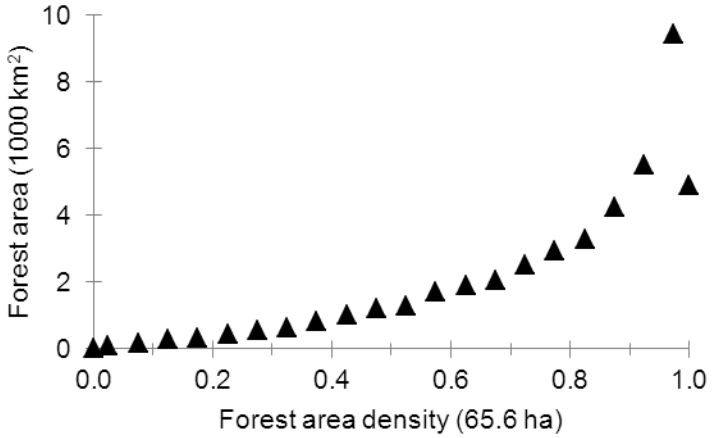
| | | |
|---|---|---|
| Forest in 2001 | 47.39 | thousand km$^2$ |
| Forest loss | 0.29 | thousand km$^2$ |
| Forest gain | 0.06 | thousand km$^2$ |
| Net change | -0.23 | thousand km$^2$ |
| Forest in 2006 | 47.16 | thousand km$^2$ |

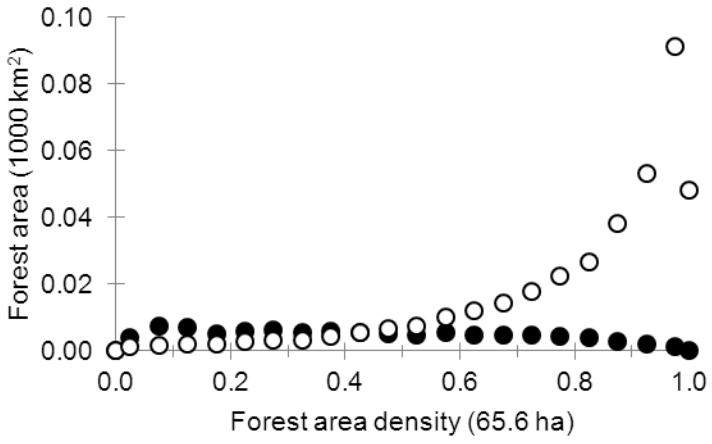


Nevada-Utah Mountains Semi-Desert - Coniferous Forest - Alpine Meadow (M341)

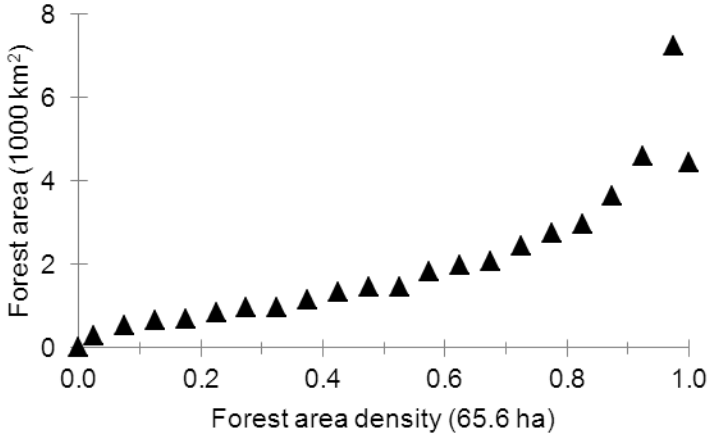
| | | |
|---|---|---|
| Forest in 2001 | 45.35 | thousand km$^2$ |
| Forest loss | 0.37 | thousand km$^2$ |
| Forest gain | 0.10 | thousand km$^2$ |
| Net change | -0.28 | thousand km$^2$ |
| Forest in 2006 | 45.07 | thousand km$^2$ |

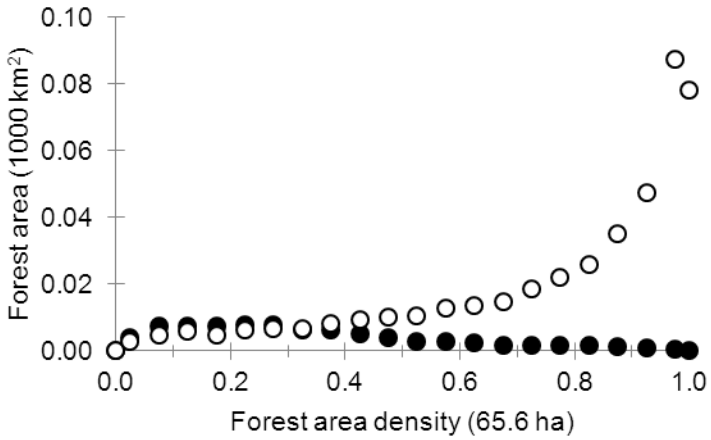


Colorado Plateau Semi-Desert (313)

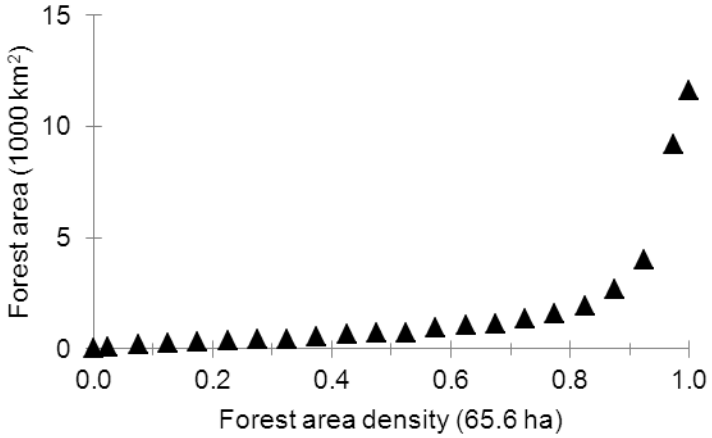
| | | |
|---|---|---|
| Forest in 2001 | 44.28 | thousand km$^2$ |
| Forest loss | 0.43 | thousand km$^2$ |
| Forest gain | 0.08 | thousand km$^2$ |
| Net change | -0.35 | thousand km$^2$ |
| Forest in 2006 | 43.93 | thousand km$^2$ |

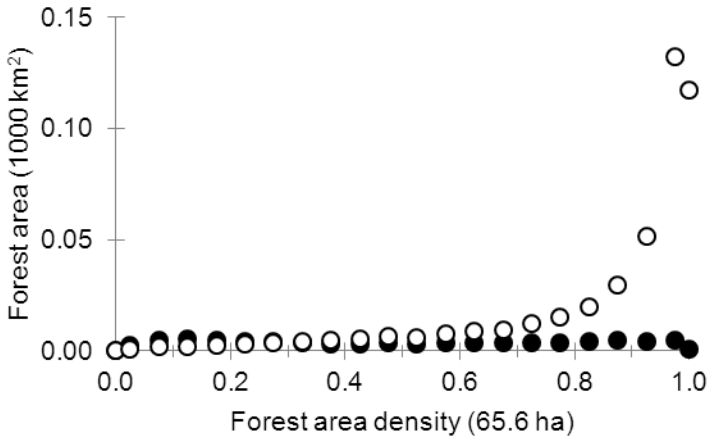


Arizona-New Mexico Mountains Semi-Desert - Open Woodland - Coniferous Forest – Alpine Meadow (M313)

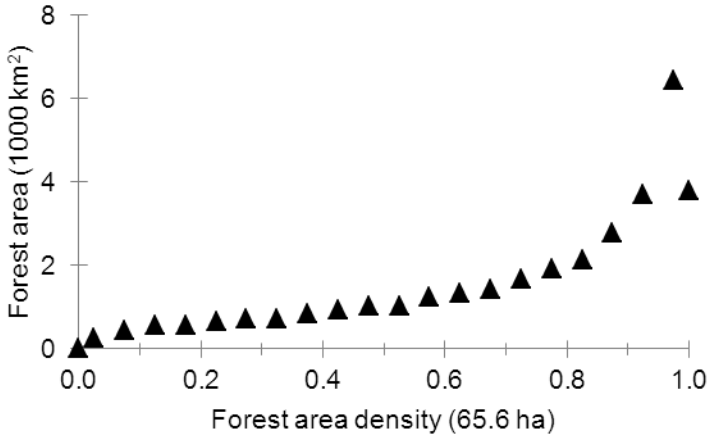
| | | |
|---|---|---|
| Forest in 2001 | 40.12 | thousand km$^2$ |
| Forest loss | 0.45 | thousand km$^2$ |
| Forest gain | 0.08 | thousand km$^2$ |
| Net change | -0.37 | thousand km$^2$ |
| Forest in 2006 | 39.76 | thousand km$^2$ |

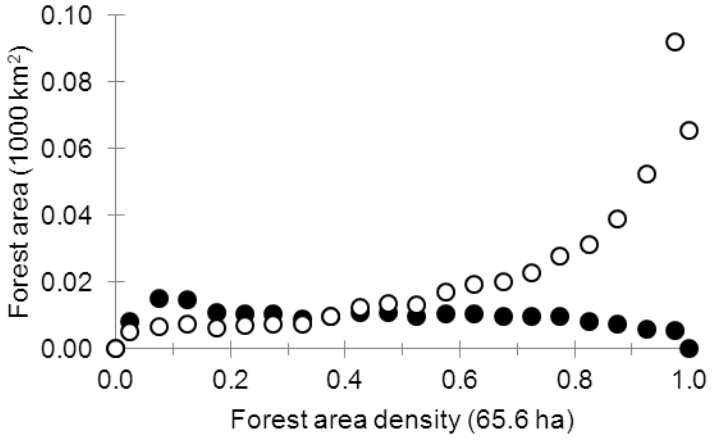


Intermountain Semi-Desert and Desert (341)

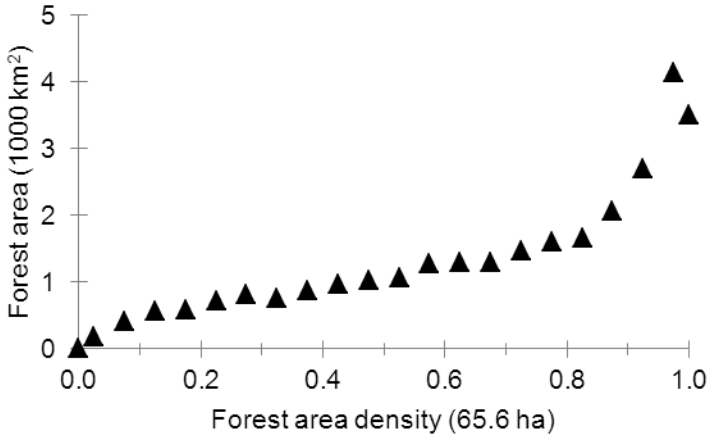
| | | |
|---|---|---|
| Forest in 2001 | 34.19 | thousand km$^2$ |
| Forest loss | 0.48 | thousand km$^2$ |
| Forest gain | 0.20 | thousand km$^2$ |
| Net change | -0.29 | thousand km$^2$ |
| Forest in 2006 | 33.90 | thousand km$^2$ |

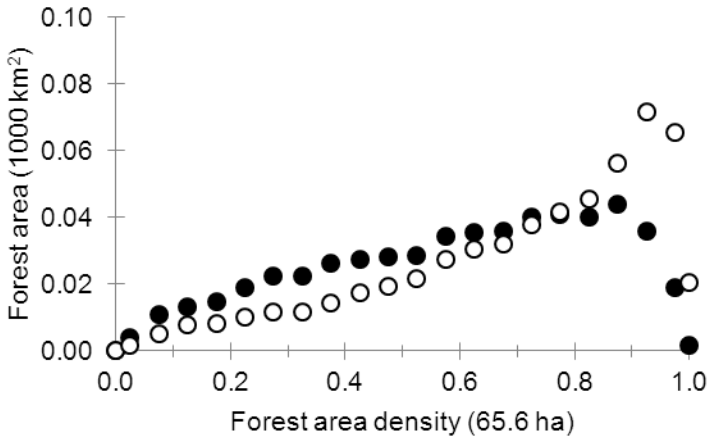


Lower Mississippi Riverine Forest (234)

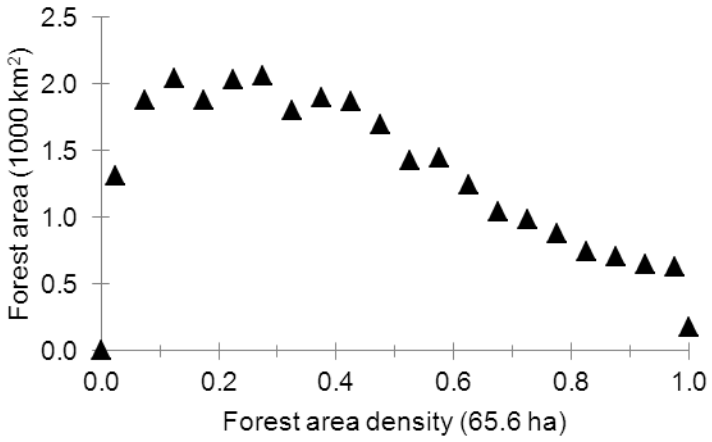
| | | |
|---|---|---|
| Forest in 2001 | 29.01 | thousand km$^2$ |
| Forest loss | 0.56 | thousand km$^2$ |
| Forest gain | 0.55 | thousand km$^2$ |
| Net change | -0.01 | thousand km$^2$ |
| Forest in 2006 | 29.00 | thousand km$^2$ |

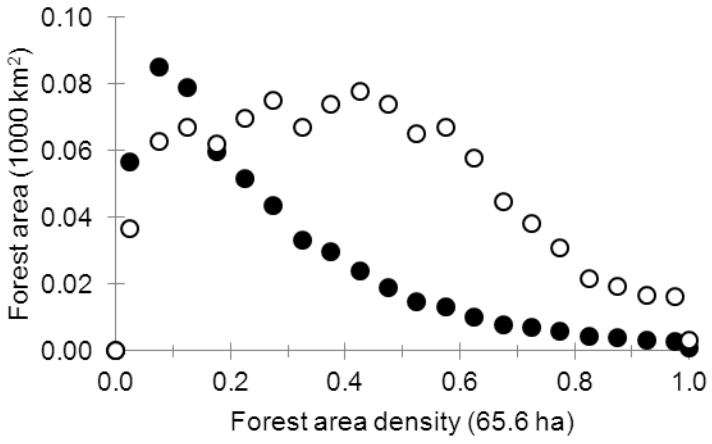


Great Plains - Palouse Dry Steppe (331)

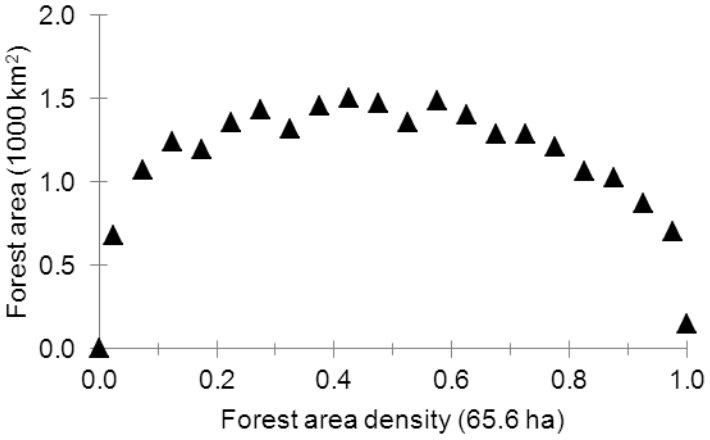
| | | |
|---|---|---|
| Forest in 2001 | 28.40 | thousand km$^2$ |
| Forest loss | 1.05 | thousand km$^2$ |
| Forest gain | 0.56 | thousand km$^2$ |
| Net change | -0.49 | thousand km$^2$ |
| Forest in 2006 | 27.90 | thousand km$^2$ |

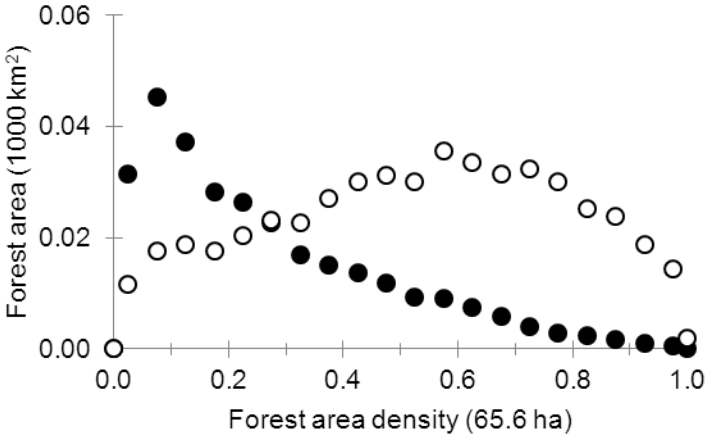


Southwest Plateau and Plains Dry Steppe and Shrub (315)

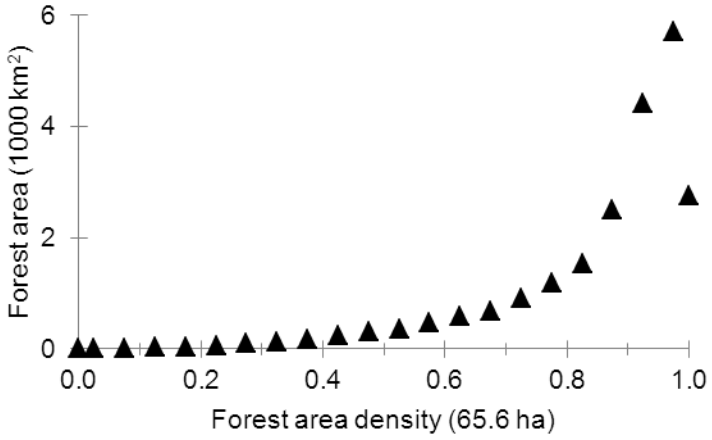
| | | |
|---|---|---|
| Forest in 2001 | 24.58 | thousand km$^2$ |
| Forest loss | 0.50 | thousand km$^2$ |
| Forest gain | 0.29 | thousand km$^2$ |
| Net change | -0.21 | thousand km$^2$ |
| Forest in 2006 | 24.37 | thousand km$^2$ |

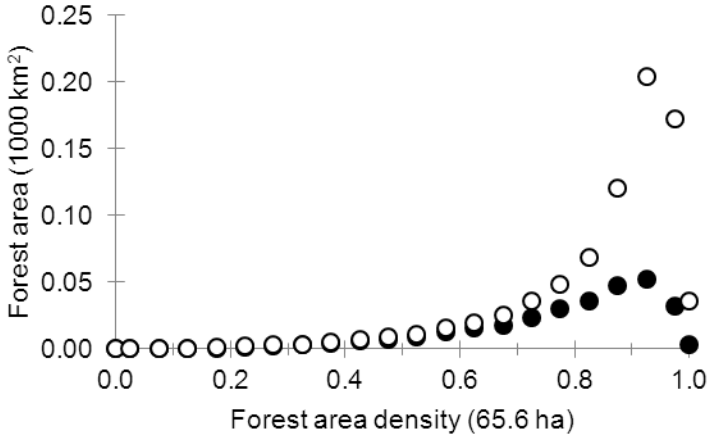


Ouachita Mixed Forest-Meadow (M231)

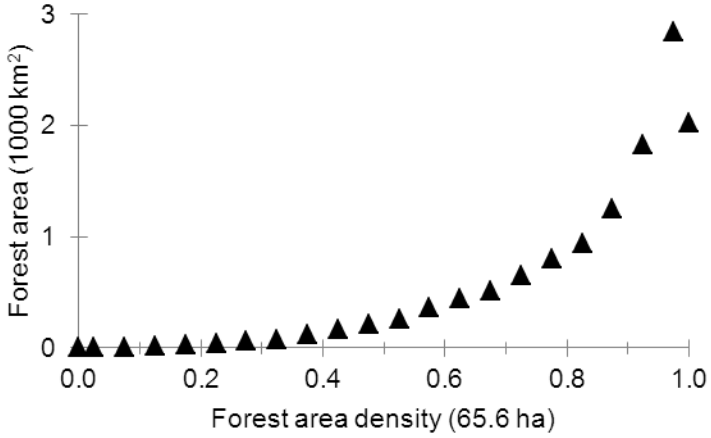
| | | |
|---|---|---|
| Forest in 2001 | 22.17 | thousand km$^2$ |
| Forest loss | 0.79 | thousand km$^2$ |
| Forest gain | 0.31 | thousand km$^2$ |
| Net change | -0.48 | thousand km$^2$ |
| Forest in 2006 | 21.69 | thousand km$^2$ |

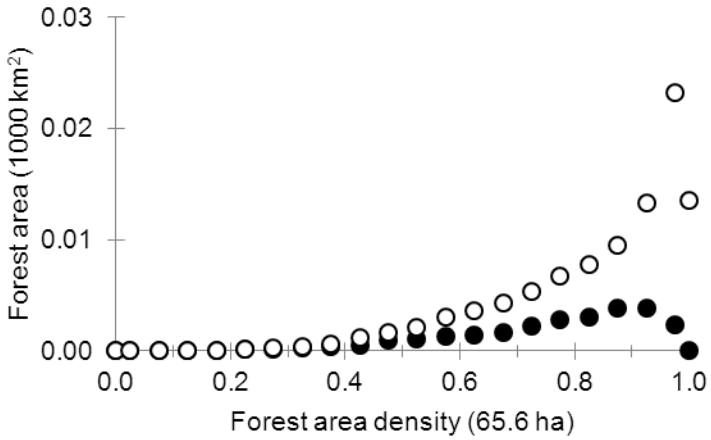


Ozark Broadleaf Forest (M223)

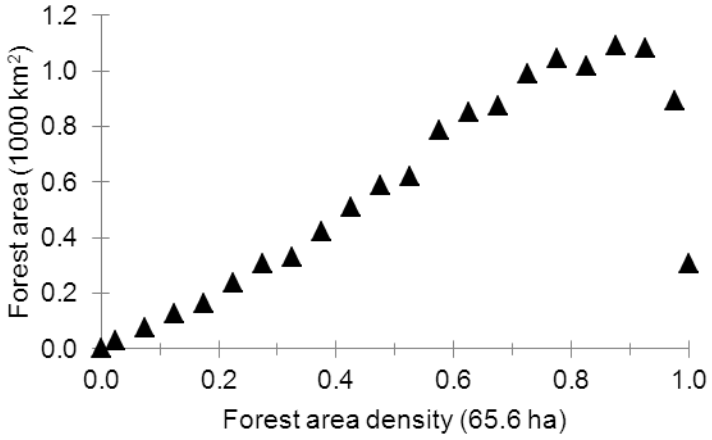
| | | |
|---|---|---|
| Forest in 2001 | 12.63 | thousand km$^2$ |
| Forest loss | 0.10 | thousand km$^2$ |
| Forest gain | 0.03 | thousand km$^2$ |
| Net change | -0.07 | thousand km$^2$ |
| Forest in 2006 | 12.56 | thousand km$^2$ |

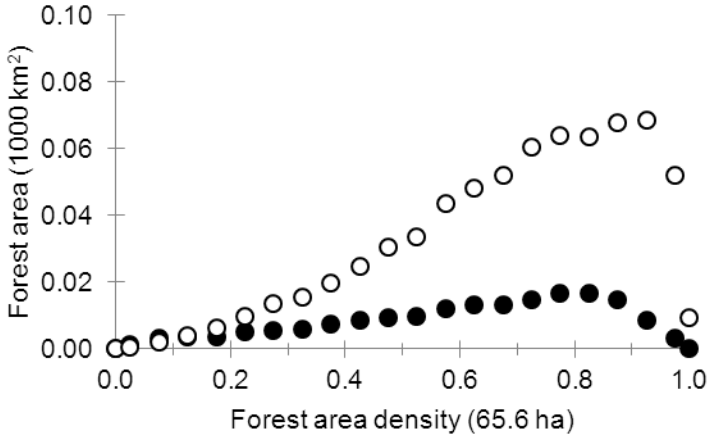


Pacific Lowland Mixed Forest (242)

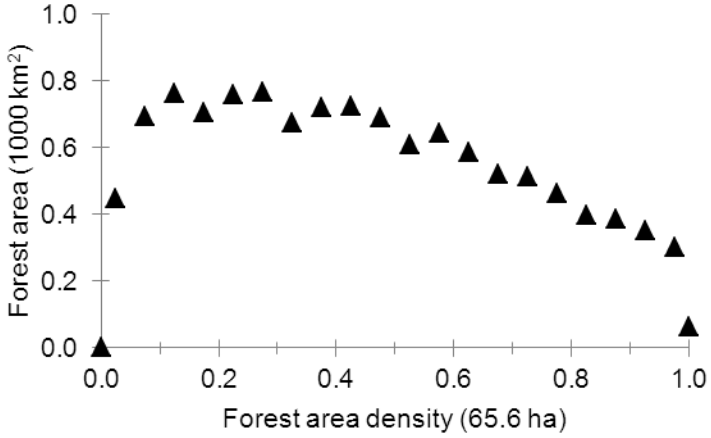
| | | |
|---|---|---|
| Forest in 2001 | 12.35 | thousand $km^2$ |
| Forest loss | 0.69 | thousand $km^2$ |
| Forest gain | 0.18 | thousand $km^2$ |
| Net change | -0.51 | thousand $km^2$ |
| Forest in 2006 | 11.83 | thousand $km^2$ |

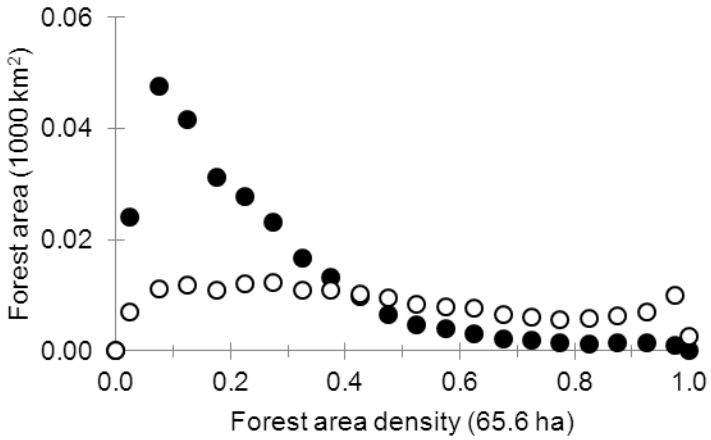


Intermountain Semi-Desert (342)

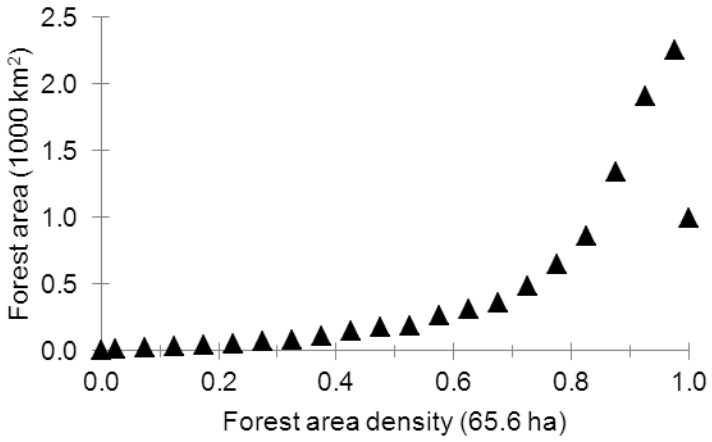
| | | |
|---|---|---|
| Forest in 2001 | 11.78 | thousand km$^2$ |
| Forest loss | 0.18 | thousand km$^2$ |
| Forest gain | 0.27 | thousand km$^2$ |
| Net change | 0.08 | thousand km$^2$ |
| Forest in 2006 | 11.87 | thousand km$^2$ |

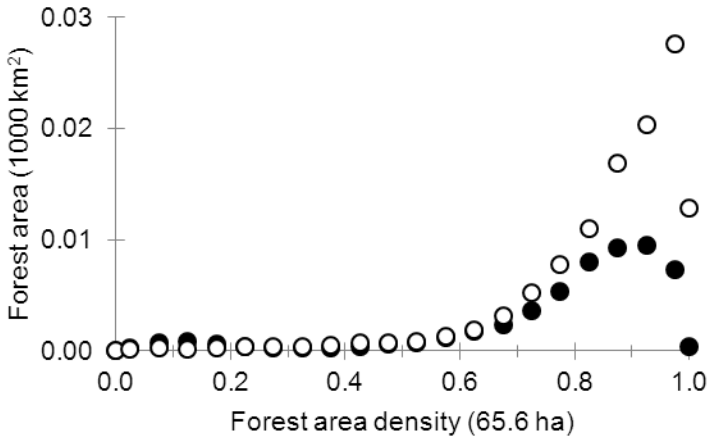


California Coastal Steppe - Mixed Forest - Redwood Forest (263)

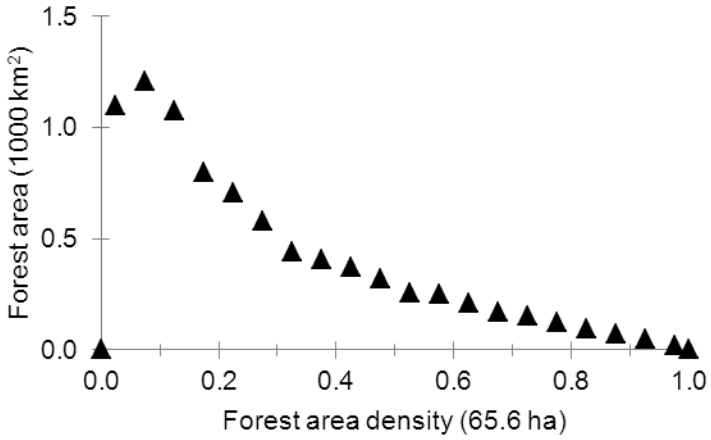
| | | |
|---|---|---|
| Forest in 2001 | 10.36 | thousand km$^2$ |
| Forest loss | 0.11 | thousand km$^2$ |
| Forest gain | 0.05 | thousand km$^2$ |
| Net change | -0.06 | thousand km$^2$ |
| Forest in 2006 | 10.30 | thousand km$^2$ |

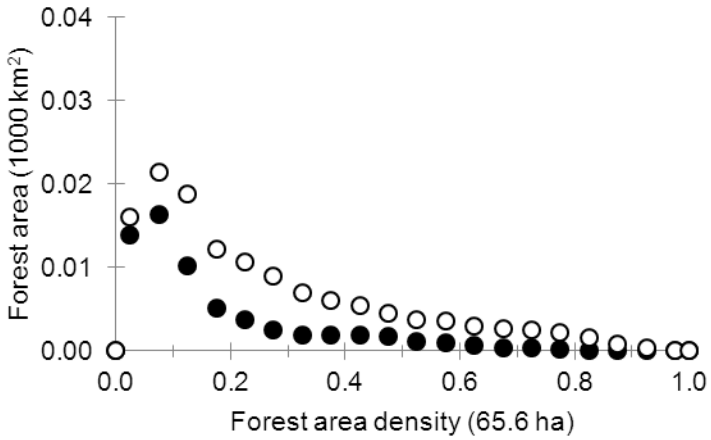


Great Plains Steppe (332)

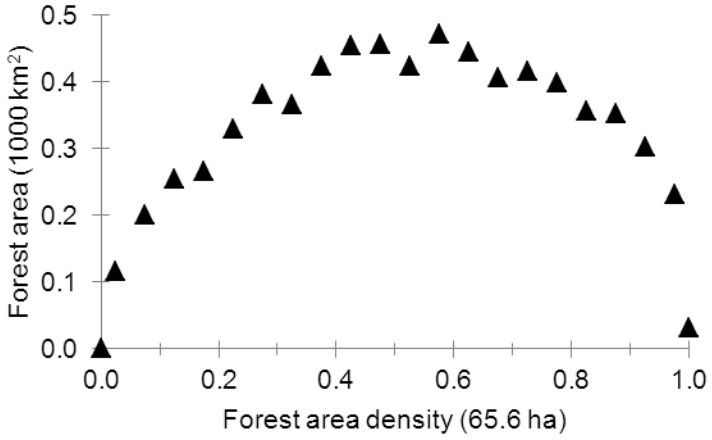
| | | |
|---|---|---|
| Forest in 2001 | 8.40 | thousand km$^2$ |
| Forest loss | 0.13 | thousand km$^2$ |
| Forest gain | 0.06 | thousand km$^2$ |
| Net change | -0.07 | thousand km$^2$ |
| Forest in 2006 | 8.33 | thousand km$^2$ |

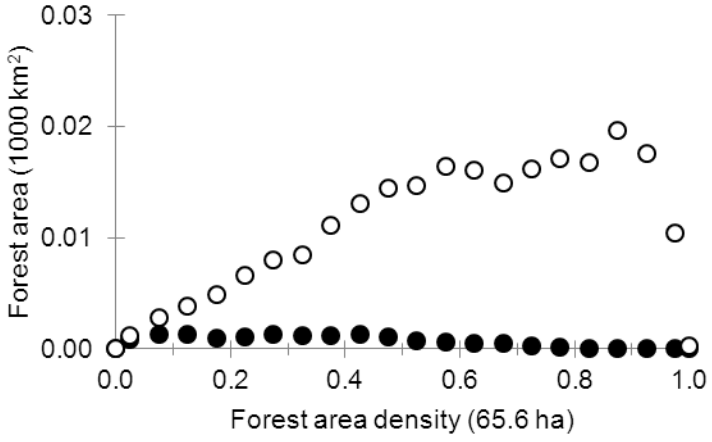


California Coastal Range Open Woodland - Shrub - Coniferous Forest - Meadow (M262)

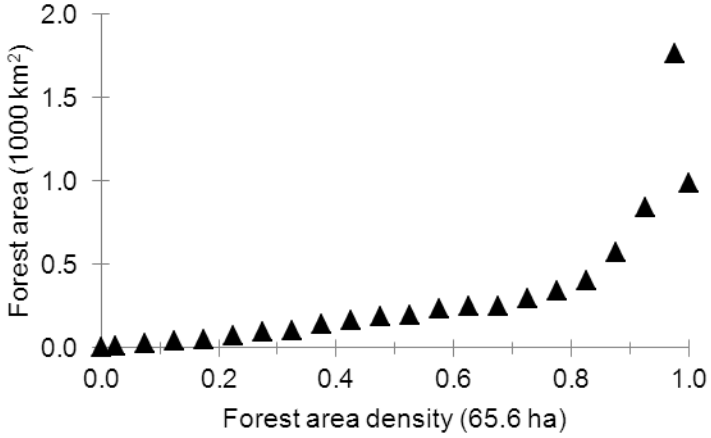
| | | |
|---|---|---|
| Forest in 2001 | 7.09 | thousand km$^2$ |
| Forest loss | 0.23 | thousand km$^2$ |
| Forest gain | 0.01 | thousand km$^2$ |
| Net change | -0.22 | thousand km$^2$ |
| Forest in 2006 | 6.87 | thousand km$^2$ |

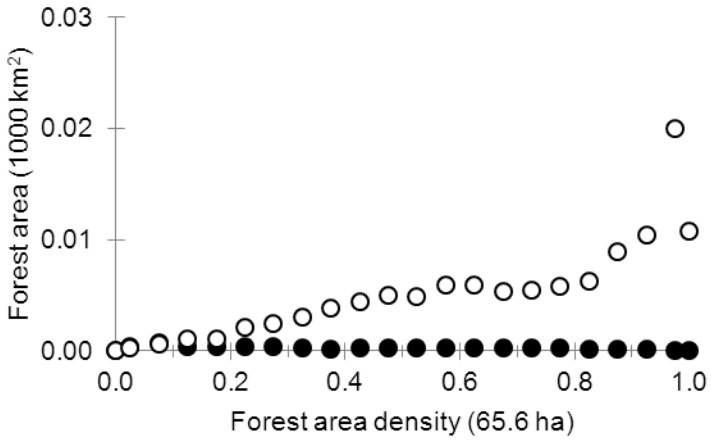


Black Hills Coniferous Forest (M334)

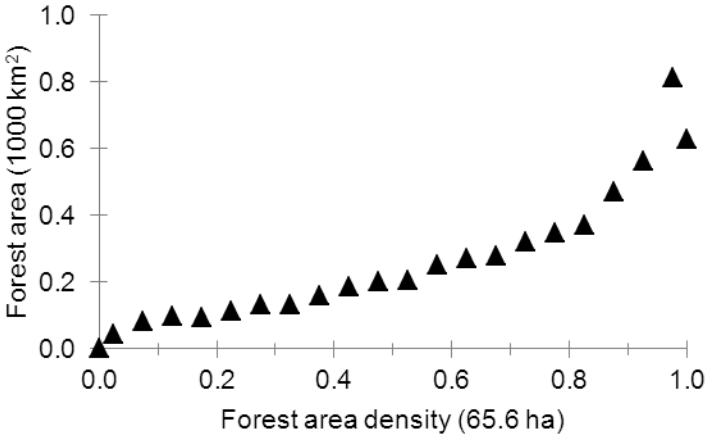
| | | |
|---|---|---|
| Forest in 2001 | 7.02 | thousand km$^2$ |
| Forest loss | 0.11 | thousand km$^2$ |
| Forest gain | 0.01 | thousand km$^2$ |
| Net change | -0.11 | thousand km$^2$ |
| Forest in 2006 | 6.91 | thousand km$^2$ |

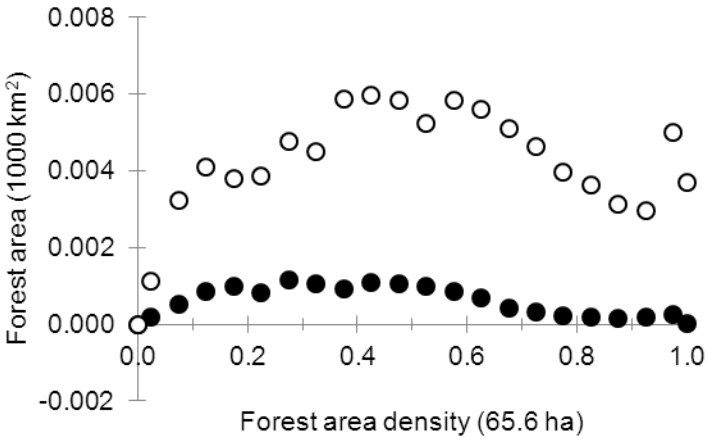


Everglades (411)

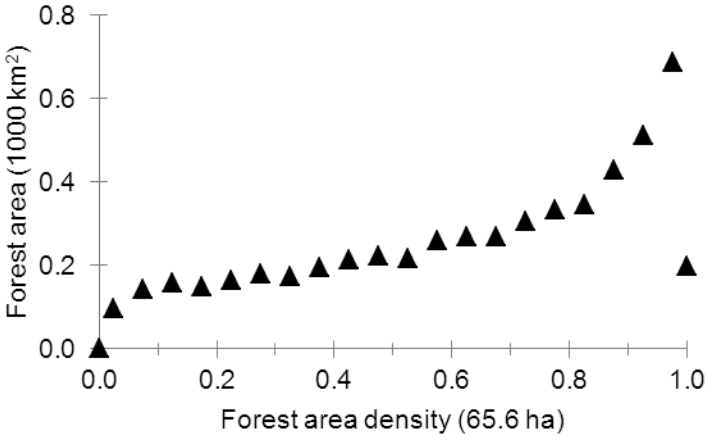
| | | |
|---|---|---|
| Forest in 2001 | 5.76 | thousand km$^2$ |
| Forest loss | 0.09 | thousand km$^2$ |
| Forest gain | 0.01 | thousand km$^2$ |
| Net change | -0.08 | thousand km$^2$ |
| Forest in 2006 | 5.69 | thousand km$^2$ |

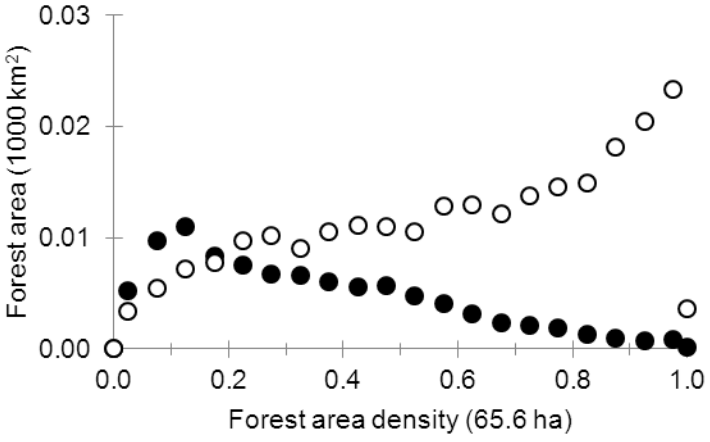


American Semi-Desert and Desert (322)

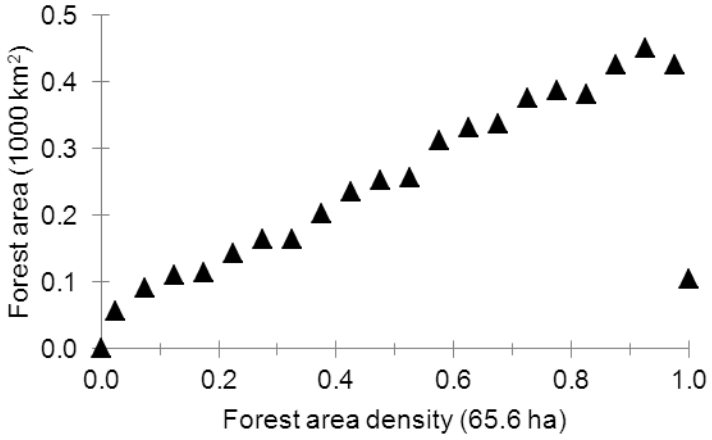
| | | |
|---|---|---|
| Forest in 2001 | 5.52 | thousand km$^2$ |
| Forest loss | 0.24 | thousand km$^2$ |
| Forest gain | 0.10 | thousand km$^2$ |
| Net change | -0.15 | thousand km$^2$ |
| Forest in 2006 | 5.37 | thousand km$^2$ |

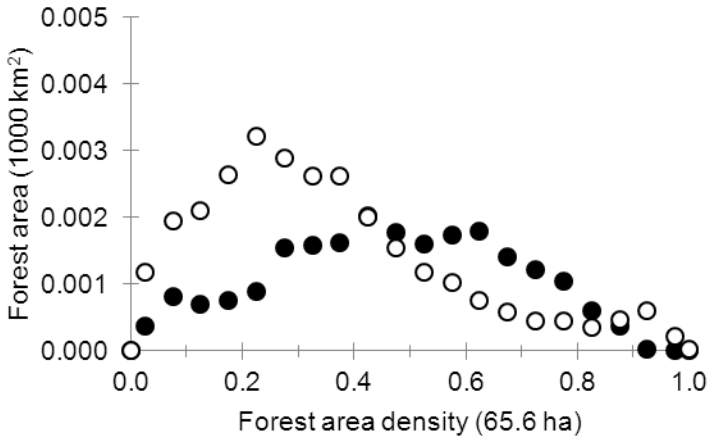


California Coastal Chaparral Forest and Shrub (261)

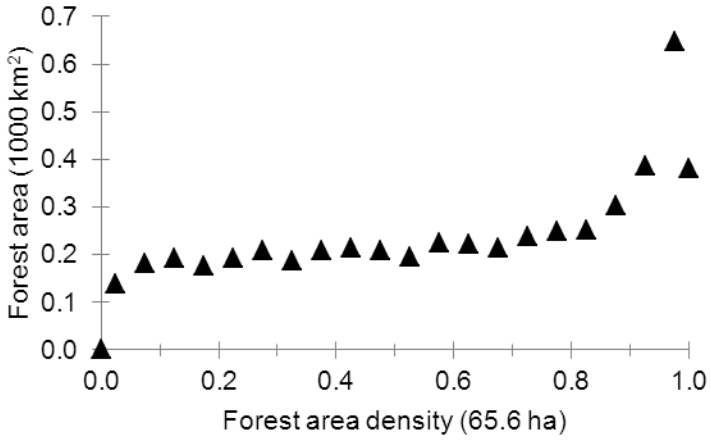
| | | |
|---|---|---|
| Forest in 2001 | 5.33 | thousand km$^2$ |
| Forest loss | 0.03 | thousand km$^2$ |
| Forest gain | 0.02 | thousand km$^2$ |
| Net change | -0.01 | thousand km$^2$ |
| Forest in 2006 | 5.32 | thousand km$^2$ |

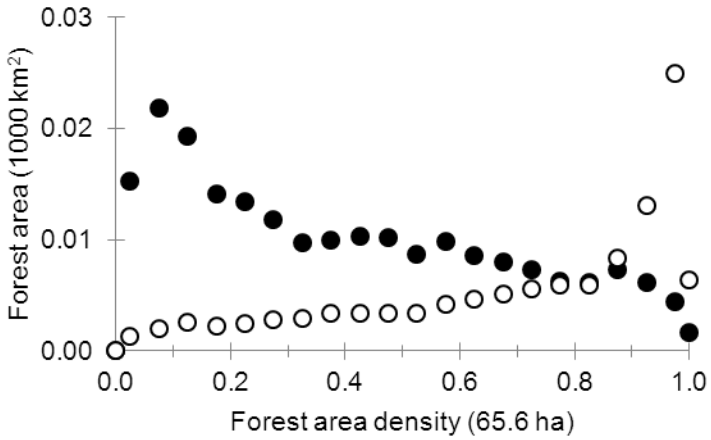


Chihuahuan Semi-Desert (321)

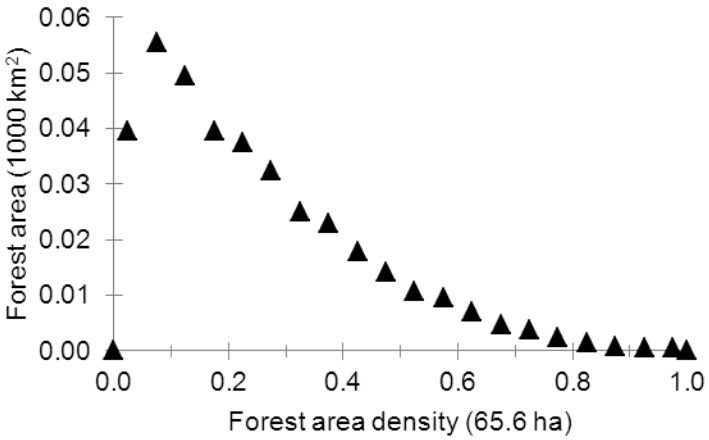
| | | |
|---|---|---|
| Forest in 2001 | 5.22 | thousand km$^2$ |
| Forest loss | 0.11 | thousand km$^2$ |
| Forest gain | 0.21 | thousand km$^2$ |
| Net change | 0.10 | thousand km$^2$ |
| Forest in 2006 | 5.31 | thousand km$^2$ |

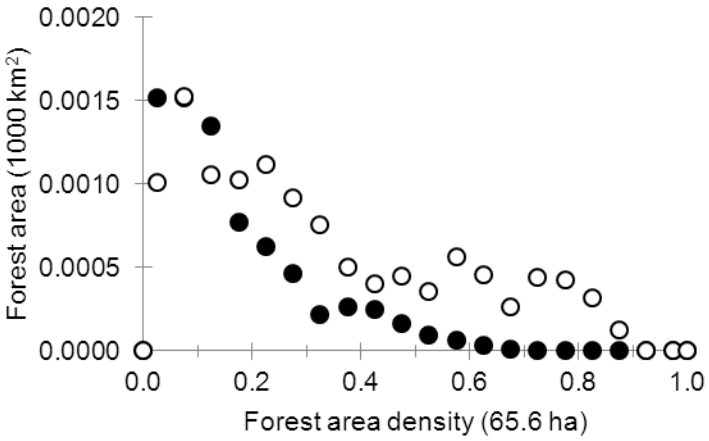


California Dry Steppe (262)

| | | |
|---|---|---|
| Forest in 2001 | 0.38 | thousand km$^2$ |
| Forest loss | 0.01 | thousand km$^2$ |
| Forest gain | 0.01 | thousand km$^2$ |
| Net change | 0.00 | thousand km$^2$ |
| Forest in 2006 | 0.37 | thousand km$^2$ |



## 4. Supplementary References.

S1. Stein, S., et al. Forests on the edge: housing development on America's private forests. Gen. Tech. Rep. PNW-GTR-636, USDA Forest Service, Portland, OR (2005).

S2. United States Department of Agriculture, Forest Service. National report on sustainable forests – 2010. FS Publication FS-979, USDA Forest Service, Washington, DC (2011).

S3. Fry, J.A., et al. Completion of the 2006 National Land Cover Database for the conterminous United States. *Photogram. Eng. Remote Sensing* **108**, 858-859 (2011).

S4. Bailey, R.G. Description of the ecoregions of the United States. Misc. Publ. No. 1391 rev., USDA Forest Service, Washington, DC (1995).

S5. McNab, W.H., et al. Description of ecological subregions: sections of the conterminous United States. Gen. Tech. Rep. WO-76B, USDA Forest Service, Washington, DC (2007).

S6. Cleland, D.T., et al. Ecological subregions: sections and subsections of the conterminous United States [1:3,500,000] [CD-ROM]. Gen. Tech. Rep. WO-76, USDA Forest Service, Washington, DC (2007).