Land Cover and Climate Change in the Uwharries

Dahl Winters
UNC-Chapel Hill Ecology 199 Class, Spring 2006

Land Use/Land Cover Change

- LULC Map Information and Accuracy (p. 2-5)
- LULC Class Definitions (p. 6-8)
- LULC Images:

- **Uwharrie Region** (p. 9-12)
  Land Cover Types, 1992 and 2001
  Changed Areas, 1992 and 2001
- **Badin Lake Area Closeup** (p. 13-16)
  Land Cover Types, 1992 and 2001
  Changed Areas, 1992 and 2001
- **Southeastern Uwharrie Closeup** (p. 17-20)
  Land Cover Types, 1992 and 2001
  Changed Areas, 1992 and 2001

Climate Change

- Assessment of Potential Climate Change Impacts in the Uwharries (p. 21-23)

- Recommendations for Future Forest Management (p. 23-24)

- References (p. 24-25)

Land Use/Land Cover Maps: Information and Accuracy

Purpose

The many plant and animal species inhabiting the Uwharrie landscape are affected only by natural boundaries such as vegetation type, soils, and topography. The parcel boundaries drawn on paper are invisible to them, but the differing, changing uses of the land by the owners of those parcel boundaries create very visible changes to the composition and pattern of the land cover. In this respect, the parcel boundaries of human importance are very much natural boundaries. Differing land uses by the Forest Service, timber companies, and private landowners with various land interests have created a mosaic of land cover types across the Uwharrie that continue to vary over space and time.

The ranges of most species do not end at the Forest Service boundary, and areas adjacent to the Uwharrie National Forest could serve as population sources that can potentially be affected by changes in land use/land cover. Well-maintained adjacent lands could be sources of species desirable for Forest Service management and/or restoration, such as longleaf pine. At the same time, disturbed adjacent lands could be sources of undesirable exotic species.

To explore how land uses adjacent to Forest Service borders may affect management and restoration activities on National Forest lands, we sought to map LULC and LULC change over the period from 1992 to 2001, for which there was easily accessible data. This time scale is long enough to pick up forest clearcuts and regrowth, the conversion of forests to grassland and agricultural use, and the spread of new developments.

Data Sources

- National Land Cover Dataset (NLCD) 1992 and 2001 by the MRLC Consortium, derived through unsupervised clustering and regression tree analysis of 30 meter resolution Landsat 5 (1992) and Landsat 7 (2001) data. Overview: http://landcover.usgs.gov/overview.asp
- US Forest Service and Uwharrie administrative boundaries provided by Holly Hixson, USFS
- LandTrust Holdings and Montgomery County parcel data (used to derive timber company holdings) from the LandTrust for Central North Carolina
- NC Counties shapefile provided by the GIS Reference Center at Davis Library, UNC-Chapel Hill

Deciding on the Classification Scheme

Initially we felt the most pertinent land cover changes to focus on from the perspective of Forest Service management would be from Deciduous, Evergreen, and Mixed to Development, Barren, Agricultural, Grassland, or Shrubland, and vice versa. There were 16 land cover classes present in the Uwharrie region in 1992, and at first we divided these classes into the above categories. However, upon closer inspection of the 1992 and 2001 datasets, we found classification differences of land cover types between the two datasets, as well as differences in accuracy for each land cover type.

We decided to reclassify the data with the goal of preserving the land cover classes we felt were most relevant to the Forest Service, while maximizing the accuracy of the final classes. To maximize accuracy, we reviewed the 1992 and 2001 LULC accuracy information provided by the MRLC Consortium. A summary of our findings is presented below, which helped us justify the final classification scheme used.

Classes Used in the LULC Maps:

Development
Bare/Mine/Transitional
Deciduous Forest
Evergreen Forest
Mixed/Shrubland
Grassland/Agricultural Land
Water/Wetland

1992 LULC Accuracy Information

Information derived from http://landcover.usgs.gov/accuracy/index.asp

The original 16 land cover classes are given at the bottom of Table 1, which shows overall and land cover class-specific accuracy estimates for Region 4 (the Southeast), where the Uwharries are located. Two columns of accuracy estimates are given, user's and producer's accuracy. A statement from the website above describes the two measures:

"The producer's accuracy relates to the probability that a reference sample (photo-interpreted land cover class in this project) will be correctly mapped and measures the errors of omission (1 - producer's accuracy). In contrast, the user's accuracy indicates the probability that a sample from land cover map actually matches what it is from the reference data (photo-interpreted land cover class in this project) and measures the error of commission (1- user's accuracy). "

Table 1: Accuracy of Land Cover Classes before Reclassification

Accuracy of Federal Region 4 (patch*)			
Land cover	*user's accuracy*	*producer's accuracy*	*Overall accuracy*
11	1.00	0.96	
21	0.38	0.55	
22	0.23	0.29	
23	0.65	0.54	
31	0.57	0.95	
32	0.48	1.00	
33	0.40	0.50	
41	0.86	0.93	
42	0.80	0.97	
43	1.00	0.24	
81	0.69	0.03	
82	0.82	0.11	
85	0.50	0.23	
91	0.77	0.94	
92	0.95	0.94	
			0.81

* In this table, agreement is defined as a match between the primary or alternate reference land-cover label and mapped land-cover class of the corresponding 3x3 pixel window which is homogeneous (using only a subset of the original samples)..

Accuracy of Federal Region 4 (mode*)			
Land cover	*user's accuracy*	*producer's accuracy*	*Overall accuracy*
11	0.97	0.90	
21	0.73	0.61	
22	0.34	0.37	
23	0.38	0.45	
31	0.48	0.80	
32	0.43	0.64	
33	0.47	0.37	
41	0.64	0.83	
42	0.56	0.95	
43	0.85	0.53	
81	0.47	0.19	
82	0.40	0.31	
85	0.63	0.23	
91	0.68	0.71	
92	0.77	0.85	
			0.66

* In this table, agreement is defined as a match between the primary or alternate reference land-cover label and the most common land-cover class of the corresponding 3x3 pixel window.

Accuracy of Federal Region 4 (pixel*)			
Land cover	*user's accuracy*	*producer's accuracy*	*Overall accuracy*
11	0.94	0.88	
21	0.58	0.39	
22	0.28	0.30	
23	0.40	0.39	
31	0.45	0.84	
32	0.38	0.58	
33	0.36	0.31	
41	0.65	0.76	
42	0.47	0.88	
43	0.80	0.51	
81	0.55	0.02	
82	0.63	0.04	
85	0.59	0.28	
91	0.68	0.64	
92	0.69	0.83	
			0.62

* In this table, agreement is defined as a match between the primary or alternate reference land-cover label and mapped land-cover class of the corresponding single pixel.

Land cover classes are: water (11), low density residential (21), high density residential (22), commercial/industrial/transportation (23), bare rock/sand/clay (31), mining (32), transitional (33), deciduous forest (41), evergreen forest (42), mixed forest (43), shrubland (51), hay and pasture (81), cropland (82), urban grass (85), woody wetland (91), emergent (herbaceous) wetland (92).

Based on this understanding, we chose the user's accuracy as our basis for picking land cover classes with the highest accuracy. We also chose to use the patch method of estimating accuracy as explained in the table, which produces the highest accuracy estimates of the three methods. Those classes with > 80% accuracy using the patch method are 11 (water), 41, 42, and 43 (forest), 82 (agriculture), and 92 (wetland). Developed areas (20's) had some of the lowest accuracies, and so were the bare/mine/transitional categories (30's). However, because we felt transitions from/to developed and bare areas could be potentially significant land cover changes that might affect Forest Service management, we wanted to leave these classes in, but somehow combine them to increase the accuracy of the overall class.

The MRLC had already computed accuracy estimates when the land cover types had been aggregated into approximately a USGS Anderson level I classification system (Table 2). They did this using the mode method, which is also explained in the above figure and yields accuracy estimates lower than that of the patch method. Looking at user's accuracy for Federal Region 4, we see that all classes have shown significant increases in accuracy. We now have > 80% accuracy for all classes except for urban (72%) and barren land (52%). The LULC maps provided on subsequent pages of this report should bear these low user's accuracies in mind; in the case of barren land, about half of these areas likely belong to a different land cover type.

Table 2: Accuracy of Land Cover Types After Reclassification

Accuracy of Federal Region 3 (mode*)					Accuracy of Federal Region 4 (mode*)			
Land cover	*user's accuracy*	*producer's accuracy*	*Overall accuracy*		*Land cover*	*user's accuracy*	*producer's accuracy*	*Overall accuracy*
water	0.89	0.96			water	0.97	0.84	
urban	0.77	0.92			urban	0.72	0.71	
barren land	0.35	0.46			barren land	0.52	0.72	
forest land	0.73	0.51			forest land	0.91	0.94	
agricultural land	0.64	0.18			agricultural land	0.83	0.38	
wetlands	0.48	0.64			wetlands	0.82	0.88	
			0.74					0.83

* for all the tables, agreement is defined as a match between the primary or alternate reference land-cover label and the most common land-cover class of the corresponding 3x3 pixel window.

Another factor in our reclassification decision was a table of the most frequently confused land cover classes (Table 3). Unfortunately no statistics were provided as to how frequently each of the misclassifications occurred, but the table does allow some sense of the errors that might appear in the LULC maps. We added a column to the table showing which classes these were reclassified to. These reclassifications eliminate all of these most frequent errors except those where other land types have been mistaken for mixed forest.

Table 3. The most frequent confusion between mapped and photo-interpreted land cover classes.

Map class name	Region 4	Classified as (added column)
Open water	Emergent wetland	90 – water/wetland
Low int. residential	Mixed Forest	20 – development
High int. residential	Low int. residential	20 – development
High int. commercial	Low int. residential	20 – development
Bare rock/sand	Other grass	30 – bare/mine/transitional
Quarry/strip mine	Bare rock/sand	30 – bare/mine/transitional
Transitional barren	Mixed forest	30 – bare/mine/transitional
Deciduous forest	Mixed forest	41 – deciduous forest
Evergreen forest	Mixed forest	42 – evergreen forest
Mixed forest	Transitional barren	43 – mixed forest/shrubland
Hay/pasture	Row crops	80 – agriculture
Row crops	Hay/pasture	80 – grassland/agriculture
Other grass	Hay/pasture	80 – grassland/agriculture
Woody wetlands	Mixed forest	90 – water/wetland
Emergent wetland	Woody wetlands	90 – water/wetland

We did not combine bare/mine/transitional (30's) with grassland/agricultural (80's), though the MRLC provides some reason for why we could. They state, "One class that suffers most is the transitional

barren, a class that is designed for conditions such as temporary clearing and regeneration of forest cover. Similar problems exist within agricultural classes due to crop rotations." We felt that bare land should be kept as a separate category since these represent areas with undetectable vegetation cover of any type.

2001 LULC Accuracy Information

No extensive accuracy analysis was readily available for the NLCD 2001 as with the NLCD 1992, but there are only a few differences between the two datasets. Information on the 2001 LULC dataset was available from http://www.mrlc.gov/mrlc2k_nlcd.asp and http://www.mrlc.gov/pdfs/July_PERS.pdf. The NLCD 2001 has 29 total classes of land cover, 13 of these that were new Alaskan and coastal classes not present in NLCD 1992. The water, forest, shrub, herbaceous, and wetland classes are nearly identical to the definitions in NLCD 1992, but agriculture, urban, and barren classes have been modified. We deleted the extra 13 classes from the LULC definitions list because they are not present in the Uwharrie area.

Land Use/Land Cover Class Definitions Used in the Maps

Development (21, 22, 23, 24)

NLCD 1992 definitions:	NLCD 2001 definitions:
Developed Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).	
21. *Low Intensity Residential* - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.	**21. Developed, Open Space** - Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes **22. Developed, Low Intensity** - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units. **23. Developed, Medium Intensity** - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
22. *High Intensity Residential* - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover. **23. *Commercial/Industrial/Transportation*** - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.	**24. Developed, High Intensity** - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

Bare/Mine/Transitional (31, 32)

NLCD 1992 definitions:	NLCD 2001 definitions:
Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.	
31. *Bare Rock/Sand/Clay* - Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material.	**31. Barren Land (Rock/Sand/Clay)** - Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
32. *Quarries/Strip Mines/Gravel Pits* - Areas of extractive mining activities with significant surface expression.	
33. *Transitional (available category, but no pixels present in the Uwharrie area)* - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).	

Hardwood Forest, Pine Forest, Mixed Forest/Shrub (41, 42, 43+51&52)

NLCD 1992 definitions:	NLCD 2001 definitions:
Forested Upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.	
41. *Deciduous Forest* - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.	**41. Deciduous Forest** - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
42. *Evergreen Forest* - Areas dominated by trees where 75 percent or more of the tree species `maintain their leaves all year. Canopy is never without green foliage.	**42. Evergreen Forest** - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
43. Mixed Forest/Shrubland **This merged category is composed of:** **A) 43. *Mixed Forest*** - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present. **B) Shrubland (available in 1992 but no pixels belonged to this category)** - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included. 51. *Shrubland* - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.	**43. Mixed Forest/Shrubland** **This merged category is composed of:** **A) 43. Mixed Forest** - Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. **B) 52. Shrub/Scrub** - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions. (51 in 2001 was an Alaska category, whereas in 1992 51 represented shrubland. The numbers don't match up from 1992-2001 so it's important to look at the definitions of the numbers when lumping the categories together or comparing them.)

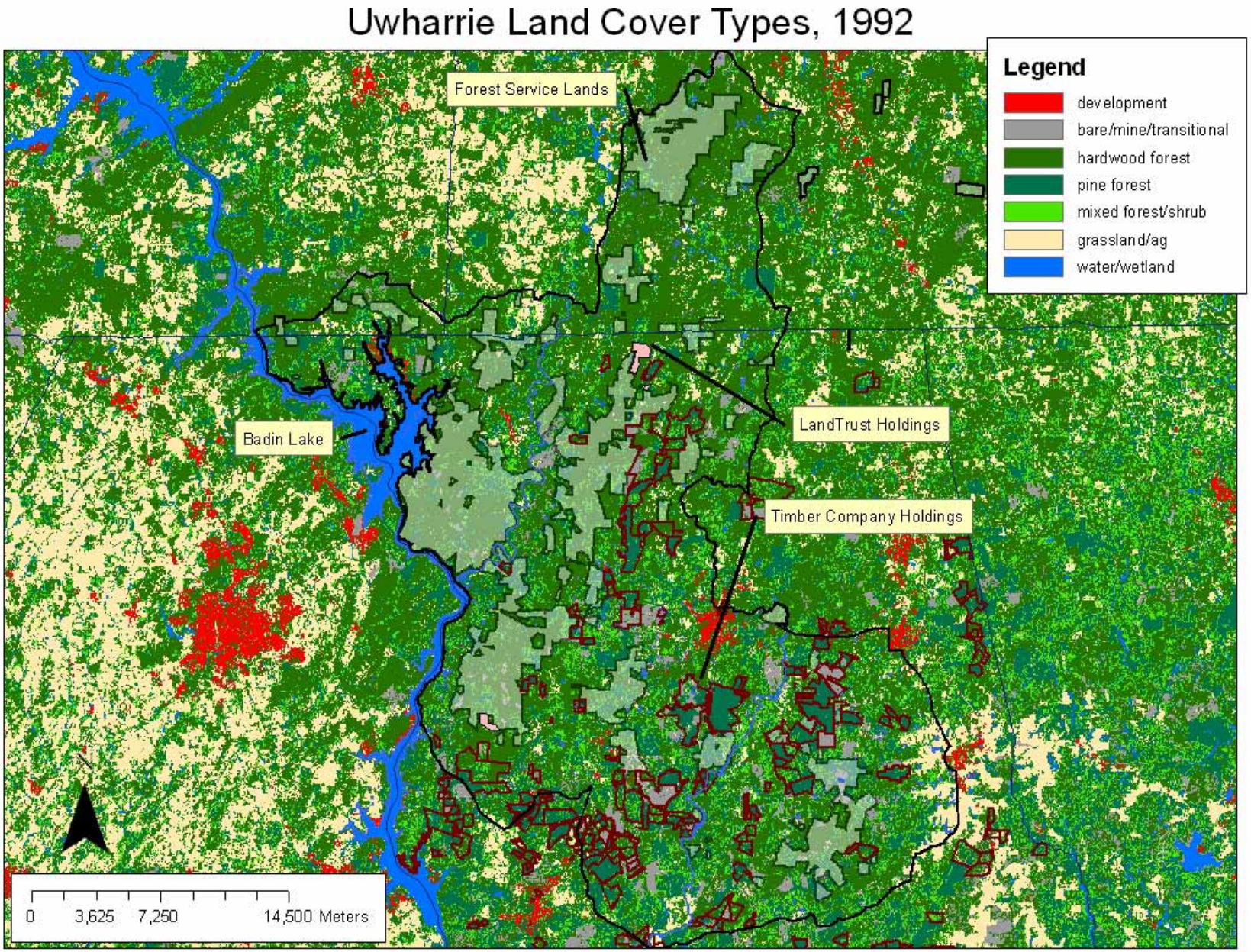
Grassland/Agriculture (71, 81, 82)

NLCD 1992 definitions:	NLCD 2001 definitions:
Herbaceous Upland (available in 1992 but no pixels belonged to this category) - Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.	
71. *Grasslands/Herbaceous* - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.	**71. Grassland/Herbaceous** - Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.	
81. *Pasture/Hay* - Areas of grasses, legumes, or grass-	**81. Pasture/Hay** - Areas of grasses, legumes, or grass-

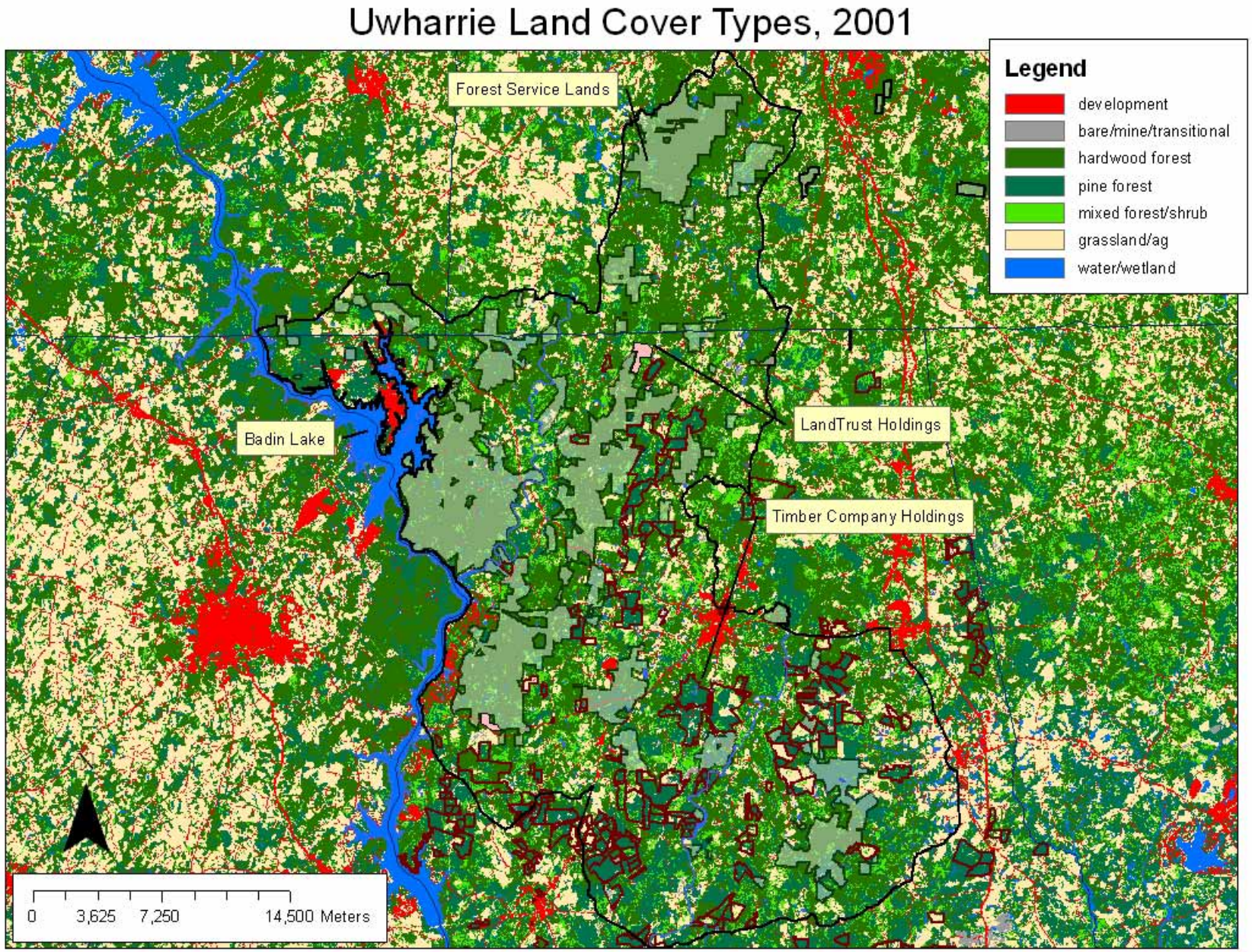
legume mixtures planted for livestock grazing or the production of seed or hay crops.	legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
82. *Row Crops* - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.	**82. Cultivated Crops** - Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
83. *Small Grains* - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.	
84. *Fallow* - Areas used for the production of crops that do not exhibit visable vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.	
85. *Urban/Recreational Grasses* - Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.	

Water/Wetland (11, 90/91, 92/95)

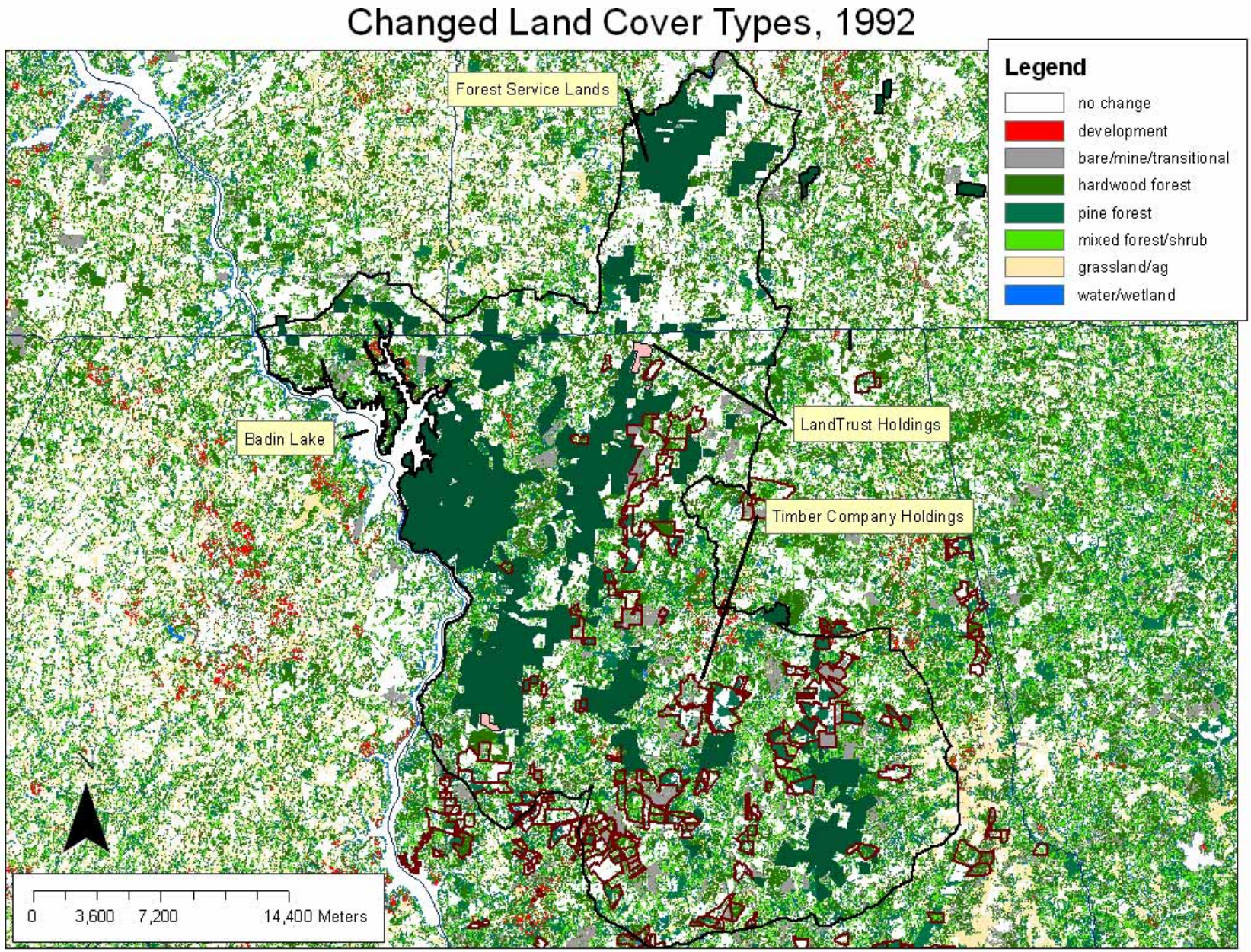
NLCD 1992 definitions:	NLCD 2001 definitions:
Water - All areas of open water or permanent ice/snow cover.	
11. *Open Water* - all areas of open water, generally with less than 25% cover of vegetation/land cover.	**11. Open Water** - All areas of open water, generally with less than 25% cover of vegetation or soil.
Wetlands - Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al.	
91. *Woody Wetlands* - Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.	**90. Woody Wetlands** - Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
92. *Emergent Herbaceous Wetlands* - Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.	**95. Emergent Herbaceous Wetlands** - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.



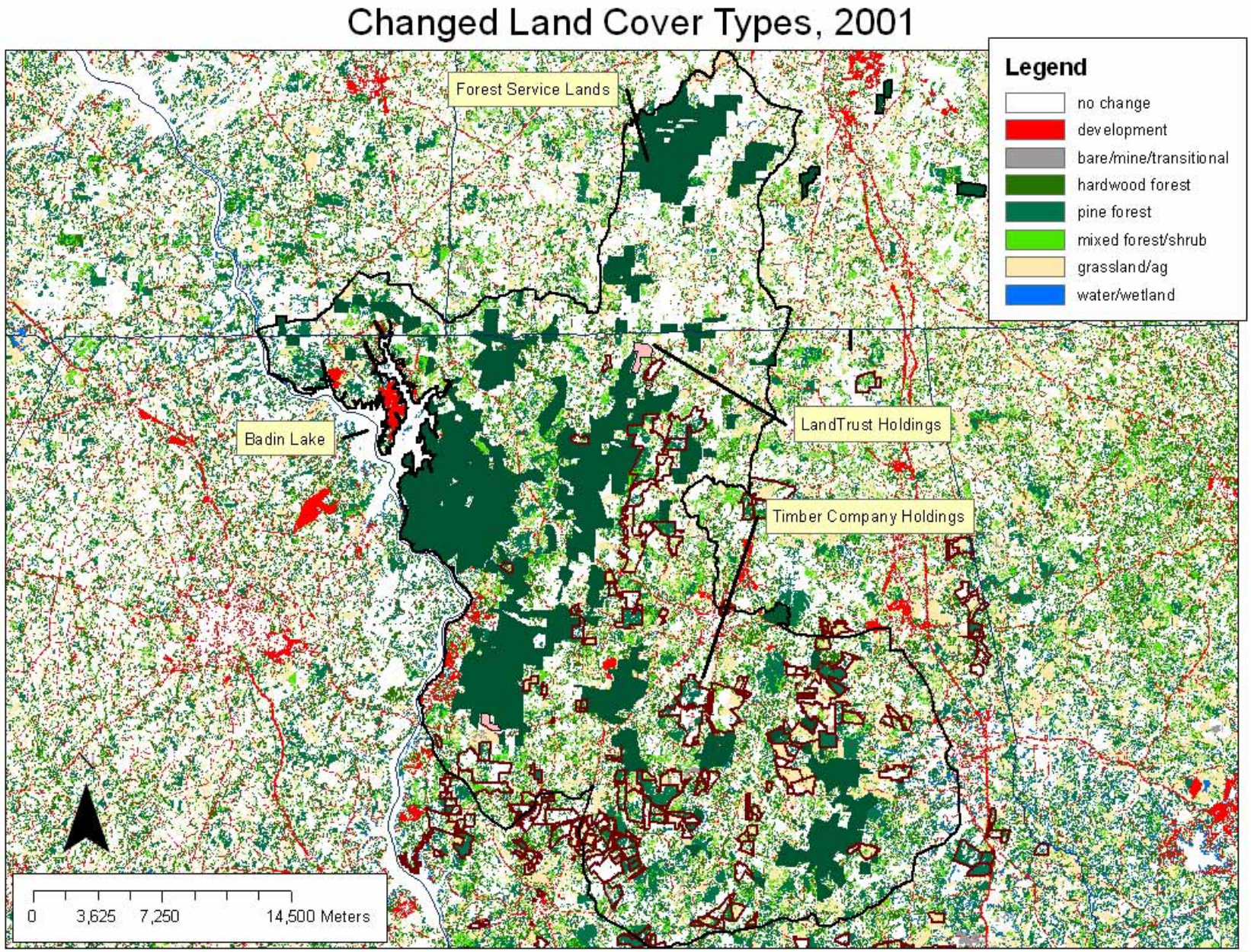
This map shows the land cover types in 1992. The Uwharrie area shows significantly more forest abundance (hardwood, pine, mixed forest/shrub) than areas outside the administrative boundary. Timber company holdings show a high abundance of pine and bare/mine/transitional types.



To the east of the Uwharrie area and to a lesser but significant extent within the administrative boundary, there is a high conversion of forest to grassland/agricultural use. Two main developed areas (Uwharrie Point and Woodrun subdivisions) appear within the Uwharrie boundary.

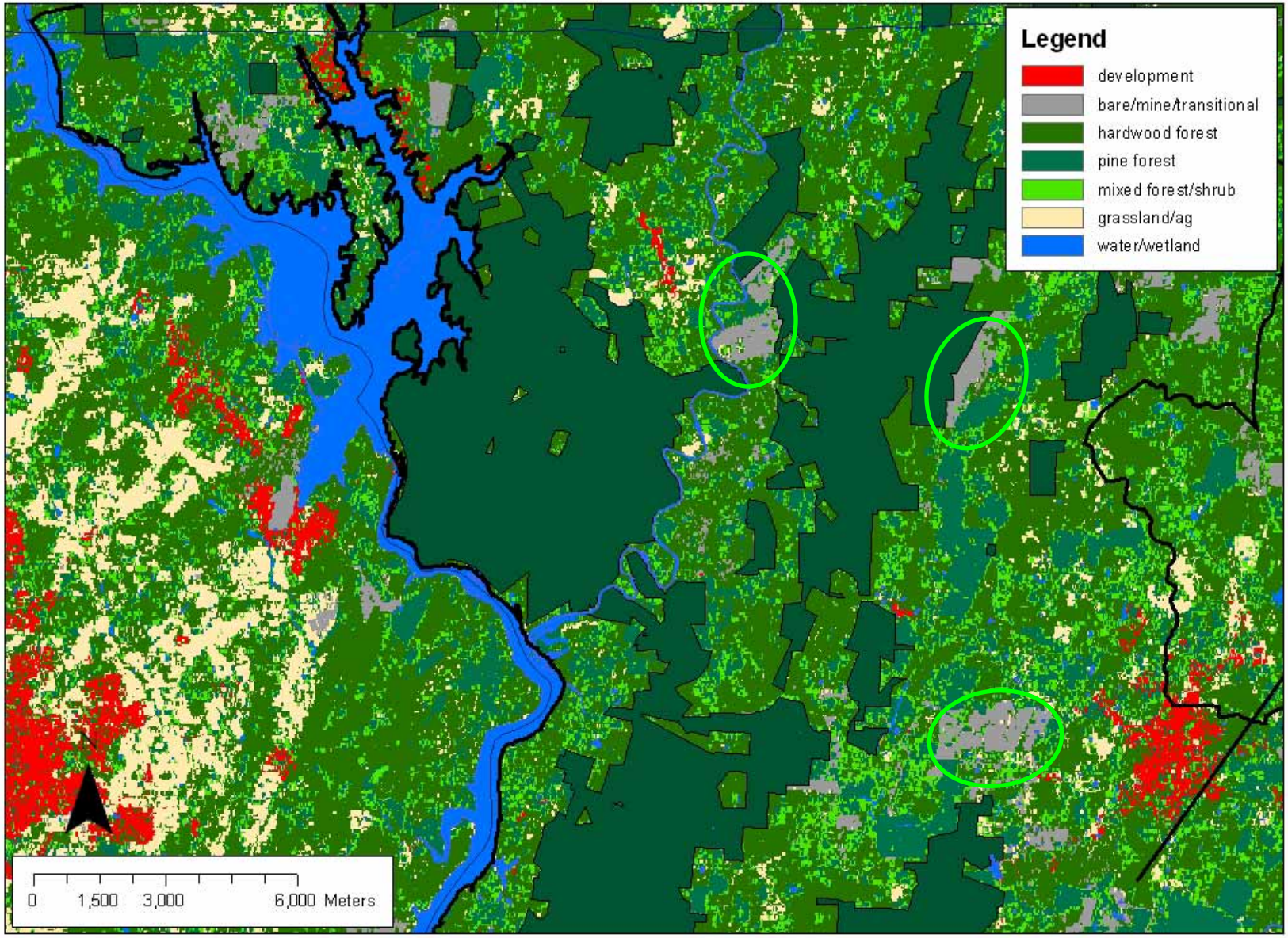


Many areas adjacent to Forest Service lands have experienced change between 1992 and 2001. This map shows what the changed lands looked like prior to the 11-year period. The majority of these lands have some forest cover; most developed areas likely did not change from development to some other land cover type, and so might be misclassification errors. Note that the other two most frequent misclassifications are mixed forest/shrub and bare/mine/transitional.



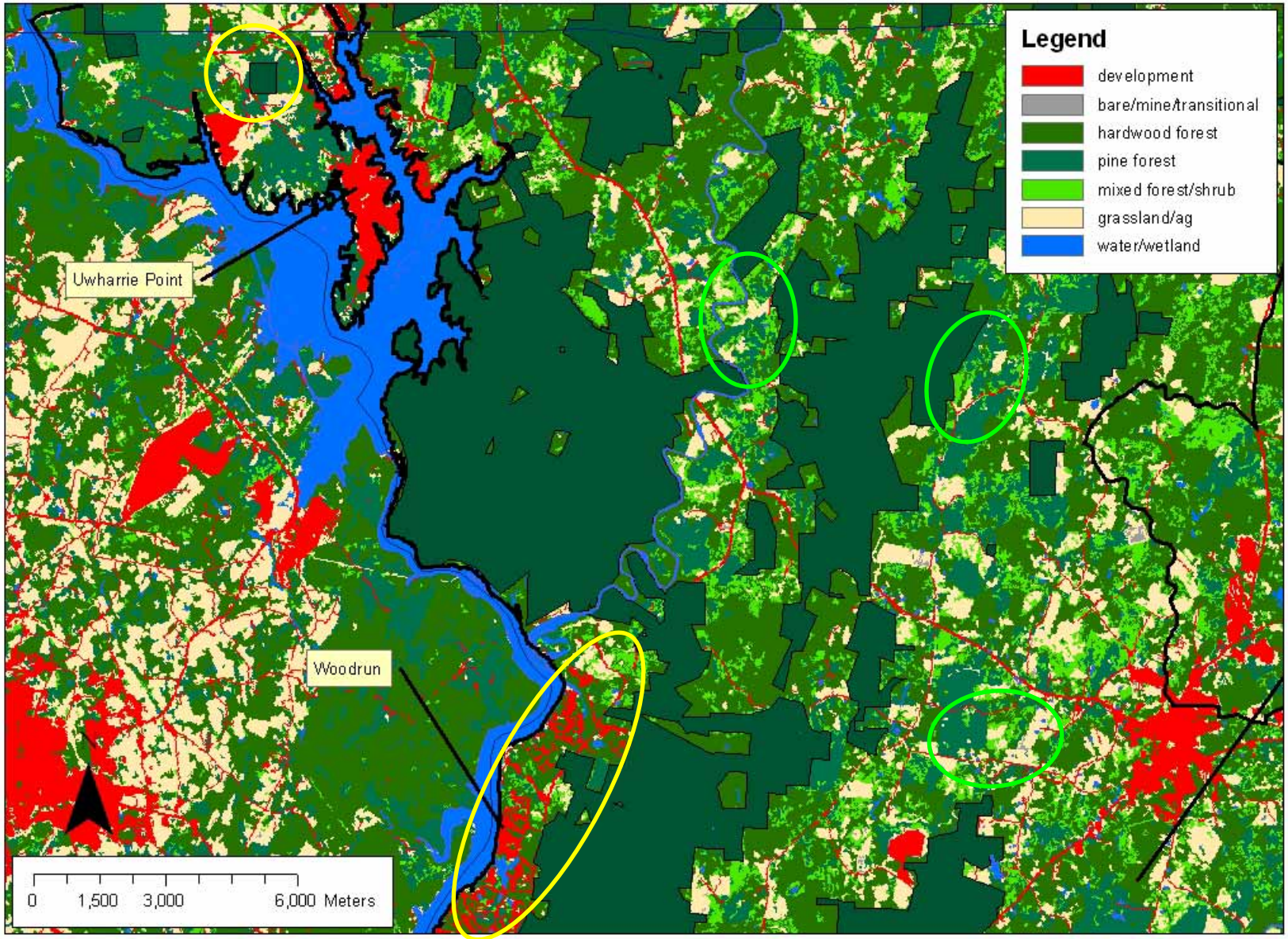
This map shows only the changed areas at the end of the 11-year period. There are two large Badin Lake developments very close to Forest Service lands, and other development has occurred adjacent to major roads within the Uwharrie. A large-scale conversion from forest to grassland/agriculture has taken place throughout most of the Uwharrie. Even with misclassification errors, the large scale of the conversion suggests a general decrease in forest density.

Land Cover, Badin Lake Area, 1992



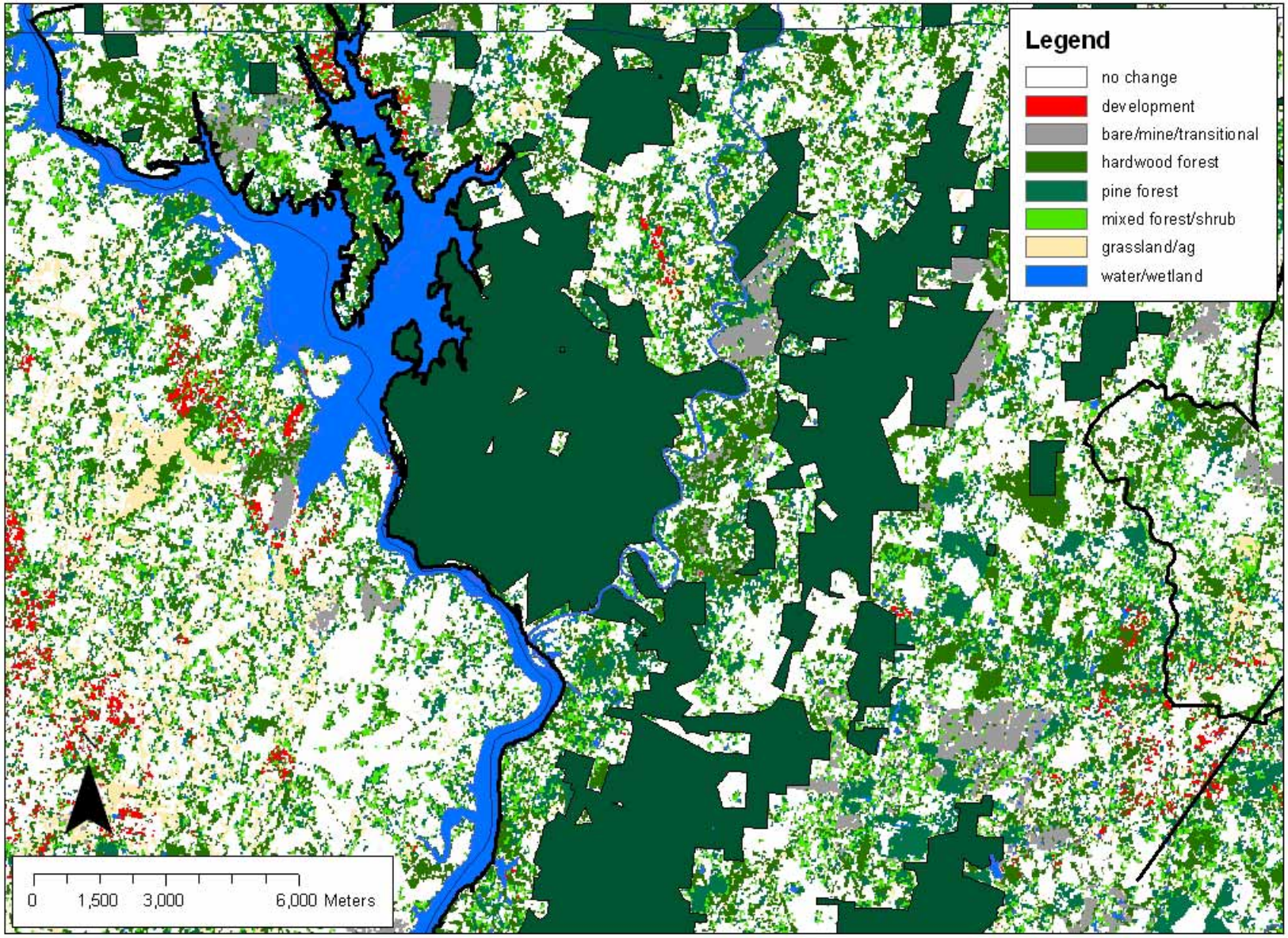
The following four maps focus on changes in the Badin Lake area, a biodiversity, archaeology, and recreational hotspot. This map shows the 1992 land cover with Forest Service lands in dark green. Most of the land is hardwood forest, with blocks of pine forest. Of note are the areas circled in green, which are unvegetated lands adjacent to Forest Service lands that became forested 11 years later.

Land Cover, Badin Lake Area, 2001

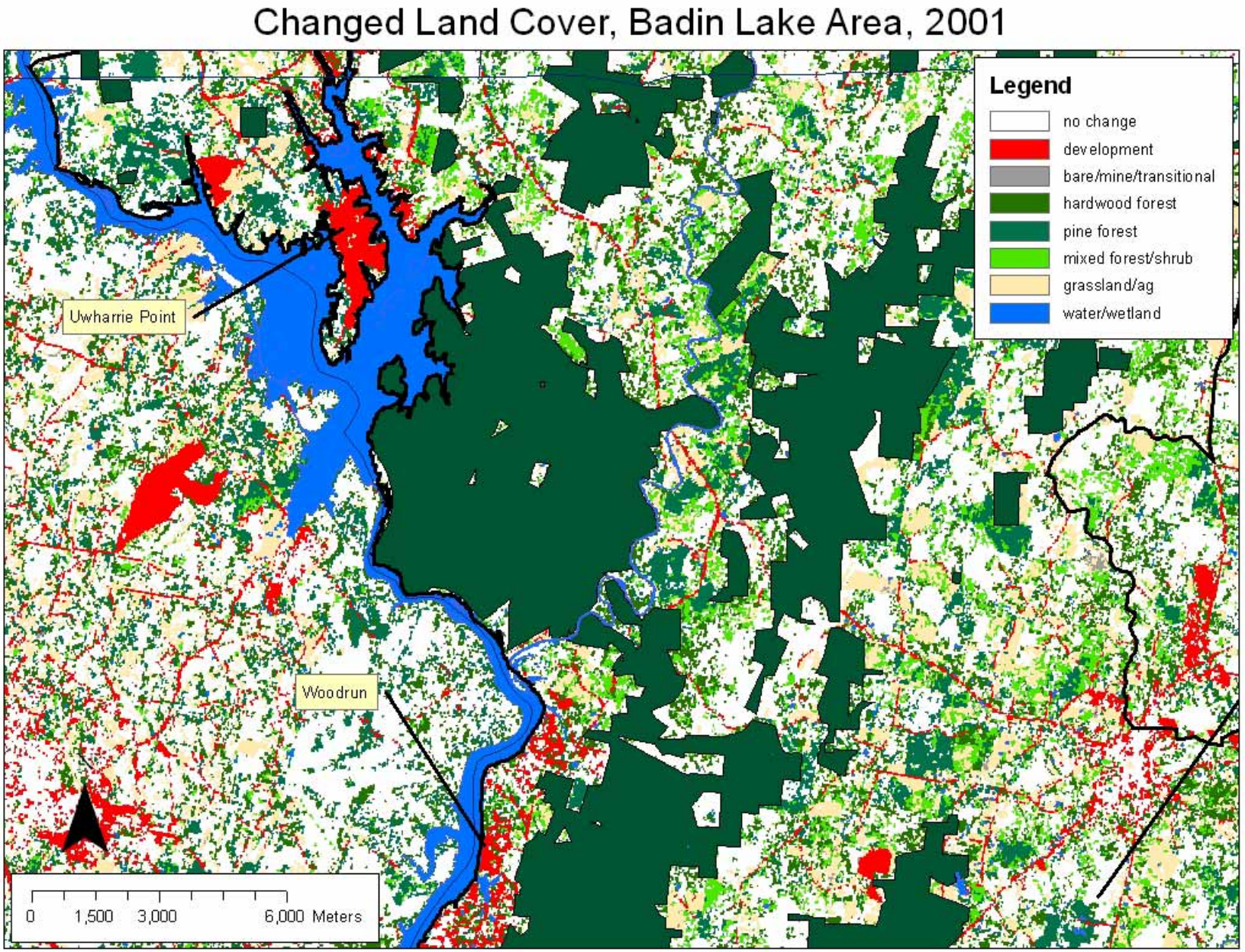


Conversion from bare land to forest next to Forest Service lands (green) can be seen here, but there are two more widespread changes. Development has spread throughout the Badin Lake area, along with a conversion of forest to grassland/agriculture that has occurred mainly near roads. Significant conversion and construction of new developments are occurring near Forest Service lands (examples in yellow), which may affect the efficacy of forest management.

Changed Land Cover, Badin Lake Area, 1992

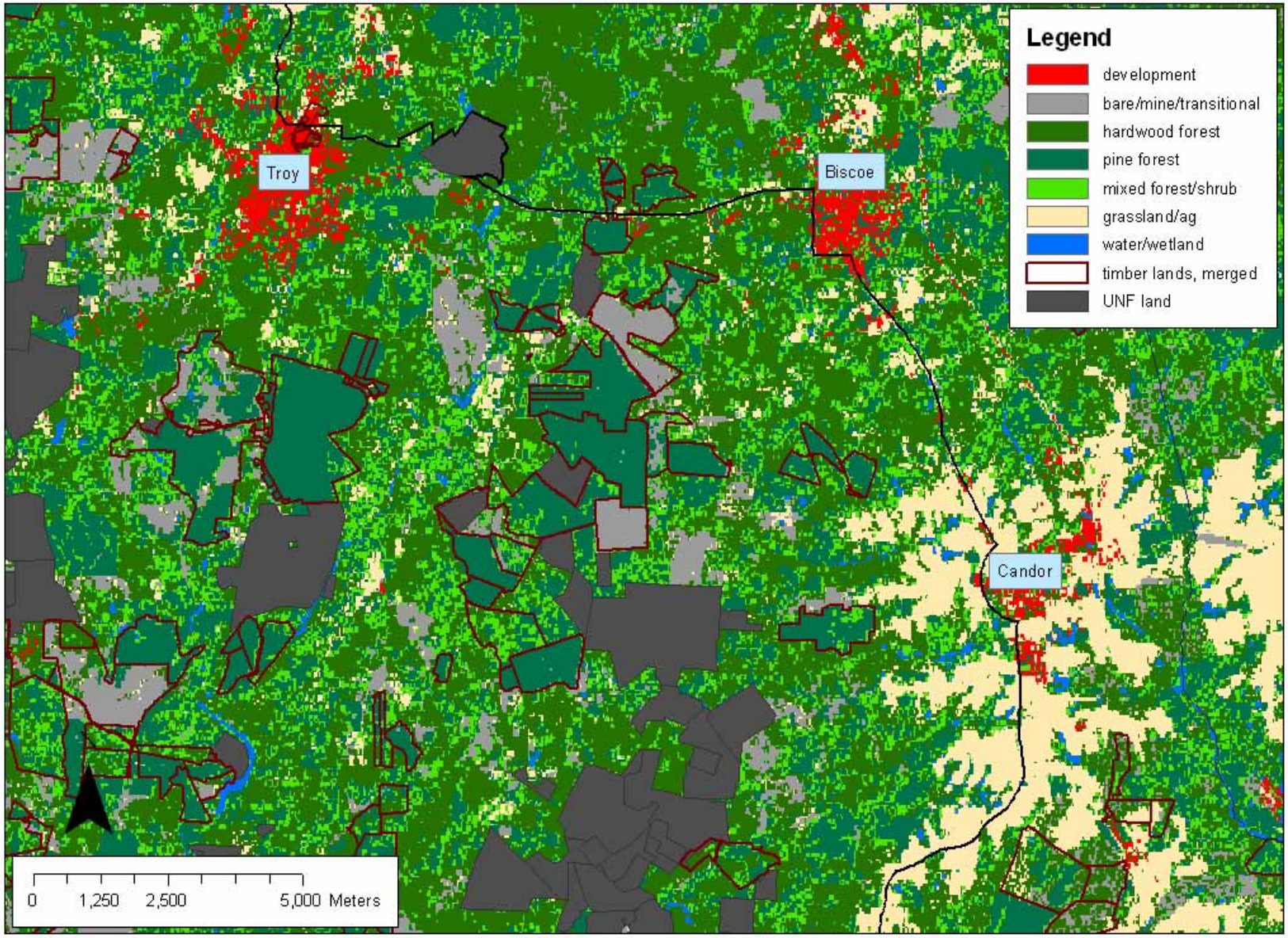


This map focuses on only the changed areas near Badin Lake, and what they looked like in 1992. Of note are the many areas near Forest Service lands that have seen a change in their land cover type. Most of these areas are some shade of green, representing high forest cover. Changes from forest to grassland or to development between 1992 and 2001 could have been significant for wildlife and fire management regimes at the borders of Forest Service lands.



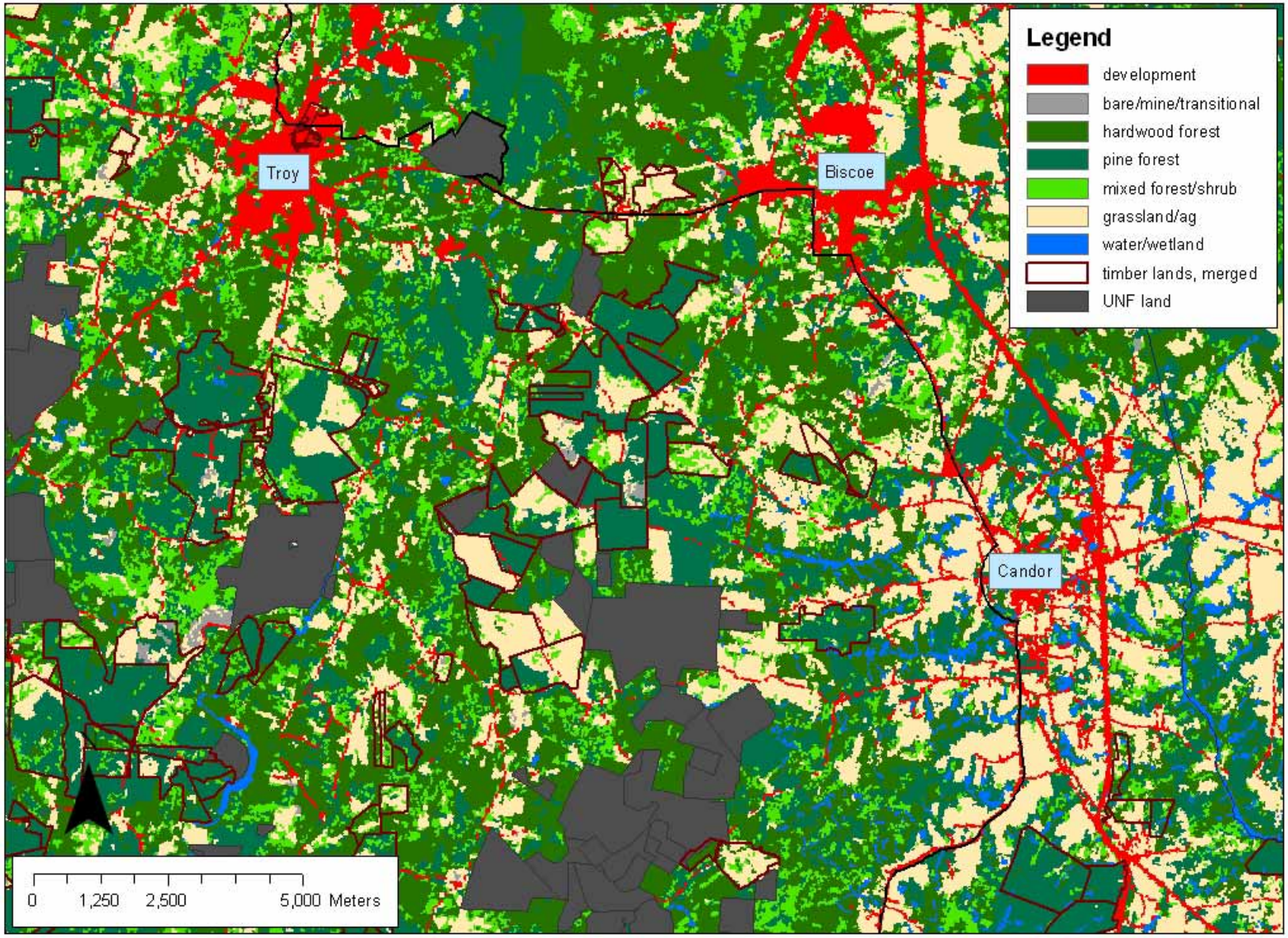
In 2001, we see that there are fewer green areas adjacent to Forest Service lands than there were in 1992. These green areas representing forests have changed to either grassland/agriculture, or to development. If the Forest Service wishes to purchase adjacent lands to increase the connectivity of its holdings, continued forest conversions will make it more difficult to do so. Non-forested acquisitions would have to undergo significant, long-term forest restoration efforts.

Land Cover Types, Southeastern Uwharrie, 1992



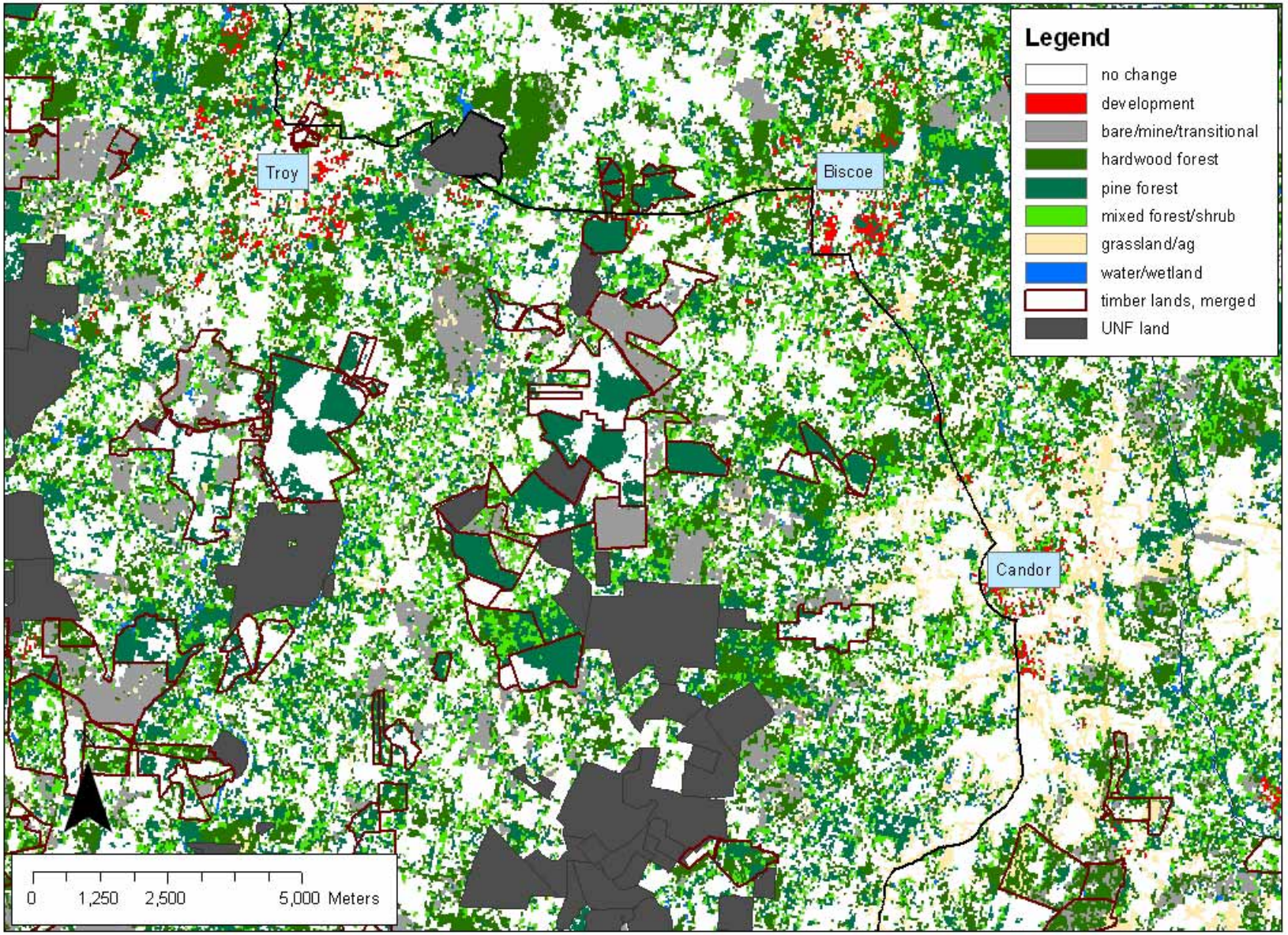
These last 4 maps focus on a southeastern Uwharrie area once covered mostly with longleaf pine savanna, but now has significant timber company ownership alongside UNF lands and is in close proximity to towns. This map shows the land cover here in 1992. Note the almost uniform pine forest within timber company parcels, and an abundance of hardwood and mixed forest elsewhere indicating a fire interval greater than the 1-3 years needed for longleaf pine restoration.

Land Cover Types, Southeastern Uwharrie, 2001

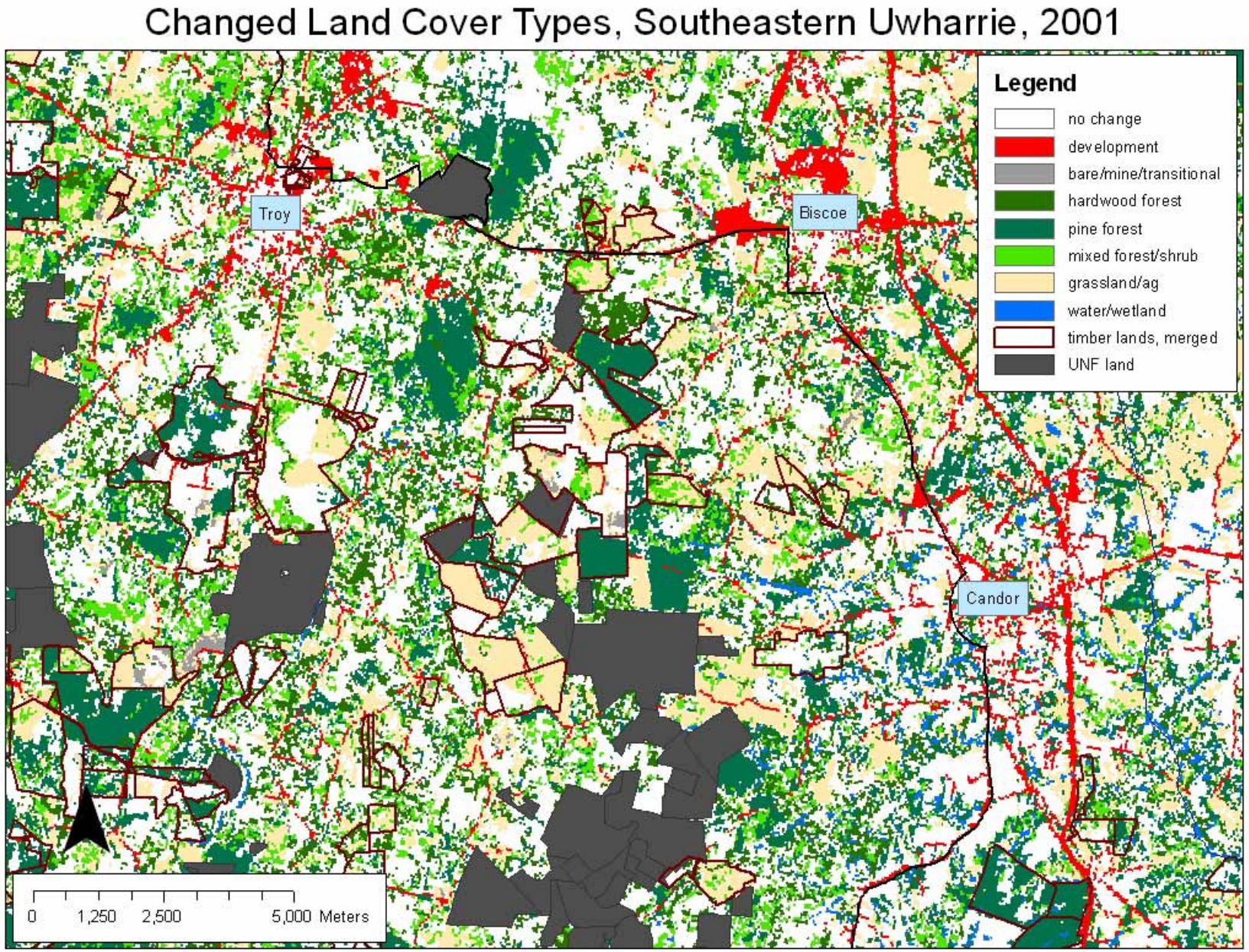


In 2001, we see a conversion of forest to grassland/agriculture throughout the area, occurring mostly along major roads. The pattern of this forest conversion greatly fragments the landscape around UNF lands into forested and non-forested areas. Some of the pine forests in timber company holdings have converted to grassland/agriculture—these have most likely been clearcut. There are many clearcut areas right next to Forest Service lands (gray).

Changed Land Cover Types, Southeastern Uwharrie, 1992



The changed areas originally had an abundance of forest types. Many of the red development areas in this image change to grassland/agriculture or mixed forest in 2001; these are most likely misclassification errors. Of note are the bare lands (gray) that are largely represented within timber company holdings. These likely represent areas that have been clearcut, because in the next image (2001) these bare lands have converted to pine forest.



Areas However, some of the timber company holdings that were covered in pine forest in 1992 have converted to grassland/agriculture, representing a decrease in forest density. Of note in this image are the large tracts of grassland/agricultural land directly adjacent to Forest Service lands. Very little bare land appears in this image; either there are misclassification errors with grassland/agriculture, or pine forests were cut sometime before 2001 so that some vegetation has regrown.

Assessment of Potential Climate Change Impacts in the Uwharries

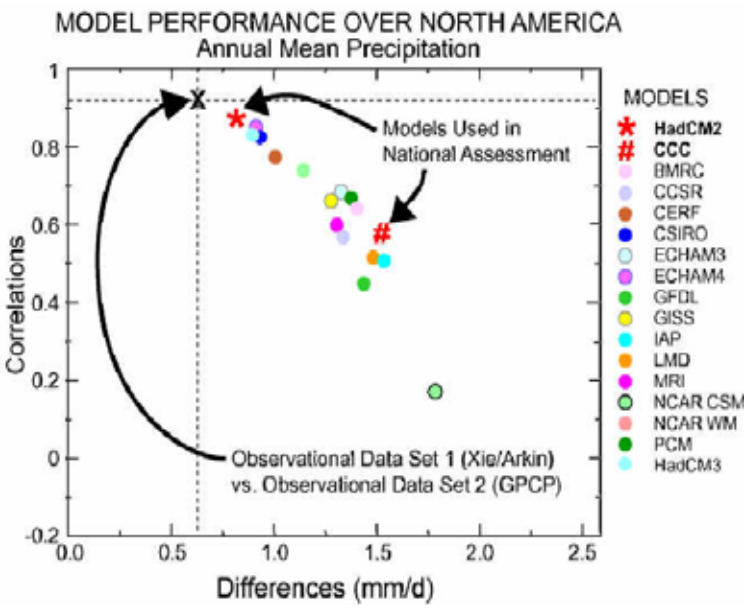
Despite previous suggestions that precipitation will increase in the southeastern US, we provide information from the IPCC suggesting that drought conditions may become more frequent in the Uwharries. If so, this would have a number of impacts on management and restoration activities in the national forest, as well as the national forest itself. These potential impacts include:

- Productivity: More frequent droughts would reduce forest productivity, creating less food for wildlife; drought conditions may affect some plant community types more than others
- Fire: Drought conditions create more fuels, but forest fragmentation will limit fire spread
- Forest health: Water stress increases tree susceptibility to insect outbreaks and disease

1. Predictions: Temperature, Precipitation, and Drought

There is a great deal of uncertainty over how climate change might impact the Uwharrie area. The two most important elements of climate change that will affect plant communities are temperature and precipitation, with precipitation being the more important of the two. Drought stress has a much greater effect on survival than increased temperature (Loehle 1998). In transplant experiments (Wright 1976), many boreal trees can survive much farther south than their natural southern range limits if there is adequate rainfall. This indicates that increased temperature in the absence of drought stress has little effect on survival (Woodward 1987, 1988).

Multiple models have overestimated annual precipitation: Much of the uncertainty over future precipitation in the Uwharrie area stems from how climate models handle their predictions of future precipitation. This is because climate models have difficulty in predicting future cloud cover and what the feedbacks might be between cloud cover, temperature, and precipitation. Researchers wanting to understand the future impacts of climate change will generally analyze different scenarios from several climate models, in hope that their results will include the whole range of scientific uncertainty (US EPA 2000). However, in the plot of climate models available in 2002 (right), we see that all of the models gave higher predictions for the annual mean precipitation than was actually observed (Karl 2002).

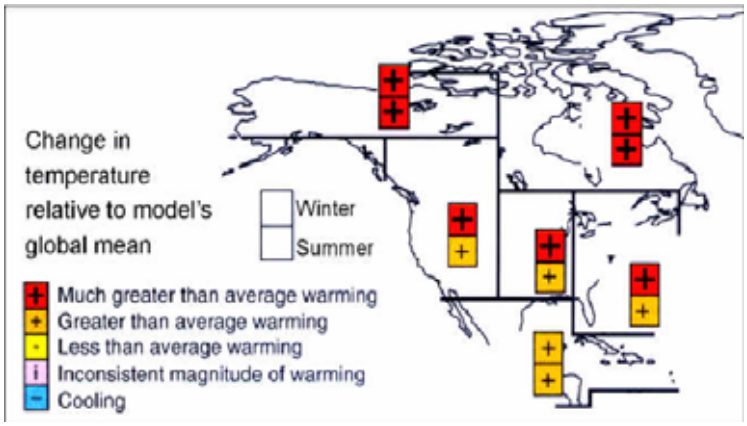


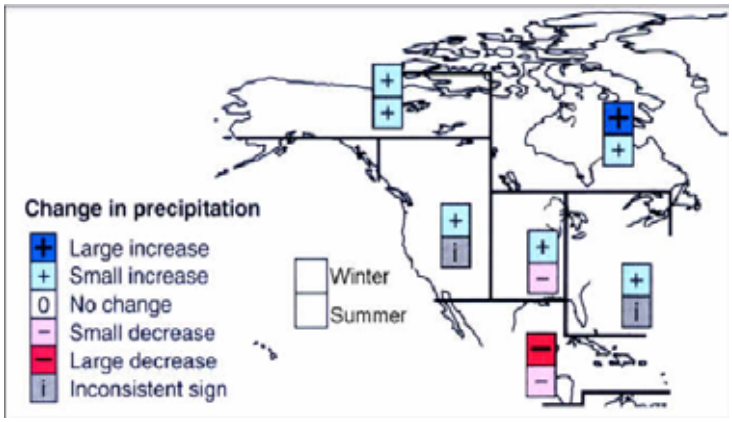
Less precipitation fell than was predicted by all 17 models used in a national assessment (Karl 2002).

Drought in the Uwharries despite predictions of increased precipitation: The HadCM3 climate change model, which has had the best predictive success for temperatures in North America thus far, suggests that precipitation in the Central Piedmont region will increase over the next 50 years (Nearing 2001). However, instead of more precipitation, the entire Central Piedmont area has actually been experiencing drought conditions since 1998 (USDA Forest Service 2003b). Instead of relying on the predictions of one model, if we expand our focus to the predictions agreed upon by 22 climate change models including the HadCM3, we get a prediction that more closely matches observed conditions of temperature and precipitation (below).

Although NC might be receiving the same or slightly more precipitation than in previous years, warmer summer temperatures create more evapotranspiration. Thus, rainfall would have to increase just to maintain current water levels. If there is not enough of a rainfall increase to balance evapotranspiration

caused by warmer temperatures, this can result in drought. The figures below show that in the southeastern United States, 22 models agree there will be a strong warming trend but little to no increase in precipitation. Thus, it is more likely that drought conditions will occur more often in the Uwharrie area than in the past, with consequences for the health of its forests.





22 climate change models agree on strong warming but little to no increase in precipitation in the southeastern US (IPCC 2001). Prolonged droughts have already been observed in the Central Piedmont area since 1998 (USDA Forest Service 2003b).

2. Impacts on Forest Productivity and Plant Communities

More conversion of sunlight into forest biomass is good for forest restoration and harvesting, but can be bad if a few species are able to take advantage of the increased CO_2 at the expense of others. This can lead to losses in biodiversity as some species outcompete others. Also, if greater productivity causes increases in tree density, this would help foster the spread of diseases and insect outbreaks. However, increased plant growth from increased CO_2 requires that there aren't other limits to plant growth, such as nutrients, diseases, fire, and droughts, which alone would increase disease susceptibility and increase the risk of damaging fires in areas having an already high fuel load due to fire suppression.

If more frequent and/or prolonged droughts occur as previously suggested, the resulting water stress would lead to a decline in productivity despite any additional CO_2 or nutrient input. This may lead to the production of fewer seeds and acorns, which in turn would cause a decline in wildlife populations higher in the food chain. The effects of drought conditions on plant communities and their associated wildlife would differ between communities, as some plant communities may be more drought-tolerant than others.

3. Altered Fire Regimes

Fire regimes have already been considerably altered in the area since pre-European times. Humans have also altered the fire regime not only spatially due to different land uses and road/trail construction, but also temporally. The historical fire regime in the Uwharrie area consisted of small fires that burned over large areas, but because of the fragmented fire compartments with heavy understory fuels that now exist, fires can cause high mortality in the fragments that manage to get ignited. The seasonality of fires has also changed—Native Americans once practiced cool season burns prior to heavy European settlement in the area (Barden 1997), but today, private landowners may decide to burn their land any time of year.

Climate change is expected to alter fire regimes by affecting the frequency and intensity of fire disturbance. Many papers have suggested that warmer temperatures and less precipitation will lead to more fires. This seems to be occurring recently in places such as California, Arizona, New Mexico, and Oklahoma that already have heavy fuel loads due to fire suppression, as well as in boreal forests, which are just as sensitive to fire and insect outbreaks as forests in the southeastern United States but have experienced greater magnitudes of climate change in recent years. Among some of these papers are that of Lynch (2003), which points out a strong correlation between fire size/severity and

temperature/precipitation, suggesting that weather is a strong factor affecting fire disturbance. Overpeck et al (1990) also indicates that wildfires will generally increase with climatic warming because warmer temperatures often give rise to drier conditions.

4. Insect Outbreaks and Disease

The southern pine beetle has been a major biological disturbance agent in North Carolina and throughout the southeastern US, attacking loblolly, shortleaf, and in epidemic years, longleaf pine which is the least susceptible species. According to records collected by the US Department of Agriculture, the total county area of the southeastern US in southern pine beetle outbreak status for at least one year was 837,075 km^2 (Williams and Liebhold 2002). The value of timber and pulpwood lost to the SPB has reached $237 million dollars/year in the recent past (Price et al 1997).

It is predicted that climate change will cause the southern pine beetle and other insects and pathogens to have a stronger negative impact on both timber production and restoration of longleaf pine forests. This is because increases in summer temperatures generally accelerates the development rate of insects, and increases their reproductive potential (Ayres 2000, Porter et al 1991). Thus with warmer temperatures, there will be a greater abundance of insects to cause outbreaks.

Of the approximately 50,000 acres within the Uwharrie National Forest area, 24,554 or approximately 49% of those acres are susceptible to the southern pine beetle. Focusing only on the total land suitable for timber production, approximately 39,200 of the ~50,000 acres are suitable, and 20,900 (53%) of those are susceptible to SPB (USDA Forest Service 2003b).

Infestations become epidemics when pine forests become stressed. This can happen when stressed by crowded growing conditions, or drought, because of damage from ice or wind, or because pines have matured. Beetle populations are able to increase exponentially due to the increase in susceptible trees. During epidemics, natural enemies of the southern pine beetle have little effect, and SPB populations become large enough that they can successfully attack healthy trees and cause widespread mortality (USDA Forest Service 2003b).

District	Uwharrie
Forest Type	Acres
Loblolly Pine and Loblolly Pine /Hardwood	10,388
Longleaf Pine	1,718
Shortleaf Pine and Shortleaf Pine /Hardwood	7,969
Virginia Pine, Virginia Pine /Hardwood, and Hardwood /Pine Types	4,480
Total	24,554

Susceptible acres by forest type in the UNF (USDA Forest Service 2003b).

Recommendations for Future Forest Management

Consider the impact of climate change on fire management, conservation, and forest restoration efforts

If droughts in the Uwharrie area continue in future years as predicted, what might be the impact of this on the different plant communities in the UNF? Areas may be more prone to fire but because of forest fragmentation, fires may not spread. There may be more insect outbreaks and diseases amongst trees. Forest productivity may actually decline, meaning less food resources for wildlife. The dieoff of trees may create more gaps throughout the forest, opening up new possibilities for longleaf pine restoration. The possible impact of climate change in the future should be taken into consideration in the next plan revision cycle.

Manage forests for biodiversity

Forests might be managed sustainably right now, but they could be managed for more biodiversity (Lamb 1998). Monocultures or plant communities with low species diversity have been shown to have greater invasibility, while invasive species have a much more difficult time getting established in high-

diversity areas (Kennedy et al 2002, Knops et al 1999). Instead of monoculture pine plantations, other native or economically important trees could be planted alongside the pines, creating more of a mixed-wood forest. Then, instead of doing clearcuts which would increase erosion and runoff during harvest and leave the land looking unsightly, only certain species would be cut at certain times. This would open up more natural gaps to accelerate tree growth beneath.

Increase cooperation between the US Forest Service, timber companies, and private landowners

The US Forest Service has opened up opportunities for more cooperation by allowing public input to be received during its planning meetings. However, more could be done to facilitate interactions within the mixed-use, mixed-ownership landscape of the Uwharrie area to make broader fire management and restoration activities possible. Perhaps subsidies could somehow be provided for timber companies to thin hardwood trees on private lands, while passing along some of the revenue to the landowner. This would allow faster restoration of longleaf pine in areas of the Uwharrie where private landowners lack the time or equipment to thin their own forests. Also, perhaps timber companies and private landowners could be encouraged to swap lands with those held by the US Forest Service. Those parties owning rocky land unsuitable for agriculture or logging with heavy equipment, but are located adjacent to areas of prime conservation importance, should be identified and presented with the possibility of doing a land swap. This would help consolidate land for conservation, at no loss to the timber company's holdings or to private landowners.

References

Ayres, M. P. and Lombardero, M. J. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. The Science of the Total Environment 262: 263-286.

Bannister, Cowan & Company. 1869. The Resources of North Carolina: Its Natural Wealth, Condition, and Advantages, as Existing in 1869. Presented to the Capitalists and People of the Central and Northern States. Electronic edition by the University of North Carolina at Chapel Hill. http://docsouth.unc.edu/nc/bannister/bannister.html.

Barden, Lawrence S. 1997. Historic prairies in the Piedmont of North and South Carolina, USA. *Natural Areas Journal* **17**: 149-152.

Cecil Frost – notes from UNC-CH Ecology 199 class interview, February 7, 2006.

Intergovernmental Panel on Climate Change (IPCC). 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Asssessment Report of the Intergovernmental Panel on Climate Change. http://www.grida.no/climate/ipcc_tar/wg1/

Lamb, David (1998). Large-scale Ecological Restoration of Degraded Tropical Forest Lands: The Potential Role of Timber Plantations. *Restoration Ecology* **6**(3), 271-279.

Nearing, M. A. 2001. Potential changes in rainfall erosivity in the U.S. with climate change during the 21st century. *J. Soil and Water Conservation*, **56**(3):229-232.

Karl, T. R. 2002. The U.S. National Climate Change Assessment: Do the Climate Models Project a Useful Picture of Regional Climate? http://energycommerce.house.gov/107/hearings/07252002Hearing676/Karl1142.htm

Kennedy, T.A., S. Naeem, K.M. Howe, J.M.H. Knops, D. Tilman, and P. Reich. 2002. Biodiversity as a barrier to ecological invasion. *Nature* **417**: 636-638.

Knops, J.M.H., D. Tilman, N.M. Haddad, S. Naeem, C.E. Mitchell, J. Haarstsd, M.E. Ritchie, K.M. Hower, P.B. Reich, E. Siemann, and J. Groth. 1999. Effects of plant species richness on invasion dynamics, disease outbreaks, insect abundances, and diversity. *Ecol. Lett.* **2**: 286-293.

Le Goff, H. and L. Sirois. 2004. Black spruce and jack pine dynamics simulated under varying fire cycles in the northern boreal forest of Quebec, Canada. *Can. J. For. Res.* **34**: 2399-2409.

Loehle, C. 1998. Height growth rate tradeoffs determine northern and southern range limits for trees. *Journal of Biogeography* **25**: 735-742.

Lynch, J. A., J. S. Clark, N. H. Bigelow, M. E. Edwards, B. P. Finney. 2003. Geographic and temporal variations in fire history in boreal ecosystems of Alaska. *J. Geophysical Research* **108**, No D1, 8152.

McNulty, S. Soil erosion map. Part of PowerPoint presentation. http://cdmc.epp.cmu.edu/mcnulty.ppt

NC Department of Environment and Natural Resources, Division of Forest Resources. 2002. Working with Wildlife: Bobwhite Quail. http://www.dfr.state.nc.us/stewardship/wwwildlife/www08.htm

Overpeck, J. T., Bartlein, P. J., and Webb, III, T. 1991, 'Potential Magnitude of Future Vegetation Change in Eastern North America: Comparisons with the Past', *Science* **254**, 692–695.

Porter JH, Parry ML, Carter TR. 1991. The potential effects of climatic change on agricultural insect pests. *Agr For Meteorol* **57**: 221-240.

Price TS, Dogget HC, Pye JM, Smith B. A history of southern pine beetle outbreaks in the southestern United States. Georgia Forestry Commission. Macon, Georgia, 1997: 72.

Rupp, T. S., A. M. Starfield, F. S. Chapin III, and P. Duffy. 2002. Modeling the impact of black spruce on the fire regime of Alaskan boreal forest. *Climatic Change* **55**: 213-233.

USDA Forest Service. 2005a. September 2005 Base Planning Map. Uwharrie National Forest Plan Revision Website. http://www.cs.unca.edu/nfsnc/uwharrie_plan/planning_documents.htm.

USDA Forest Service. 2005b. Uwharrie National Forest – A Strategic View. July 2005. http://www.cs.unca.edu/nfsnc/uwharrie_plan/uwharrie_cer.pdf

USDA Forest Service. 2004. Uwharrie National Forest Watershed Analysis. Draft – Sept. 2004.

USDA Forest Service. 2003a. Roads Analysis Process Report, Uwharrie National Forest, Dec. 2003.

USDA Forest Service. 2003b. Uwharrie National Forest. Southern Pine Beetle Infestation Suppression Environmental Assessment. http://www.cs.unca.edu/nfsnc/nepa/uwharrie/uwharrie_spb_ea.pdf

US Environmental Protection Agency (EPA). 2000. U.S. Climate. http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ClimateFutureClimateUSClimate.html

Williams D. W. and A. M. Liebhold. 2002. Climate change and the outbreak ranges of two North American bark beetles. *Agricultural and Forest Entomology* **4**: 87-99.

Woodward, F. I. 1987. *Climate and plant distribution.* Cambridge University Press, Cambridge.

Woodward, F. I. 1988. Temperature and the distribution of plant species and vegetation. *Plants and temperature. Vol. 42* (ed. by S. P. Long and F. I. Woodward), pp. 59-75. The Company of Biologists Limited, Cambridge.