# ASSESSMENT OF LAND USE CHANGE IN THE COTERMINOUS UNITED STATES AND ALASKA FOR GLOBAL ASSESSMENT OF FOREST LOSS CONDUCTED BY THE FOOD AND AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS

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**Abstract.**—The Food and Agricultural Organization (FAO) of the United Nations conducted a global assessment for forest change in 2010 using satellite imagery from 1990, 2000, and 2005. The U.S. Forest Service was responsible for assessing forest change in the United States. A polygon-based, stratified sampling design developed by FAO was used to assess change in forest area within 10 km by 10 km tiles at every 1° from 1990, 2000, and 2006 using Landsat TM and ETM+ data. The assessment included: 1) mapping land cover (tree and non-tree) and land use (forest and nonforest) within these tiles for each time period; 2) a segment-based analysis of land use transition between 1990 and 2000, and 2000 and 2005; 3) reporting forest change (area) by FAO ecoregions; and 4) comparing the estimates from segment-based analysis of land cover and land use change in the coterminous United States between the study periods. The current paper summarizes the estimates of land use change by FAO ecoregions in the United States between 1990 and 2000, and 2000 and 2006 based on the survey and compares land cover and land use change estimates for the coterminous United States. Our analysis shows that most forested and nonforested areas remained unchanged during each time period. Overall rate of forest loss was higher between 1990 and 2000 than between 2000 and 2006. Net forest loss in the United States for the entire study period was 0.79 percent. The ecoregion stratum subtropical humid forest showed the highest net forest loss, followed by temperate continental forest and temperate mountain system. Net forest and tree cover change was higher in 1990-2000 than 2000-2006 in the coterminous United States and confirmed that land cover change does not necessarily indicate land use change.

## INTRODUCTION

The Remote Sensing Application Center conducted a survey of land cover and land use change in the United States (including Alaska) using a forest sampling design developed by the Food and Agricultural Organization (FAO) of the United Nations (Ridder 2007) for global assessment of forest loss. The survey included a segment-based assessment of land use and land cover types within 10 km by 10 km grids at every 1° interval for 1990, 2000, and 2006 (Fig.1). Land cover (tree, woodland, other, and water) and land use (agriculture, bare, built-up, forest, natural herb, other wooded land, wetland, and water) were mapped within these grids (Fig.1). For simplicity of analysis the land cover types were merged into two broad classes "Tree" and "NonTree" while the land use types were merged into "Forest" and "NonForest"' classes to assess change and meet FAO's goal of global assessment of forest loss (Table 1). Woodland and other wooded land were included in "NonTree" and "NonForest,"

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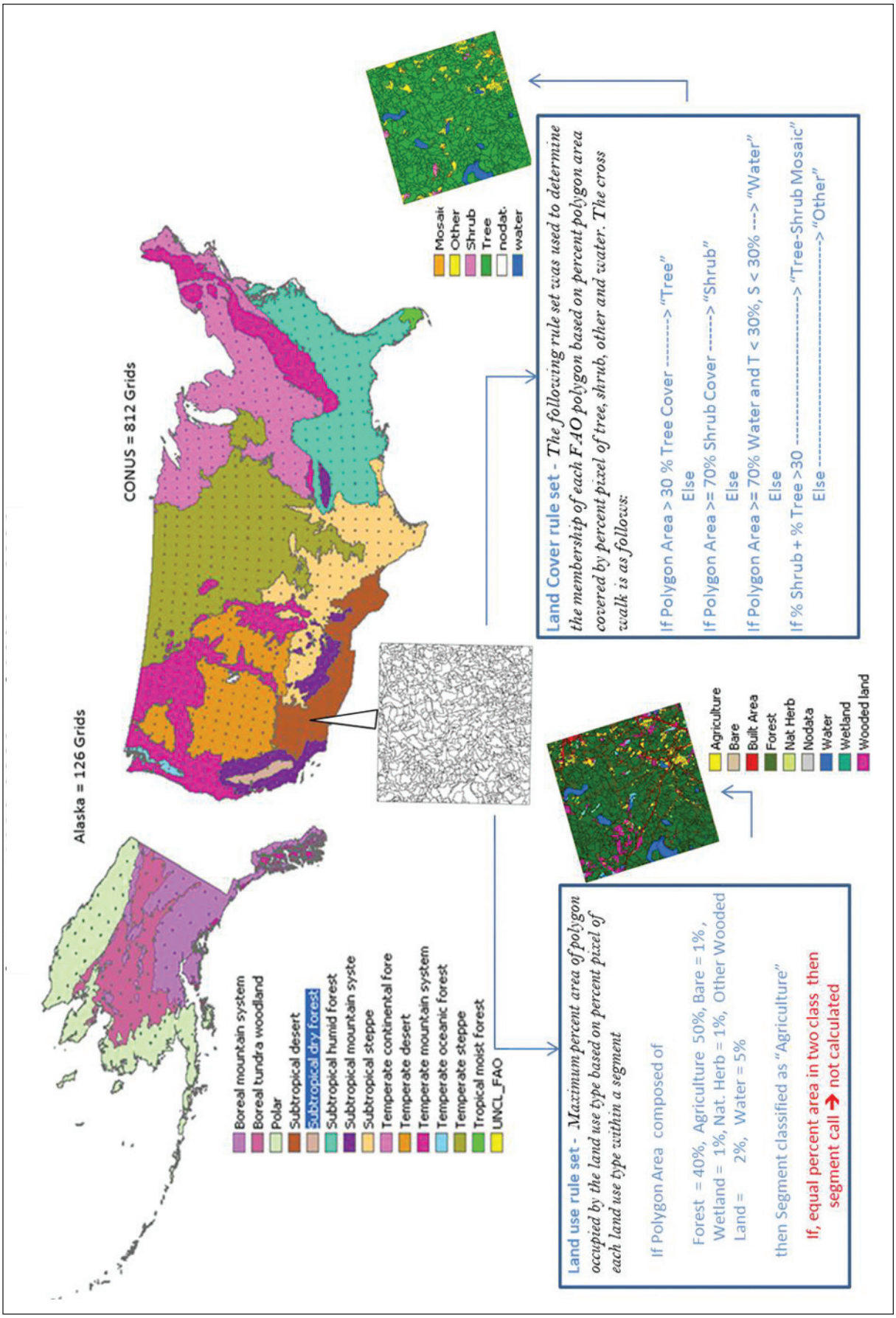



Figure 1.—Distribution of the 10 km x km study grids and the rule set used to classify the segments within the grids into land cover and land use types based on the corresponding NLCD data for assessing land use and land cover changes within the United States between 1990, 2000, and 2006. These rule sets were only used to classify the segments within the survey grids within CONUS based on pixel (30 m resolution) information available from NLCD data cross walked to corresponding land use and land cover product for each time period.

**Table 1. Cross walk between NLCD land cover types and FAO land use and land cover types**

| NLCD Class (1990, 2000, 2006) | FAO Classes-Level I | | FAO Classes-Level II | |
|---|---|---|---|---|
| | Land Use | Land Cover | Land Use | Land Cover |
| Deciduous Forest | Forest | Tree | Forest | Tree |
| Evergreen Forest | Forest | Tree | Forest | Tree |
| Mixed Forest | Forest | Tree | Forest | Tree |
| High Intensity Residential | Built-Up | Other | NonForest | NonTree |
| Low Intensity Residential | Built-Up | Other | NonForest | NonTree |
| Commercial Industrial | Built-Up | Other | NonForest | NonTree |
| Open Water | Water | Water | NonForest | NonTree |
| Orchard/Vineyards | Agriculture | Other | NonForest | NonTree |
| BareRock/Sand/Fallow/Barren | Bare | Other | NonForest | NonTree |
| Pasture/Hay | Natural Herb | Other | NonForest | NonTree |
| Grassland/Herbaceous | Natural Herb | Other | NonForest | NonTree |
| Emergent Herbaceous Wetlands | Wetlands | Other | NonForest | NonTree |
| Row Crop/Small Grain | Agriculture | Other | NonForest | NonTree |
| Shrubland | Woodland | Shrub | NonForest | NonTree |
| Transitional | Woodland | Shrub | NonForest | NonTree |
| Urban | Built-Up | Other | NonForest | NonTree |
| Woody Wetland | Other Wooded Land | Other | NonForest | NonTree |
| Quarry, Mine | Bare | Other | NonForest | NonTree |
| Perennial Ice/Snow | Bare | Other | NonForest | NonTree |
| Dwarf Scrub | Other Wooded Land | Shrub | NonForest | NonTree |

respectively (Table 1). Changes in land use and land cover within these grids were summarized by different ecoregions (Commission for Environment Cooperation 2006) in the United States between 1990 and 2000, and 2000 and 2006. The current paper provides an overview of the methods and assessment of land use change conducted in the United States.

## METHODS

We assessed forest loss in the entire United States based on 938 grids provided by FAO (Fig.1). The following section discusses the methods used for mapping, change detection, and validation of change in the coterminous United States (CONUS) (812 grids) and Alaska (126 grids).

### Mapping

**(i) Coterminous United States.** The National Land Cover Database (NLCD) product (30-m resolution raster, available from the corresponding time period [1990, 2001, and 2006]) was used for the assessment in the coterminous United States (Fry et al. 2011, Homer et al. 2007, Vogelmann et al. 2001). The NLCD land cover types corresponded closely to FAO's land cover and land use classes of interest by FAO (Table 1). The segments within the grids (n=812) were classified based on pixel (30-m resolution) using information available from NLCD-derived land use and land cover product for each time period (Fig. 1).

**(ii) Alaska.** Absence of NLCD product for Alaska from all study periods led to independent unsupervised classification of Landsat TM imagery of 126 grids into forest and nonforest classes for each time period. Zonal majority of area under forest and nonforest within each segment was eventually used to classify the segments to the dominant land use type.

### Change Detection

**(i) Land Use.** The land use types from each time period from CONUS were merged to forest and

nonforest classes (Table 1) to assess change in the United States across four transition types: forest to nonforest (forest loss), nonforest to forest (forest gain), forest to forest (no change forest) and nonforest to nonforest (no change nonforest). Change in area (ha) under each transition type was summarized by each ecoregion for 1990 to 2000, and 2000 to 2006. A latitude correction factor was used to account for the variation in area of each segment in the study area based on location relative to the equator (Equation 1). The correction factor was applied to all the segments prior to assessing area under different land use transitions.

$$\text{Latitude Correction Factor} = 2*pi*R*\cos(lat) / (2*pi*R*\cos(lat0)) = \cos(lat)/\cos(lat0) \quad \text{Eq (1)}$$

**(ii) Land Cover.** Land cover change was conducted only for the coterminous United States across four transition types: tree to non-tree, non-tree to tree, no change tree, and no change non-tree. The latitude correction factor was used to summarize the area estimates of land cover change within the four transition types.

## Validation

The validation exercise was conducted only for land use change to meet FAO's goal of estimate of forest loss. A stratified random sampling approach was used to photo interpret (PI) a minimum of 20 random points within each land use transition in each FAO region for each time period. Google Earth™, National Agricultural Imagery Program imagery from 2000 and 2006, and ground knowledge of the PI personnel were used to validate the land use transition of the segment that intersected with the random points. The agreement matrix for validation was enumerated from the weights of sampled points instead of actual count of points within each transition. The weight of each sampled point within each stratum was developed as a function of the area of the land use change stratum relative to the total area and total number of points within the stratum (Fig. 2). The proportion of agreement and disagreement in the land use transitions observed between the PI land use change call and NLCD results was used to develop a correction factor for the final estimate of area under each transition type in each FAO region.

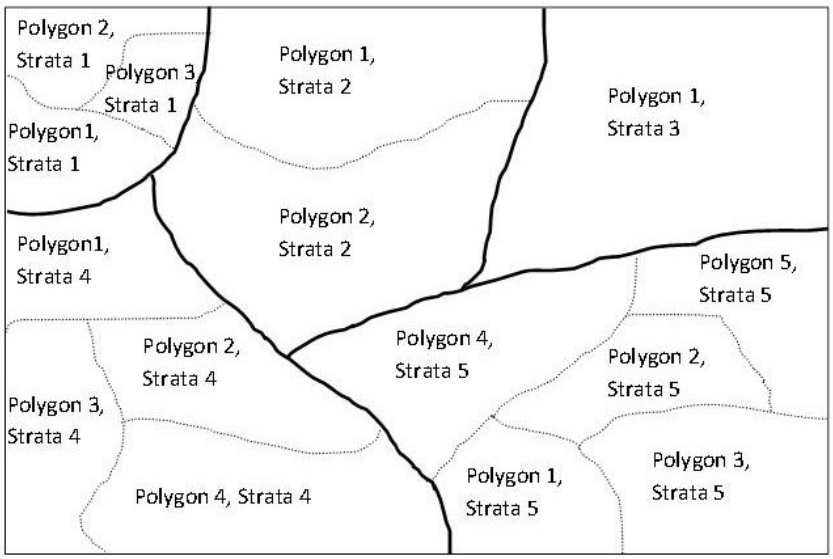
A total of 2,536 points were validated for observed land use transitions between 1990 and 2000 with 120 points in Alaska and the rest in CONUS. For the second time period 1,280 points were validated for all the land use transition types observed in each FAO region between 2000 and 2006. For the first time period sampling for validation was done within 64 land use transitions before merging the land use classes to forest and nonforest and without the knowledge of the FAO ecoregions. Using the weights of the sampled points instead of actual counts also accounted for the difference in sampled size under each land use transition between the study periods.

# RESULTS

## Land Use Change

Land use change (overall forest loss and forest gain) was assessed based on the original area of segment, area corrected by latitude, and latitude-corrected area post-validation and by different ecoregion (Fig. 3). These results suggest the importance of latitude correction and an accuracy assessment of change, and effect of location and relative size of the segments, on the overall estimate of forest loss. Segments from Alaska (Ecoregion - Polar and Boreal) after the latitude correction had considerable influence on the overall estimate and percent forest loss and forest gain. The final estimates used to report and summarize land use change during this study were derived from the latitude correction function and validation.

The results of the survey indicate more nonforested area than forested area, with most of the forest (28.8% in 1990-2000, 30.8% in 2000-2006) and nonforest (68.6% in 1990-2000, 68.2% in 2000-2006) area remaining stable (Table 2). Overall rate of loss of




To determine the weight each polygon contributes to accuracy we can use the chain rule to define a strategy for finding this probability of selection:

$$p(\text{strata} = i, \text{polygon} = j) = p(\text{polygon} = j \mid \text{strata} = i) * p(\text{strata} = i)$$
$$= (1/n_i) * p(\text{strata} = i) = p(\text{strata} = i) / n_i$$

where,

$n_i$ is the number of samples within strata I

$p(\text{strata} = i)$ is area of strata _ i / Total Area of all strata

These probabilities are simply the proportion, by area, of each polygon. The points divide the strata into $n_i$ equal areas (again, where i is the i'th strata).

E.g, The weight of 10 random points sampled within Forest-NonForest Transition can be computed by the following formula :

Area Forest-NonForest Transition/Total Study Area *1/10

Figure 2.—Calculating the weight of each sample point by land use change strata.

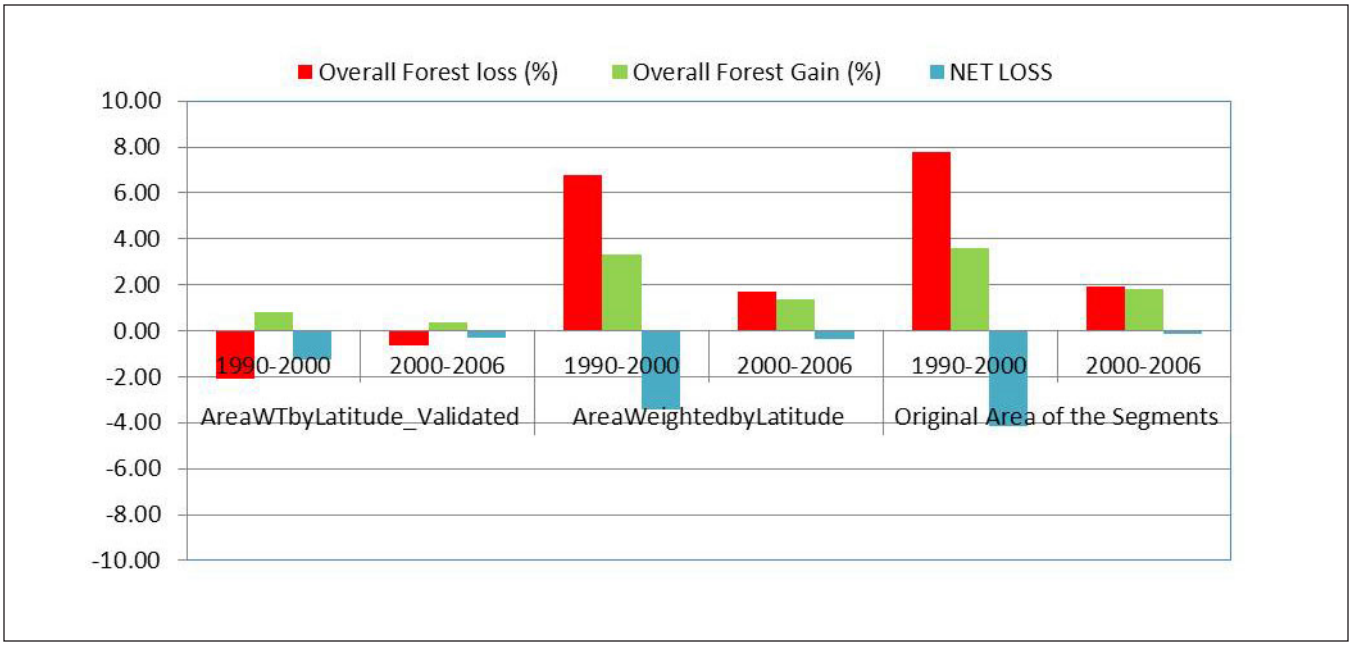



Figure 3.—Comparing differences in assessment of forest loss and forest gain, based on the original area of the segments, after the latitude correction function on the original segments (AreaWeightedby Latitude) and validation of the latitude corrected segments (AreaWTbyLatitude_Validated) within the coterminous United States.

**Table 2.—Comparison of overall estimates of area (ha) (validated and weighted by latitude) under different land use transitions in the United States between 1990 and 2000, and 2000 and 2006, based on the survey grids**

| Land Use Change | 1990-2000 | 2000-2006 |
|---|---|---|
| Forest to nonforest | 123,927.05 (1.8%) | 43,133.15 (0.63%) |
| No change forest | 1,968,040.55 (28.8%) | 2,106,957.36 (30.86%) |
| No change nonforest | 4,683,794.57 (68.6%) | 4,653,012.52 (68.2%) |
| Nonforest to forest | 51,730.53 (0.8%) | 24,389.67 (0.36%) |
| Total Area | 6,827,492.71 | 6,827,492.71 |

forest was higher between 1990 and 2000 (1.8%) than between 2000 and 2006 (0.63%). Rate of overall forest loss was higher than forest recovery during both the study periods. Overall rate of both forest loss and forest gain declined by 1.17 percent and 0.44 percent, respectively (Fig. 3, AreaWTbyLatitude_validated), reducing the overall net forest loss in the United States. Net loss of forest was less than 1 percent between 2000 and 2006. Given the large proportion of area under stable forest, the observed change in forest area was minimal.

Subtropical humid forest region underwent the highest net forest loss, followed by the Polar region, Subtropical steppe, and temperate mountain system. The pattern was consistent for both study periods (Fig. 4a). Net percent forest loss was higher between 2000 and 2006 than between 1990 and 2000 in most ecoregions except Boreal and Temperate steppe. Boreal tundra woodland and Temperate steppe showed net forest gain between 1990 and 2000 and net forest loss between 2000 and 2006, although the percent change was small. Percent forest gains in these ecoregions were higher than percent forest loss in 1990-2000. Percent forest gain in Polar, Subtropical humid forest, Temperate continental forest, and Temperate mountain system was lower than percent forest loss for each time period, resulting in net forest loss (Fig. 4a).

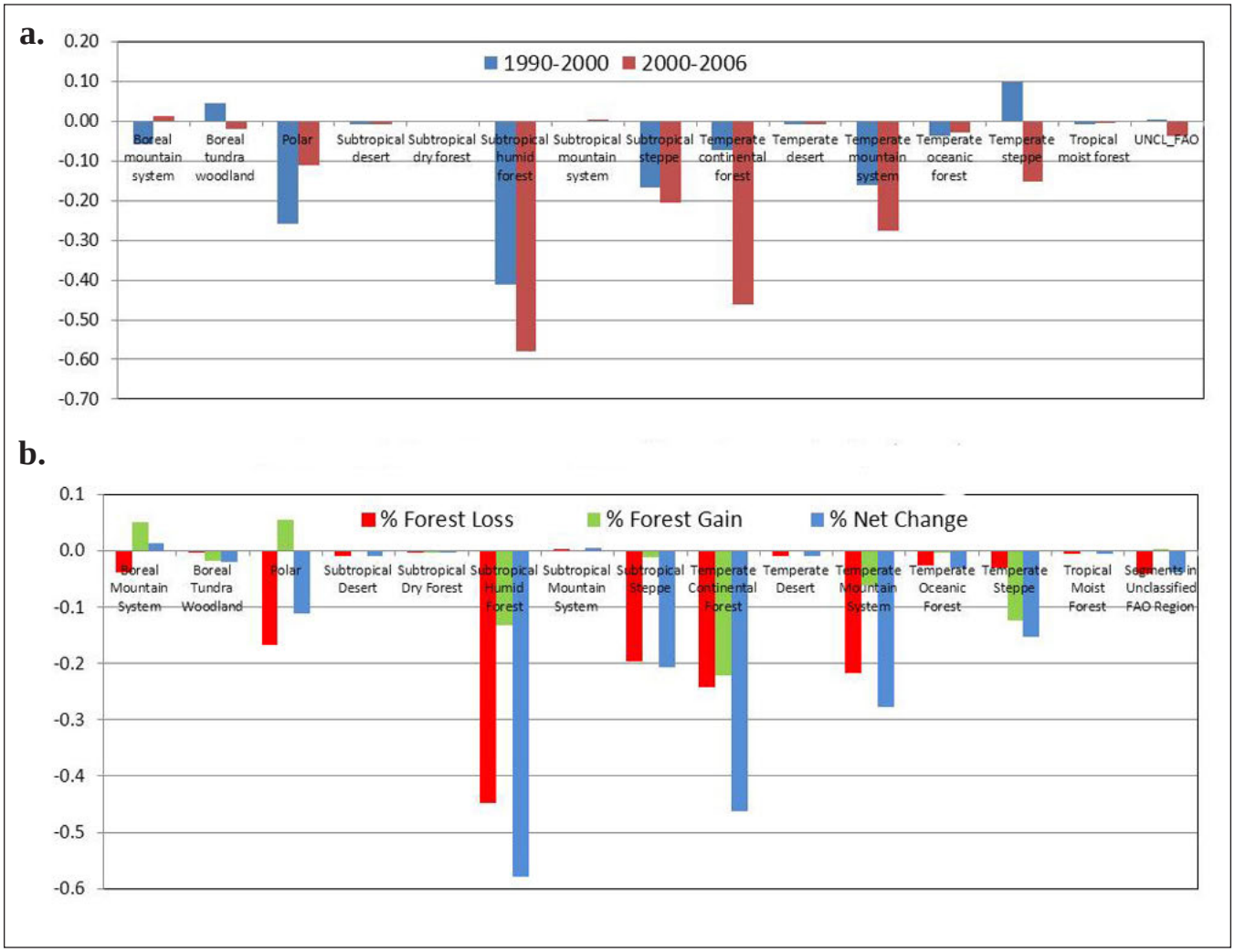



Figure 4.—(a) Comparing net percentage change in forest (Forest Gain – Forest Loss) between 1990-2000 and 2000-2006 by ecoregion; (b) Overall net change in forest area within the United states by FAO ecoregion for the entire study period.

Overall net forest loss in the United States was less than 2 percent (Fig. 4b). Net forest area increased the most in Boreal Tundra (4,965.4 ha, Table 3) and Boreal mountain system (495 ha, Table 3) for 1990-2000 and 2000-2006. Net forest loss was highest in Subtropical Humid Forest (36,255.6 ha, Table 3) and Temperate Continental Forest (32,782.9 ha, Table 3) followed by Temperate Mountain system (14,638.7 ha) and Subtropical Steppe (11,546.5 ha, Table 3) with net percent loss being less than 1 percent. Increased forest loss and reduced forest gain led to increased forest loss in these regions. A similar pattern was observed in other regions with net loss being less than 9,000 ha (1%, Fig. 4b). According to the recent Forest Inventory and Analysis report (Smith et al. 2009), forest land across the Nation has increased by 4 percent since 1987; it decreased 3 percent between 1953 and 1987. In the North region, forest area has increased by nearly 7 percent while it declined by 5 percent in the South region since 1953. In the Rocky Mountain region forest acreage rose by 6 percent whereas in the Pacific Coast region (including Alaska) forested acreage declined by 4 percent between 1953 and 2007. These trends seem to be consistent with the patterns observed during this survey (Fig. 4b).

**Table 3.—Change in area (ha) under forest gain and forest loss between 1990 and 2000, and 2000 and 2006 in the United States by FAO region (estimates are based on the segments from the survey grids that were corrected for latitude and validated)**

| FAO Ecoregions | Forest to Nonforest | Nonforest to Forest | Net Change |
|---|---|---|---|
| Boreal Mountain System | -2078.4 | 2,527.8 | 449.4 |
| Boreal Tundra Woodland | 2,994.1 | 1,971.3 | 4,965.4 |
| Polar | -10,908.2 | 3,316.2 | -7,592.0 |
| Subtropical Desert | 0.0 | 8.9 | 8.9 |
| Subtropical Dry Forest | -188.9 | -0.6 | -189.5 |
| Subtropical Humid Forest | -11,229.2 | -9,391.4 | -36,255.6 |
| Subtropical Mountain System | -17,845.7 | 67.0 | 248.2 |
| Subtropical Steppe | -11,229.2 | -317.3 | -11,546.5 |
| Temperate Continental Forest | -17,845.7 | -14,937.2 | -32,782.9 |
| Temperate Desert | -935.0 | 8.4 | -926.6 |
| Temperate Mountain System | -11,199.7 | -3,438.9 | -14,638.7 |
| Temperate Oceanic Forest | -1,193.0 | -92.8 | -1,285.8 |
| Temperate Steppe | -1,242.6 | -7,212.8 | -8,455.4 |
| Tropical Moist Forest | -368.3 | 0.0 | -368.3 |
| Segments in Unclassified FAO Region | 84.2 | 150.6 | 234.8 |
| Overall net change in forest area | -79,761.4 | -31,387.0 | -10,8134.8 |

## Land Cover Change

Land cover change estimates from the coterminous United States showed higher estimates of net change in tree cover (3.2%, 201,761.4 ha in 1990-2000 and 0.6%, 40,126.4 ha in 2000-2006) than net forest change (2.2%, 139,067.3 in 1990-2000 and 0.8%, 53,267.8 in 2000-2006) (Fig.5). Both net forest and tree cover change was higher in 1990-2000 than 2000-2006. These estimates for the coterminous United States were calculated prior to the validation and hence cannot be used to report actual change. These patterns suggest, however, that estimates calculated from land cover change, as opposed to land use change, overestimate change. Area under forest loss included areas with gain in tree cover. Likewise area under forest gain included area with conversion of tree to non-tree (loss of tree cover). Stable non-forest area included 1.4% (58850.7 ha) gain in tree cover. Forest loss observed between 1990 and 2000, and 2000 and 2006, showed 82,203 ha and 29,736 ha of persistent tree cover, respectively, and included gain in tree cover as well (19.7 ha and 58.2 ha, respectively). These patterns primarily confirm that land cover change does not necessarily indicate land use change. Unless a forest segment has undergone a change in its use to a non-forest class, observed change in the land cover type is only a transitional state to the next successional or vegetation type.

## CONCLUSION

Based on the survey conducted within the FAO grids, most of the forested area remained stable between 1990, 2000, and 2006. Overall forest gain and loss ranged from less than 1 percent to 2 percent during the study periods. Subtropical humid forest showed the highest net forest loss, followed by temperate oceanic forest. Overall rate of loss of forest was higher between 1990 and 2000 than between 2000 and 2006. Accounting for the latitude of the segments significantly altered the estimate of area under different land use change. Accuracy assessment of the land use change further reduced the estimated area under change. This study demonstrated the importance of a latitude correction and validation on actual estimates and indicated that most of the forest area within the surveyed grid in the United States remained stable after 2000.

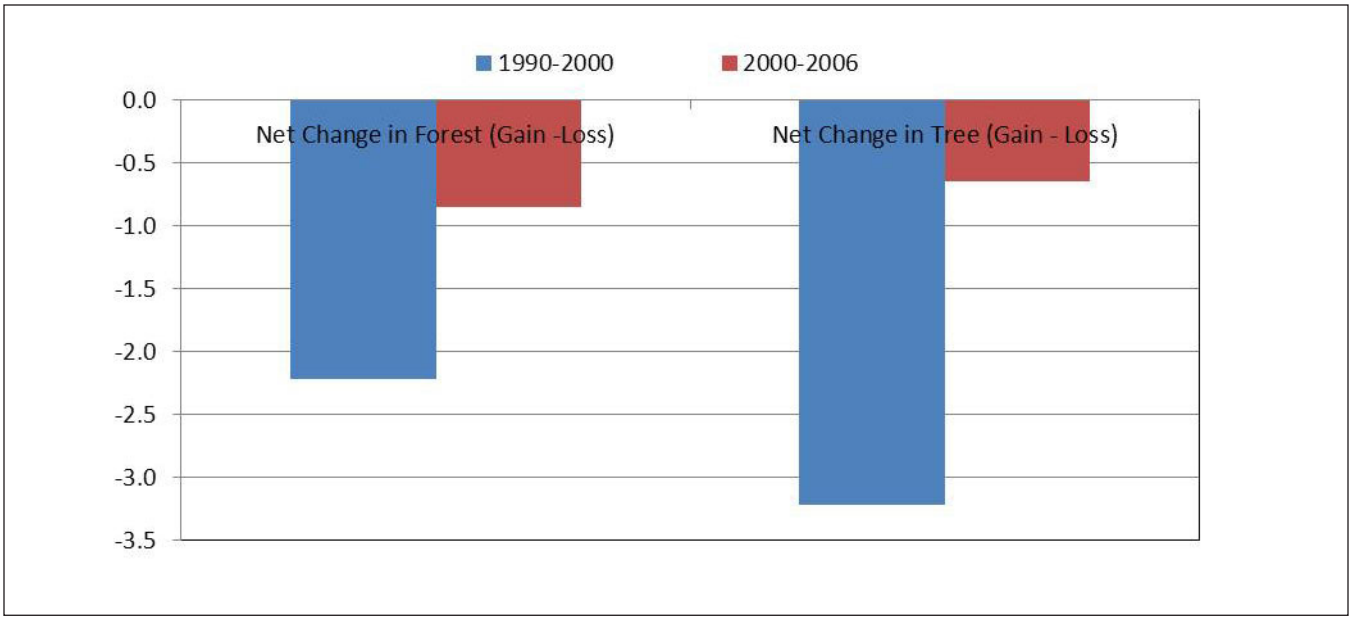



Figure 5.—Comparing net percent change in forest (NonForest to Foreste – Forest to NonForest) and tree (NonTree to Tree – Tree to NonTree) between 1999-2000 and 2000-2006 within the coterminous United States.

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