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Past and Potential Future Land Cover Change Around Wisconsin's State Forests

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Abstract

Land use and land cover change have shaped Wisconsin's landscape for centuries. We examined recent past and potential future land cover change surrounding Wisconsin state forests to better understand how landscape structure will be affected by land acquisition and planning decisions. Our objectives were to: 1) quantify land cover change from 1992 to 2001, including forest loss and afforestation, and the impacts on core forest area and connectivity, 2) develop scenarios of land cover change from 2001 to 2051, and 3) estimate potential impacts of future land cover change on forest connectivity and carbon sequestration and storage. We used the National Land Cover Dataset (NLCD) Land Cover Change Retrofit product (Fry et al. 2009), the NLCD 2001 land use-land cover product, an econometric model of land cover change for projecting land cover change (Radeloff et al. 2012), and spatial pattern analysis to accomplish these objectives. Overall, we found high variability in the forested context of Wisconsin's state forests. Land cover change from 1992 to 2001 was greater in northern Wisconsin than in southern Wisconsin. The primary impact to northern forests was forest loss to grassland or cropland, with a secondary threat of forest loss to housing. Projected future land cover change under our Dynamic Forest scenario indicated potential for greater change in forests of southern Wisconsin than in northern Wisconsin. The primary threat to southern forests was conversion of forest to urban land uses. Projected future land cover change under our Dynamic Forest scenario indicated potential for core forest area and connectivity to increase in northern forests. Projected future land cover change under the Dynamic Forest scenario indicated that potential negative impacts of forest loss on carbon sequestration and storage exist for at least four forests: Havenwoods and the Lapham Peak, Loew Lake, and Pike Lake units of the Kettle Moraine. We concluded that the diverse landscapes of Wisconsin's state forests —some in highly forested regions and others in largely agricultural regions—demand diverse forest management strategies. Buffers around state forests face likely changes both from afforestation and from forest loss to cropland, development, and grasslands. Understanding these changes can help managers and planners better anticipate future challenges and allocate acquisition and stewardship resources in ways that will be most effective and efficient.


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Key Findings

- *A summary of land cover change from 1992 to 2001 shows some loss of forests to grassland, cropland, and housing.*
- *Land cover change models indicate a potential net increase in forest cover through 2051.*
- *These models, however, also project some loss of existing forest to housing and other land uses.*
- *Core forest area and connectivity may increase around state forests in northern Wisconsin, but decrease around state forests in southern Wisconsin.*
- *Land acquisition and outreach to surrounding landowners should prioritize areas that are threatened by forest loss.*

Contents

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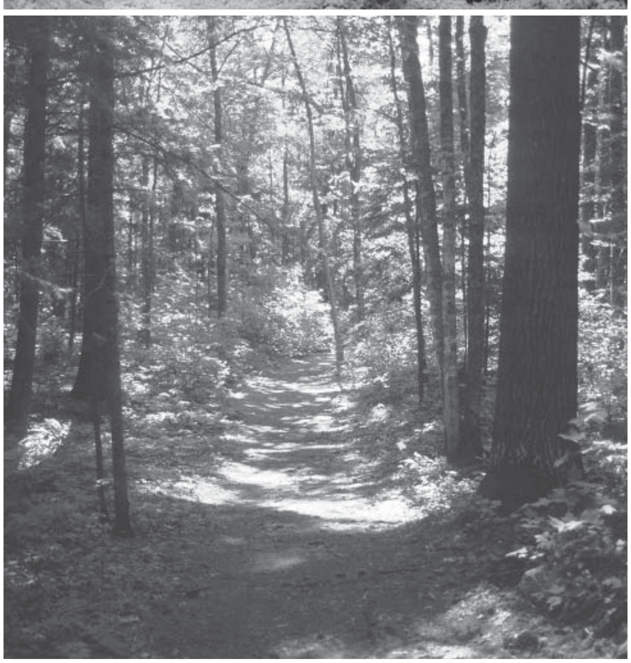

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Introduction

Land use and land cover change have shaped Wisconsin's landscape for centuries (Lentz 2000). The impacts of land use and land cover change have occurred through agrarian Native American settlements and Euro-American settlement, agriculture, and large-scale clearing of forests, followed by extensive afforestation. Today, areas with high residential and agricultural land cover are where forest loss continues to be highest (Rittenhouse et al. 2012). Rural residential development is increasing in predominately forested, amenity-rich areas. Housing growth in forested areas has economic, social, and ecological impacts.

Housing growth increases parcelization and alters the scale of harvestable properties (Rickenbach and Steele 2006, Haines et al. 2011). When combined with forest loss, the economic impacts on regional timber economies can be substantial (Barlow et al. 1998, Rickenbach and Gobster 2003). Parcelization and new landowners can increase social conflict, including boundary issues and encroachment, and differing expectations about land management (Rickenbach and Reed 2002, Knoot et al. 2009). Compounding these issues, the borders of public lands can attract housing development due to higher amenity value (McConnel and Walls 2005), which can result in greater housing growth near public lands than what might otherwise occur (Hammer et al. 2009, Gimmie et al. 2010, Radeloff et al. 2010). Further, housing growth and forest loss reduce carbon sequestration and storage by forests (Zheng et al. 2011).

This report examines past and potential future land cover change surrounding Wisconsin state forests. Understanding where forest change has occurred and where the threat of forest conversion is highest can help land managers prioritize where to focus acquisition, land use planning, and community outreach efforts. Specifically, our objectives are to: 1) quantify land cover change from 1992 to 2001, including forest loss and afforestation, and the impacts on core forest area and connectivity, 2) develop scenarios of land cover change from 2001 to 2051, and 3) estimate potential impacts of future land cover change on forest connectivity and carbon sequestration and storage.

Methods

State Forest Descriptions

We included 18 state forest units in this analysis (Table 1, Figure 1), including 10 state forests, a nature center, an experimental forest, and six units of the Kettle Moraine (KM) State Forest. We obtained state forest purchase boundaries from the Wisconsin Department of Natural Resources (Wisconsin DNR) and used those boundaries to define a purchase area for each state forest unit. The purchase boundary represented the extent of state authority to purchase and add land to the state forest. For some state forests, the purchase boundary was the same as the state forest boundary. For others, the purchase boundary extended beyond land owned by the state, and included private lands. We applied a 5 km buffer to purchase boundaries. We chose a 5 km boundary because it provided a spatially representative characterization of land cover change processes, which were modeled at the county level (see "Potential Land Cover Change Scenarios" below). When the purchase area contained inholdings, or private lands, we included those in the buffer.

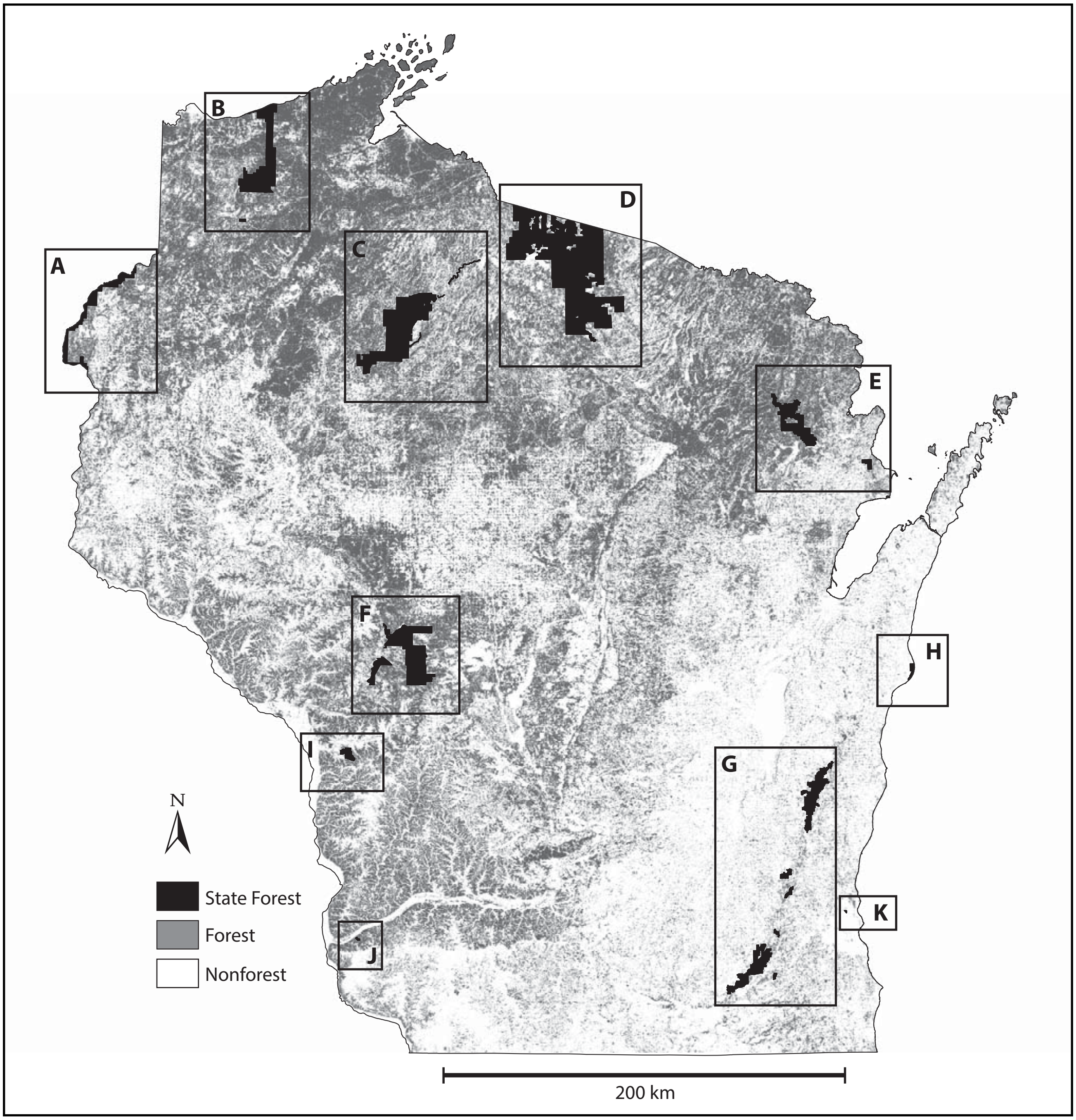

Figure 1. *Location of 18 Wisconsin state forest units, including six northern state forests (A–F) and 12 southern state forests and units (G–K).*

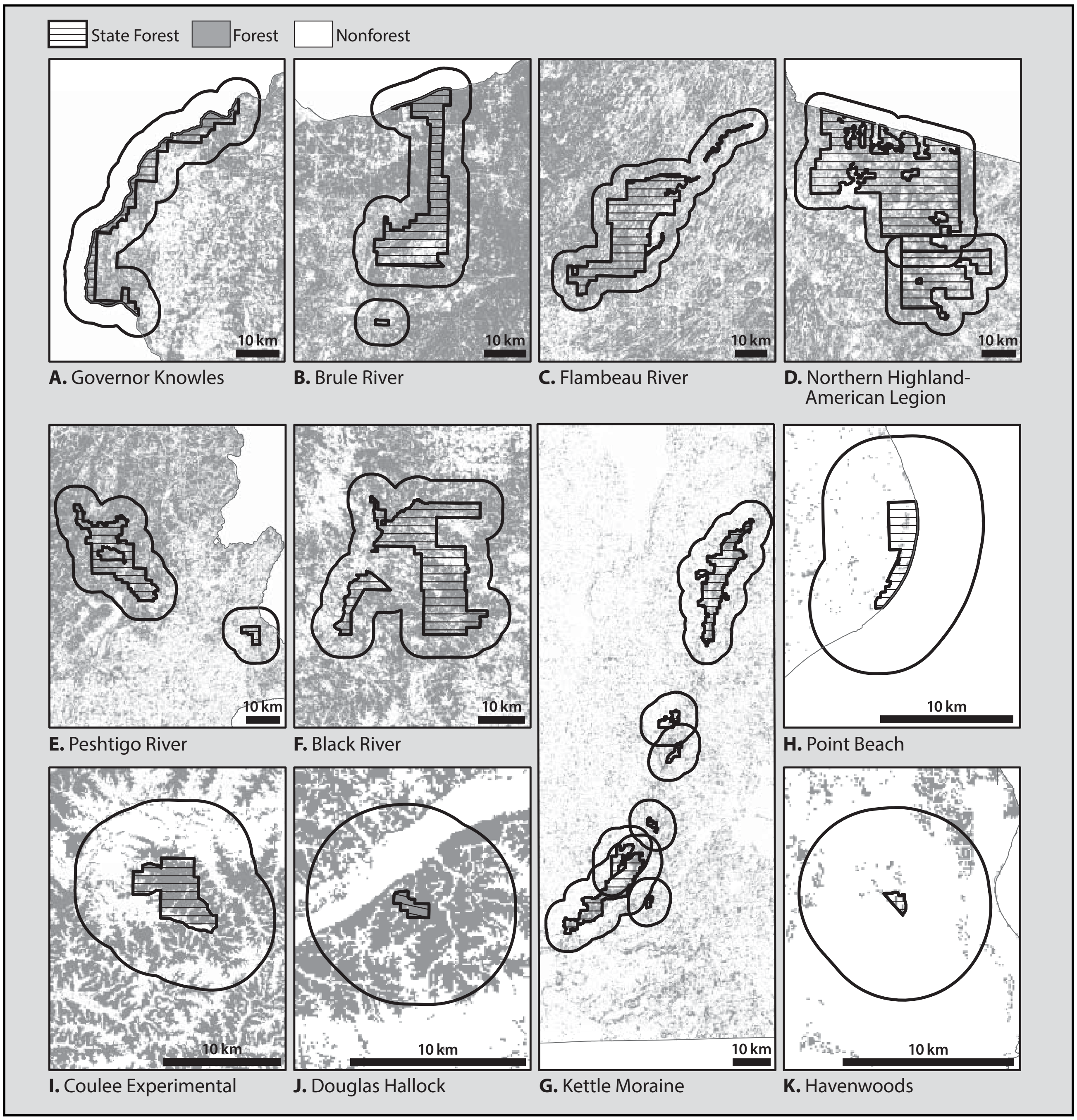

Figure 1 *(continued). State forest units with respective 5 km buffers of purchase unit boundaries.*

Table 1. *Area (ha) within purchase boundary and 5 km buffer of Wisconsin state forest unit purchase boundaries. Kettle Moraine state forest abbreviated as KM. Multiplication of 5 km buffer area by percents in Table 3 yields area of 5 km buffer in each land cover change class.*

Name	Purchase area	5 km buffer
Brule River	33801	90212
Peshtigo River	20614	71429
Black River	39470	95019
Douglas Hallock	181	10895
Flambeau River	59675	118099
Governor Knowles	15678	93329
American Legion	39647	62796
Northern Highland	120995	113851
Coulee Experimental	2627	19463
KM Paradise Valley	2557	21323
KM Lapham Peak	456	13545
KM Loew Lake	909	16074
KM Mukwonago River	376	12379
KM Southern Unit	11855	45826
KM NU-IANSR	15821	56012
KM Pike Lake	1435	17243
Havenwoods	87	9975
Point Beach	1228	17877

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Past Land Cover Change (1992–2001)

We used the National Land Cover Dataset (NLCD) Land Cover Change Retrofit product (Fry et al. 2009) to identify land cover transitions that occurred between 1992 and 2001 within the purchase area and in a 5 km buffer of each state forest unit purchase boundary. The Land Cover Change Retrofit product consisted of a 1) reclassification of the original Landsat images used in the NLCD 1992 and NLCD 2001 products to a common classification system using a modified Anderson Level I class code (i.e. retrofit) at 30 m pixel size, so they could be comparable in change-detection applications, 2) post classification comparison of disagreement between the reclassified maps, 3) spectral change analysis using ratio differencing techniques, and 4) final product compilation based on results of 2 and 3 to enable direct comparisons of the location and type of land cover change from 1992 to 2001. No formal assessment of the classification error rate has been conducted (Fry et al. 2009).

The modified Anderson Level I classification contained eight class codes (i.e. open water, urban, barren, forest, grass/shrub, cropland, wetland, and ice/snow), which we collapsed into six class codes for compatibility with the potential land cover change scenario modeling (see below). The six class codes for the Land Cover Change Retrofit product were water (open water, barren, and wetland), cropland (row crop), grassland (pasture and hay), forest (coniferous, deciduous, or mixed coniferous-deciduous trees >5 m and >20% cover), urban, and shrubland (grassland, and shrub-scrub and early successional forest <5 m tall and >20% cover). We included barren and wetland in water because they had no development potential in the land cover change scenario modeling.

The Land Cover Change Retrofit product used a "from-to" class code matrix to classify land cover change, where "from" corresponds to 1992 land cover type and "to" to the 2001 land cover type (Table 2). This classification scheme enabled back-calculating 1992 land cover conditions, obtaining 2001 land cover conditions, as well as tracking all transitions.

Potential Future Land Cover Change Scenarios (2001–2051)

We considered three land cover change scenarios: two that represented endpoints of a gradient from no change in recent forest cover (Static Forest, the 2001 baseline) to maximum afforestation potential (All Forest), and one that represented an intermediate position of projected land change (Dynamic Forest). We established initial conditions for all three scenarios using the 2001 NLCD. We grouped 2001 NLCD classes into the same class codes as described above, which included water (NLCD classes 11, 12, 31, 90, 95), cropland (82), grassland (81), forest (41, 42, 43), urban (21, 22, 23, 24), and shrubland (52, 71). The potential for land cover change varied by scenario, land cover type, and ownership:

1. **Static Forest** – all land cover types, including forest, held constant from 2001 to 2051 on public and private lands. While land cover did not change under this scenario, we assumed tree growth and regeneration continued. The resulting land cover/land use change map constituted the 2051 Static Forest map, which is a baseline of recent conditions, used for comparison with scenarios that project changes over time.
2. **Dynamic Forest** – all cropland, grassland, forest, and shrubland land cover types on private lands had a probability of transitioning to another land cover type by 2051. The probability of land cover change was based on an econometric model of observed land use change trends from 1992 to 1997 (Radeloff et al. 2012), which used data on current land use (cropland, grassland, forest, urban, Conservation Reserve Program, and shrubland), estimated per-acre county-level net economic returns to each of the land uses modeled, the economic costs of conversion among land uses, and soil quality and agricultural potential (USDA 1973). County-level net returns were defined as the average annual profit (revenues less costs) observed in the county from each land use from 1992 to 1997 (Lubowski et al. 2006). The econometric model provided transition probabilities for a single 5-year time step (1992 to 1997), and the 50-year transition probability matrices were obtained through matrix multiplication (Radeloff et al. 2012). Protected lands, which included all federal, state, county, and tribal lands in the U.S. Geological Survey's 2005 GAP dataset (U.S.G.S. 2005) and all properties in the Wisconsin DNR's 2009 Managed Forest Law database, had zero probability of transitioning to another land cover type under this scenario. We used ESRI's ArcMap version 10 to determine on a cell-by-cell basis the highest probability across all land cover types and assigned the corresponding land cover type to a given cell. The resulting land cover/land use change map constituted the 2051 Dynamic Forest map.
3. **All Forest** – all cropland, grassland, and shrubland land cover types on public and private lands transitioned to forest by 2051. The resulting land cover/land use change map, which contained only water, forest, and urban land cover types, constituted the 2051 All Forest map. This map represented a hypothetical situation used for highlighting limitations on afforestation.

Assessment of Past and Potential Future Changes in Land Cover

We assessed past and potential future changes in land cover, forest attributes, and carbon sequestration within the purchase area and in a 5 km buffer of each state forest unit purchase boundary. The buffer included inholdings within the purchase boundary and lands adjacent to state forests regardless of scenario, land cover type, or ownership.

To assess past and potential future changes in land cover, we tracked all transitions in a "from-to" fashion for each scenario (Table 2). For example, a cell containing forest cover in 2001 that transitioned to urban by 2051 was classified as "forest-to-urban" in our summary. This enabled identification of the source land cover (i.e. forest) and the result of the transition (i.e. gain

Table 2. *Possible land cover type transitions for past and potential future land cover change within and near Wisconsin state forests. Parentheses indicate groupings used to identify changes in forest cover and compare among state forest units (e.g., Figures 2 and 3). Only land cover type transitions that actually occurred are reported in the following tables and figures.*

	"To" Class					
"From" Class	**Water**	**Cropland**	**Grassland**	**Forest**	**Urban**	**Shrubland**
Water	water (water)	water-to-cropland (non-forest change)	water-to-grassland (non-forest change)	water-to-forest (afforestation)	water-to-urban (non-forest change)	water-to-shrubland (non-forest change)
Cropland	cropland-to-water (non-forest change)	cropland (persistent non-forest)	cropland-to-grassland (non-forest change)	cropland-to-forest (afforestation)	cropland-to-urban (non-forest change)	cropland-to-shrubland (non-forest change)
Grassland	grassland-to-water (non-forest change)	grassland-to-cropland (non-forest change)	grassland (persistent non-forest)	grassland-to-forest (afforestation)	grassland-to-urban (non-forest change)	grassland-to-shrubland (non-forest change)
Forest	forest-to-water (forest loss)	forest-to-cropland (forest loss)	forest-to-grassland (forest loss)	forest (persistent forest)	forest-to-urban (forest loss)	forest-to-shrubland (forest loss)
Urban	urban-to-water (non-forest change)	urban-to-cropland (non-forest change)	urban-to-grassland (non-forest change)	urban-to-forest (afforestation)	urban (persistent non-forest)	urban-to-shrubland (non-forest change)
Shrubland	shrubland-to-water (non-forest change)	shrubland-to-cropland (non-forest change)	shrubland-to-grassland (non-forest change)	shrubland-to-forest (afforestation)	shrubland-to-urban (non-forest change)	shrubland (persistent non-forest)

The diverse landscapes of Wisconsin's state forests–some in highly forested regions and others in largely agricultural regions–demand diverse management strategies.

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of urban). We also grouped land cover types generally as persistent non-forest (cropland, grassland, urban, and shrubland), non-forest change (any "from-to" transition among non-forest land cover types), forest loss (any "from forest to non-forest"), afforestation (any "from non-forest to forest"), and persistent forest. The definition of afforestation excluded reforestation (e.g., forest harvest and regeneration). These definitions enabled identification of changes in forest cover and comparison among state forest units.

To assess past and potential future changes in forest connectivity within the purchase area and in the 5 km buffer of each state forest unit purchase boundary, we used morphological spatial pattern analysis to quantify forest core, connector, edge, and patch area (Soille and Vogt 2009) from forest land cover in the Static Forest, Dynamic Forest, and All Forest maps. Morphological spatial pattern analysis consisted of a sequence of logical operations conducted within a moving window of specified size. We used a 3 by 3 cell window size, equivalent to an 8-cell neighborhood surrounding the center (focal) cell. We used a cell size of 100 m and specified a size parameter of 1 cell, meaning that core forest was at least 100 m (1 cell) from a forest–non-forest boundary. The 100-m distance approximated the reported distances abiotic and biotic edge effects penetrated into forests (Murcia 1995). Core forest was assigned to the center cell provided all cells within the window contained forest (Figure 2). Connector forest was defined as a subset of edge forest that connected at least two different core forest areas, but did not itself contain core forest (i.e. consisted of forest edge only). Edge forest was defined as forest adjacent to non-forest. Patch forest was defined as isolated forest that was too small to contain core forest.

We also assessed similarity of changes in land cover and forest attributes among state forest units, lands adjacent to state forests, and land cover change scenarios. We conducted three similarity analyses of land cover attributes based on the following comparisons of state forest unit purchase areas to buffers:

1. land cover change from 1992 to 2001,
2. land cover change from 2001 to 2051 under the Static Forest scenario, and
3. land cover change from 2001 to 2051 under the Dynamic Forest scenario.

We also conducted four similarity analyses of forest attributes (i.e. core, connector, edge, and patch forest) based on the following comparisons of state forest unit purchase areas to buffers:

1. year 1992,
2. year 2001,
3. Dynamic Forest scenario, and
4. All Forest scenario.

We used the Yue-Clayton (2005) index to calculate similarity based on the proportional area of shared and non-shared land cover types (or forest attributes) among two landscapes. The range of the Yue-Clayton index is 0–1, with 0 indicating completely different landscapes with respect to land cover types (or forest attributes) and proportional area.

To assess potential future changes in carbon sequestration and storage, we used a multi-step process to estimate aboveground carbon sequestration potential of live trees by 2051 under the three scenarios of land cover change. Data sources included the LANDFIRE Existing Vegetation Type layer (U.S.G.S 2011) to map existing vegetation type and forest cover for Wisconsin and U.S. Forest Service Forest Inventory and Analysis data for initial biomass and forest type-specific age information (Blackard et al. 2008). We used forest type-specific carbon sequestration equations to calculate carbon sequestration potential for live trees based on the proportions of each forest type within each state forest and buffer (Smith et al. 2006). We made two important assumptions regarding carbon sequestration and storage. First, we assumed natural regeneration of tree species in the same proportion as the current composition of tree species within each ecological landscape. In other words, we did not account for potential tree species migration, or tree-species specific differences in mortality or recruitment due to climate change or other factors. Second, we assumed no-net-change in tree mortality from present due to tree harvest or other sources of mortality. This assumption provided a "theoretical maximum" scenario of carbon sequestration potential and facilitated comparison among scenarios. We expressed carbon in teragrams of carbon (TgC).

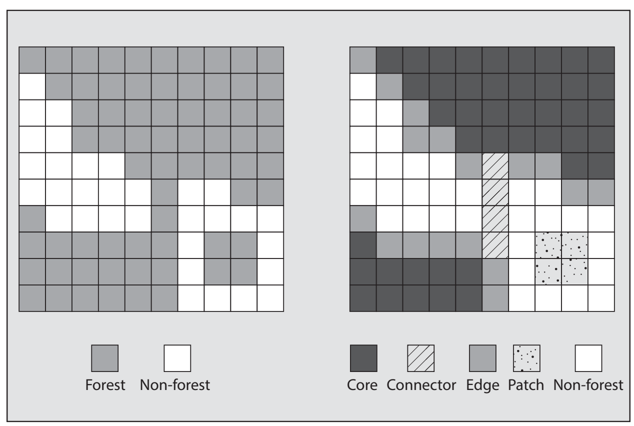

Figure 2. *Illustrative forest and non-forest landscape (left) and classification of forest attributes using morphological spatial pattern analysis (right). Forest attributes include core, connector, edge, and patch forest.*

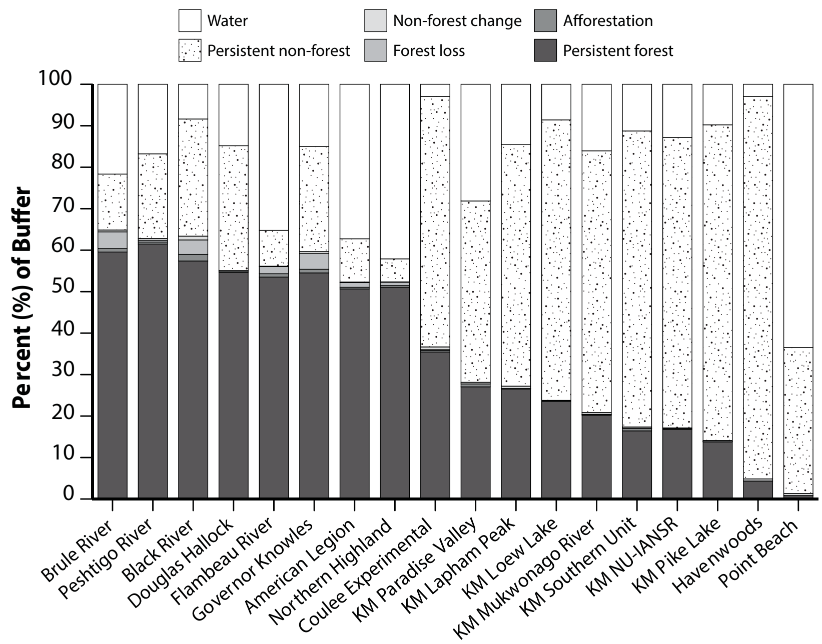

Figure 3. *Land cover change from 1992 to 2001 for lands within 5 km of Wisconsin state forest unit purchase boundaries. Kettle Moraine State Forest abbreviated as KM.*

Table 3. *Land cover change from 1992 to 2001 for lands within 5 km of state forest unit purchase boundaries in Wisconsin. Only land cover type transitions that actually occurred are reported. Values are percent of buffer.*

State Forest	Water	Cropland	Cropland to Forest	Grassland to Cropland	Grassland	Grassland to Forest	Grassland to Urban	Forest to Water	Forest to Cropland	Forest to Grassland	Forest	Forest to Urban	Urban	Row Total Change
Brule River	22	5	1	<1	5	<1	<1	1	<1	2	60	<1	3	5
Peshtigo River	17	10	<1	<1	5	<1	<1	<1	<1	<1	61	<1	5	1
Black River	8	12	1	<1	10	<1	<1	1	1	1	57	<1	5	5
Douglas Hallock	15	26	<1	<1	<1	<1	<1	<1	<1	<1	55	<1	4	<1
Flambeau River	35	3	1	<1	3	<1	<1	1	<1	1	53	<1	3	2
Governor Knowles	15	15	1	<1	7	<1	<1	2	1	1	54	<1	3	5
American Legion	37	1	<1	<1	2	<1	<1	<1	<1	<1	51	<1	7	1
Northern Highland	42	<1	<1	<1	1	<1	<1	<1	<1	<1	51	<1	5	1
Coulee Experimental	3	51	<1	<1	1	<1	<1	<1	<1	<1	35	<1	8	1
KM Paradise Valley	28	36	1	<1	2	<1	<1	<1	<1	<1	27	<1	5	1
KM Lapham Peak	15	37	<1	<1	3	<1	<1	<1	<1	<1	26	<1	17	<1
KM Loew Lake	9	56	<1	<1	4	<1	<1	<1	<1	<1	24	<1	7	<1
KM Mukwonago River	16	46	<1	<1	5	<1	<1	<1	<1	<1	20	<1	12	<1
KM Southern Unit	11	59	1	<1	4	<1	<1	<1	<1	<1	16	<1	8	1
KM NU-IANSR	13	60	<1	<1	3	<1	<1	<1	<1	<1	17	<1	7	<1
KM Pike Lake	10	59	<1	<1	2	<1	<1	<1	<1	<1	14	<1	15	<1
Havenwoods	3	1	<1	<1	<1	<1	<1	<1	<1	<1	4	<1	91	<1
Point Beach	63	27	<1	<1	1	<1	<1	<1	<1	<1	1	<1	7	<1

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Results

Changes in Land Cover (1992–2001)

From 1992 to 2001, the dominant land cover classes in the 5 km buffer around the purchase boundary of state forest units were: forest (8 of 18 state forest unit buffers) and cropland (8 of 18), followed by urban (1 of 18), and water (1 of 18) (Table 3). Land cover changes constituted 1% or less of the buffer area for 14 of 18 state forest units. Four state forest units had >1% land cover change: Brule River (5% change), Black River (5% change), Governor Knowles (5% change), and Flambeau River (2% change). In these four state forests, forest loss-to-grassland or forest loss-to-water exceeded forest loss-to-urban.

Afforestation occurred in all state forest unit buffers except American Legion. Forest loss exceeded afforestation in the Brule River, Black River, Governor Knowles, Flambeau River, Northern Highland, and American Legion state forests (Figure 3). All other state forest units had greater afforestation than forest loss.

Potential Future Land Cover Changes

Potential land cover changes within state forest unit buffers is projected to vary greatly by property location and the character of the surrounding landscape, and by land cover change scenario. Under the Static Forest scenario, which maintained land cover types that existed in 2001, we observed a clear north-south distinction in the composition of the area around State Forests (Figure 4). In northern Wisconsin, buffers consisted primarily of forest (mean=57.0%, sd=7.2, range=49.3–69.9), followed by water (mean=25.4%, sd=13.9, range=9.3–43.7) and non-forest (mean=17.6%, sd=8.8, range=7.0–31.9). In contrast, buffers in southern Wisconsin consisted primarily of non-forest (mean=65.0%, sd=6.9, range=30.7–92.9), followed by forest (mean=21.9%, sd=14.7, range=1.8–54.5) and water (mean=13.1%, sd=7.3, range=2.9–28.8). This north-south distinction in landscape context for state forests affected forest loss and afforestation potential under the Dynamic Forest and All Forest scenarios of land cover change.

Under the Dynamic Forest scenario, forest loss is projected to occur only in buffers of Kettle Moraine State Forest units located in southeastern Wisconsin (mean=8.3%, sd=5.4, range=0–17.0) and the Coulee Experimental State Forest located in western Wisconsin (6.5%; Table 4). In contrast, afforestation is projected to occur in buffers of all state forest units (mean=4.0%, sd=4.2, range=0–12.4) except Havenwoods, the Lapham Peak unit of Kettle Moraine State Forest, and the American Legion State Forest (Table 4). A net loss of forest cover (i.e. forest loss exceeded afforestation) is projected to occur in the Lapham Peak, Loew Lake, and Pike Lake units of the Kettle Moraine State Forest.

Under the All Forest scenario, afforestation potential is projected to be limited by the availability of non-forest land that was not urban land cover (Figure 4, Table 4). Among all state forests, afforestation potential is projected to be highest in southern Wisconsin (mean=47.7%, sd=19.4, range=1.6–64.2) and lowest in northern Wisconsin (mean=12.7%, sd=8.8, range=1.3–26.0).

Similarity of land cover for state forest unit purchase areas and 5 km buffers also is projected to vary with landscape context and by land cover change scenario. We found lower similarity of land cover types comparing state forest unit purchase areas to buffers in southern Wisconsin than in northern Wisconsin for the Static Forest and Dynamic Forest scenarios (Table 5). The lower similarity

Table 4. *Potential land cover change from 2001–2051 under the Dynamic Forest scenario of land cover change for lands within 5 km of state forest unit purchase boundaries in Wisconsin. Values are percent of buffer.*

State Forest	Water	Cropland	Grassland	Grassland to Cropland	Grassland to Forest	Grassland to Urban	Forest	Forest to Urban	Urban	Shrubland
Brule River	11	1	<1	<1	6	<1	70	<1	4	8
Peshtigo River	17	9	<1	<1	2	<1	62	<1	5	5
Black River	9	12	<1	<1	1	<1	59	<1	6	12
Douglas Hallock	15	17	<1	2	8	<1	54	<1	4	<1
Flambeau River	36	3	<1	<1	<1	<1	54	<1	3	3
Governor Knowles	24	4	1	<1	3	<1	53	<1	4	10
American Legion	38	2	<1	<1	<1	<1	51	<1	7	3
Northern Highland	44	<1	<1	<1	<1	<1	49	<1	6	1
Coulee Experimental	3	39	<1	1	12	<1	29	7	8	2
KM Paradise Valley	29	28	<1	1	3	4	25	2	5	2
KM Lapham Peak	16	22	<1	<1	<1	16	8	17	17	3
KM Loew Lake	9	35	<1	1	1	20	10	14	7	4
KM Mukwonago River	17	31	<1	<1	8	6	16	4	12	5
KM Southern Unit	12	41	<1	1	9	8	12	5	8	4
KM NU-IANSR	13	36	<1	1	12	10	10	7	7	3
KM Pike Lake	10	38	1	1	1	18	6	8	15	2
Havenwoods	3	2	<1	<1	<1	<1	4	<1	91	<1
Point Beach	19	26	30	3	3	<1	2	<1	15	3

Table 5. *Similarity of changes in land cover for Wisconsin state forest unit purchase areas and respective 5 km buffers under past and potential future scenarios of land cover change.*

State Forest	1992 – 2001	2001 – 2051 Static	2001 – 2051 Dynamic
Brule River	0.88	0.97	0.97
Peshtigo River	0.98	0.98	0.98
Black River	0.96	0.96	0.96
Douglas Hallock	0.67	0.69	0.69
Flambeau River	0.97	0.97	0.97
Governor Knowles	0.91	0.91	0.91
American Legion	0.99	0.99	0.99
Northern Highland	1.00	0.99	0.98
Coulee Experimental	0.58	0.59	0.52
KM Paradise Valley	0.96	0.95	0.69
KM Lapham Peak	0.79	0.77	0.43
KM Loew Lake	0.57	0.61	0.50
KM Mukwonago River	0.43	0.49	0.48
KM Southern Unit	0.47	0.49	0.41
KM NU-IANSR	0.50	0.51	0.42
KM Pike Lake	0.93	0.90	0.89
Havenwoods	0.03	0.04	0.04
Point Beach	0.86	0.24	0.24

Table 6. *Similarity of forest attributes for Wisconsin state forest unit purchase areas and respective 5 km buffers under past and potential future scenarios of land cover change.*

State Forest	1992	2001	Dynamic 2051	All 2051
Brule River	0.95	0.93	0.95	0.94
Peshtigo River	0.95	0.96	0.97	1.00
Black River	0.92	0.90	0.91	0.97
Douglas Hallock	0.36	0.29	0.43	0.84
Flambeau River	0.94	0.94	0.94	0.97
Governor Knowles	0.80	0.83	0.87	0.90
American Legion	0.98	0.98	0.98	0.99
Northern Highland	0.92	0.99	0.99	0.99
Coulee Experimental	0.45	0.47	0.46	0.93
KM Paradise Valley	0.94	0.95	0.94	0.97
KM Lapham Peak	0.77	0.85	0.73	0.91
KM Loew Lake	0.62	0.63	0.70	0.71
KM Mukwonago River	0.63	0.67	0.91	0.82
KM Southern Unit	0.55	0.54	0.57	0.98
KM NU-IANSR	0.57	0.55	0.59	0.95
KM Pike Lake	0.95	0.95	0.97	0.93
Havenwoods	0.87	0.87	0.87	0.03
Point Beach	0.22	0.22	0.23	0.24

for the Static Forest scenario arose from differences in initial landscape conditions. For example, Havenwoods is set within a predominantly (91%) urban landscape and Point Beach lies within a predominantly (~50%) cropland and grassland landscape (Table 4). The lower similarity for the Dynamic Forest scenario arose from differences in initial landscape conditions as well as projected land cover change within the buffer.

Potential Future Changes in Core, Connector, and Edge Forest

Potential changes in forest attributes within state forest unit buffers are projected to vary greatly by landscape context and land cover change scenario. Under the baseline, Static Forest scenario, we observed a clear north-south distinction with respect to percent of core, connector, and edge forest (Figure 5). In northern Wisconsin, buffers consisted primarily of core forest (mean=20.4%, sd=7.1, range=14.6–34.3), followed by edge forest (mean=19.4%, sd=1.4, range=18.0–21.4) and connector forest (mean=15.1%, sd=1.5, range=13.1–17.6). In contrast, buffers in southern Wisconsin consisted primarily of edge forest (mean=8.4%, sd=6.6, range=0–23.2), followed by connector forest (mean=3.8%, sd=2.7, range=0–9.7) and core forest (mean=4.6%, sd=6.7, range=0–20.7).

This north-south distinction in forest attributes is projected to be exacerbated by land cover change under the Dynamic Forest scenario. In northern Wisconsin, core forest, connector forest, and forest patches in the buffer are projected to increase nominally or stay the same size compared to the Static Forest scenario (Figure 6). In southern Wisconsin buffers, core forest is projected to decrease, while patch forest is projected to increase, compared to the Static Forest scenario. The net impact of land cover change in southern Wisconsin is projected to be a decrease in forest area and an increase in forest fragmentation.

Similarity of forest attributes for state forest unit purchase areas and 5 km buffers also is projected to vary from northern to southern Wisconsin, as an expression of differences in landscape context, and by land cover change scenario. Similarity of forest attributes, comparing state forest unit purchase areas to buffers, is projected to be lower in southern Wisconsin than in northern Wisconsin for the Static Forest and Dynamic Forest scenarios (Table 6). The lower similarity for the Static Forest scenario is projected to arise from differences in the percent of non-forest and water in initial landscape conditions.

Potential Future Changes in Carbon Sequestration and Storage

Potential changes in carbon sequestration and storage from 2001 to 2051 within state forest unit buffers is projected to vary by landscape context and land cover change scenario. Assuming no-net-change in tree harvest or mortality besides land cover change, carbon sequestration and storage potential is projected to be 16.6 TgC under the Static Forest scenario (227% increase from 2001), 17.2 TgC under the Dynamic Forest scenario (235% increase), and 22.1 TgC under the All Forest scenario (302% increase). Compared to the Static Forest scenario, the Loew Lake and Lapham Peak Units of the Kettle Moraine State Forest are projected to have a net loss of carbon due to forest loss (Figure 7). Under the All Forest scenario, the Northern and Southern Units of the Kettle Moraine are projected to have the highest potential change in carbon sequestration and storage due to afforestation of cropland and grassland.

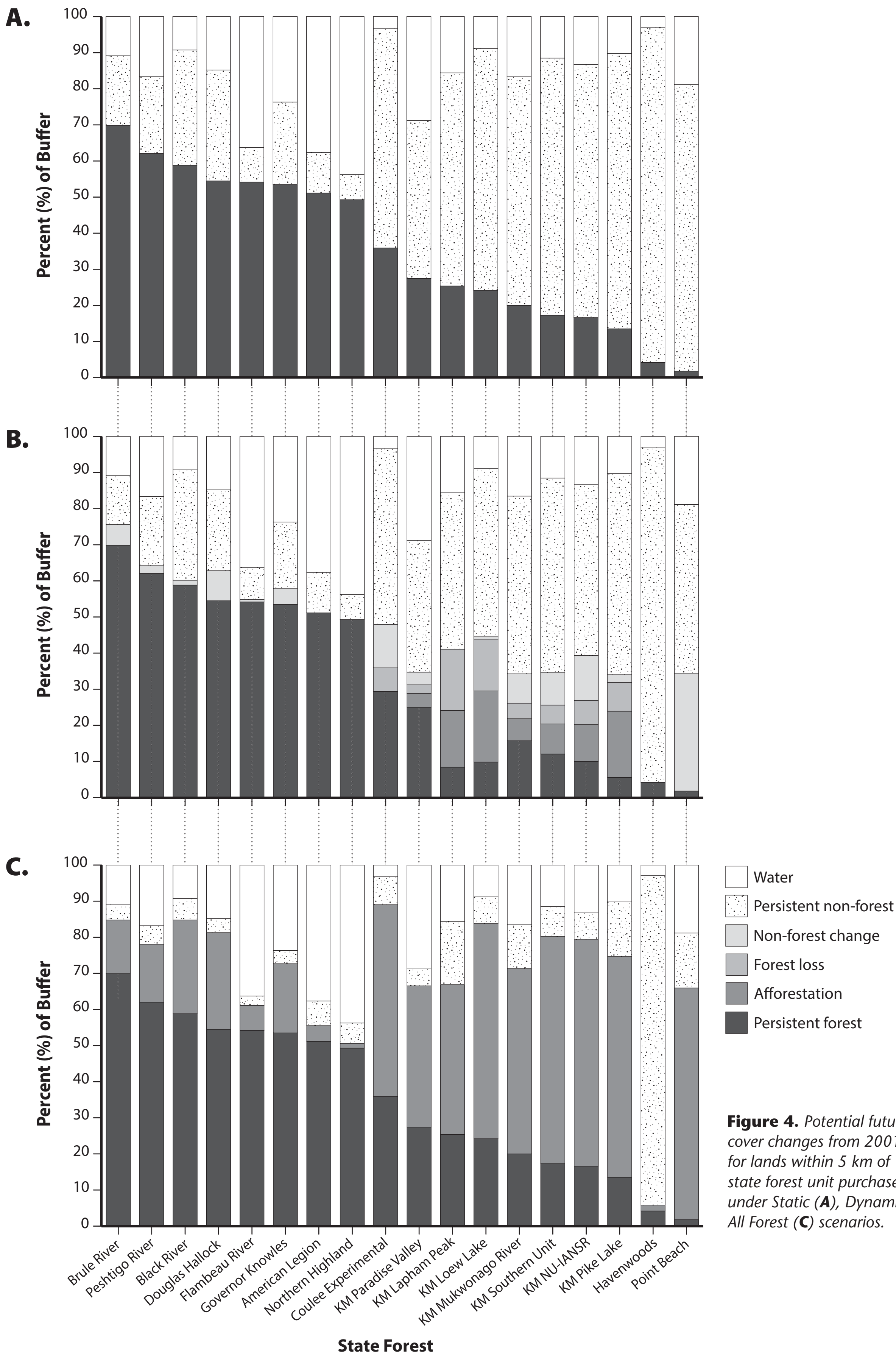

Figure 4. *Potential future land cover changes from 2001 to 2051 for lands within 5 km of Wisconsin state forest unit purchase boundaries under Static (**A**), Dynamic (**B**), and All Forest (**C**) scenarios.*

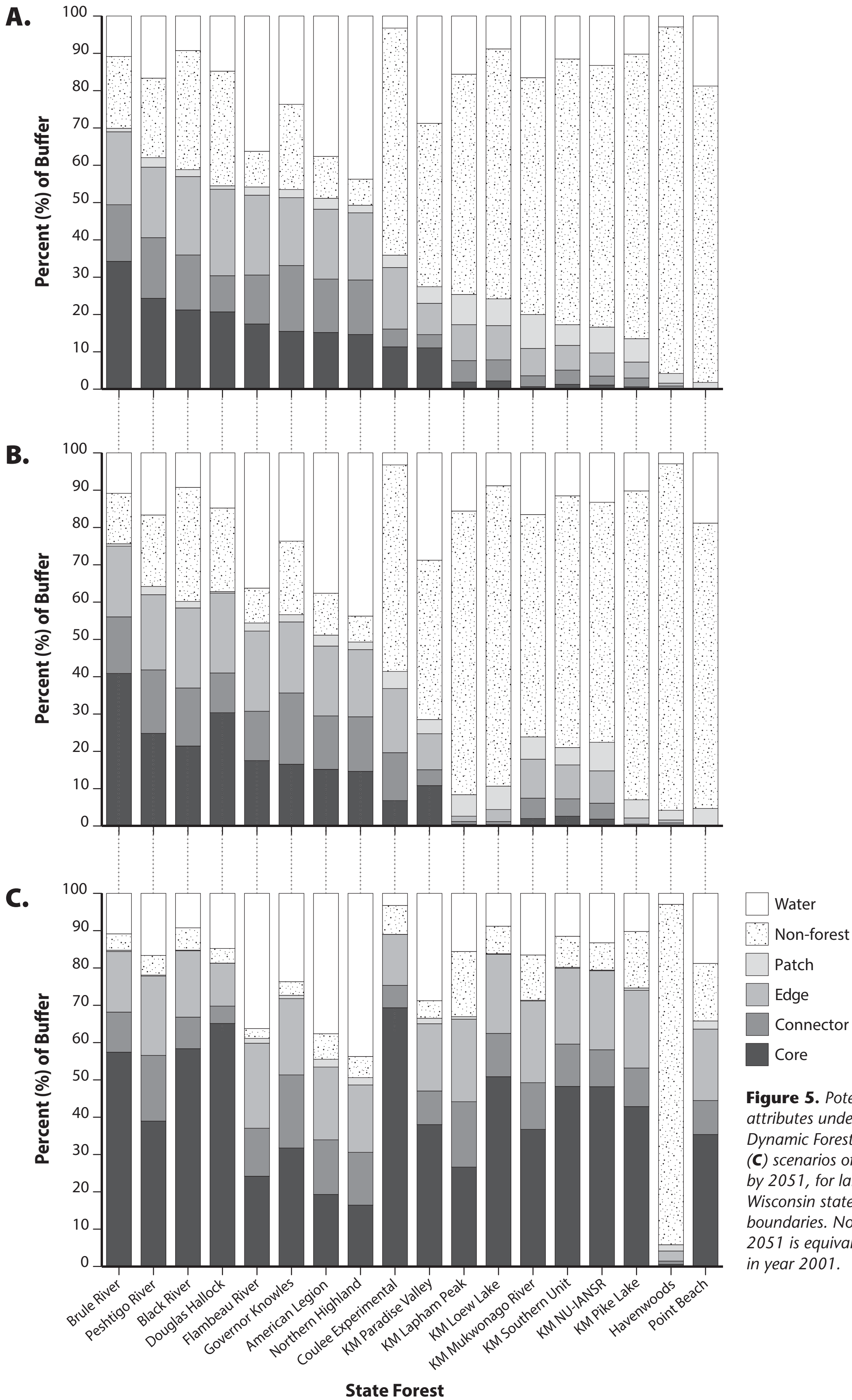

Figure 5. *Potential future forest attributes under Static Forest (**A**), Dynamic Forest (**B**), and All Forest (**C**) scenarios of land cover change, by 2051, for lands within 5 km of Wisconsin state forest unit purchase boundaries. Note Static Forest year 2051 is equivalent to forest attributes in year 2001.*

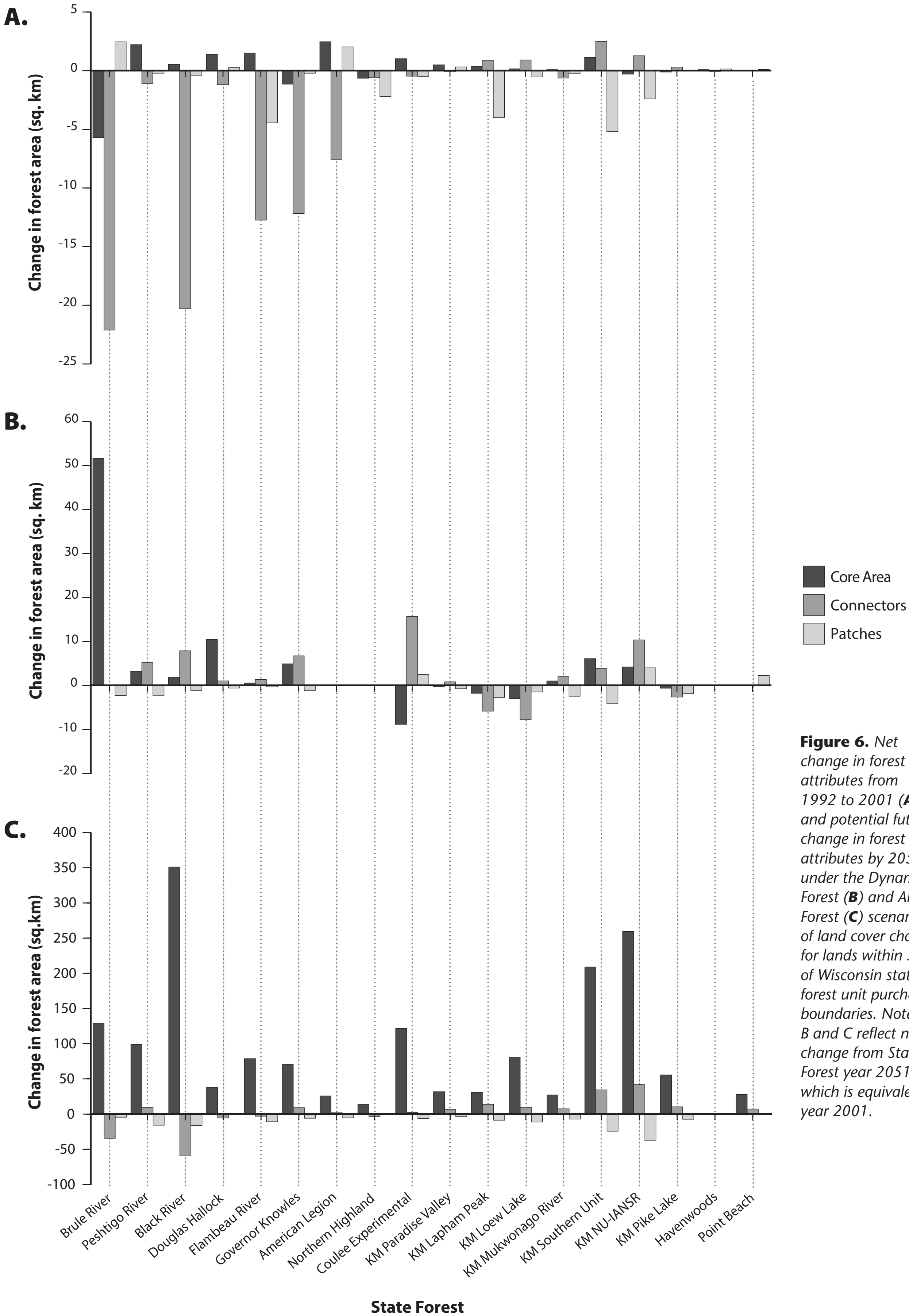

Figure 6. *Net change in forest attributes from 1992 to 2001 (**A**), and potential future change in forest attributes by 2051 under the Dynamic Forest (**B**) and All Forest (**C**) scenarios of land cover change, for lands within 5 km of Wisconsin state forest unit purchase boundaries. Note B and C reflect net change from Static Forest year 2051, which is equivalent to year 2001.*

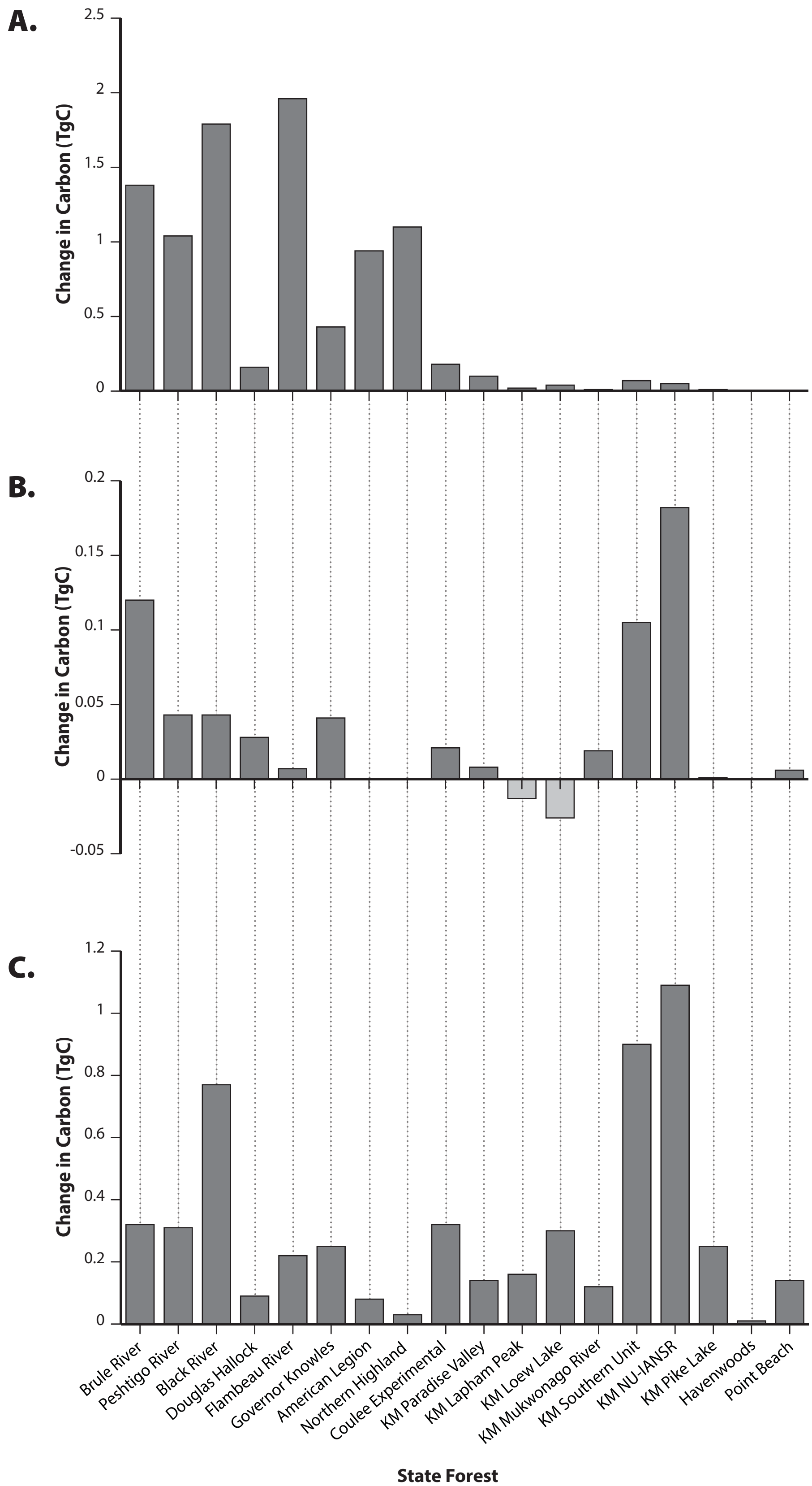

Figure 7. *Potential future carbon sequestration and storage from 2001 to 2051 under the Static Forest (**A**) scenario of land cover change, and net change from Static Forest scenario under the Dynamic Forest (**B**) and All Forest (**C**) scenarios, for lands within 5 km of Wisconsin state forest unit purchase boundaries.*

Discussion

This analysis of past and projected future land cover change revealed four general patterns of impacts to state forests of Wisconsin. First, land cover change from 1992 to 2001 was greater in lands surrounding state forests in northern Wisconsin than in lands surrounding state forests in southern Wisconsin. The primary impact to northern forests was forest loss to grassland or cropland, with a secondary threat of forest loss to housing. Forest loss decreased the size of connector forest in northern Wisconsin, which supports concerns that land cover change near state forests negatively impacts forest connectivity. The similarity of northern forests and their buffers remained high, however, indicating that as a proportion of the landscape, northern forests, unlike southern forests, were not islands in a sea of development and agriculture.

Second, the projected future land cover change under the Dynamic Forest scenario indicated potential for greater change in forests of southern Wisconsin than in northern Wisconsin. In southern Wisconsin, land cover change resulted in forest loss in eight forest units. The primary threat to southern forests was conversion of forest to urban. Projected afforestation offset forest loss in six of those eight forest units. The flux in forest cover – afforestation and forest loss – would decrease core forest area and connector forest, despite the net increase in forest cover overall. The concentration of afforestation potential in southern Wisconsin reflected the current pattern of land use, private land ownership, and enrollment in the Conservation Reserve Program. Past trends indicate that approximately 9% of Conservation Reserve Program lands in the United States afforested from 1986 to 1995 (Barker et al. 2005), which is consistent with our results for projected future land cover change in southern Wisconsin. At present, grasslands and savannas in southern Wisconsin provide important habitat for sensitive plant and animal species. Land acquisition and planning efforts in southern Wisconsin should consider potential negative impacts of afforestation.

Third, the projected future land cover change under the Dynamic Forest scenario indicated potential for core forest area and connectivity to increase in northern forests. This finding results from afforestation of cropland and grassland exceeding forest loss. Within the predominantly forested landscape that is characteristic of northern forests, an increase in forest cover is more likely to increase core forest area or connector forest.

Fourth, projected future land cover change under the Dynamic Forest scenario indicates that potential negative impacts of forest loss on carbon sequestration and storage exist for at least four forest units: Havenwoods and the Lapham Peak, Loew Lake, and Pike Lake units of the Kettle Moraine State Forest.

We offer several important cautions regarding our analysis of land cover change, forest connectivity, and carbon sequestration. First, an important caution with the land cover change scenarios is that some rural residential development of houses mixed with tree cover continues to be classified as forest by satellite images. Thus, these results under-represent rural housing and forest fragmentation. Second, the future projections of land cover change rely on countywide average conversion rates that are projected across each county. The projections do not measure local variability in housing or agricultural pressures at a sub-county level. Finally, our assumption of no-net-change in tree mortality likely overestimated the potential amount of carbon sequestered and stored by forests. The actual amount of carbon sequestered and stored by forests varies by tree species and tree age. Thus, species-specific differences in harvest, regeneration, or mortality from present rates may reduce the amount of carbon sequestered and stored by forests.

Based on projected future land cover change, managers of state forests should expect increased development and land conversion near forest boundaries and plan accordingly. Many of the state forest master plans have involved an expansion of state forest boundaries and ongoing acquisition programs to acquire lands from willing sellers. Priority setting for land acquisition should consider goals and landscape context. Goals to maintain the amount or extent of forest cover versus the structure of the forest (i.e. core forest, connector, edge, and patches) may present tradeoffs in some landscapes but not others. For example, a goal of maintaining or increasing the extent of forest cover in urban-agriculture landscapes of southeastern Wisconsin, where the threat of forest conversion is high, will likely come at substantial economic expense and minimally increase protected core forest area or connectivity among forests. In contrast, the extent of forest cover is high in northern Wisconsin and acquisition of key parcels may increase substantially the protected core forest area or connectivity among forests.

A strategy termed "benefit-cost-loss targeting" may be useful in this regard (Newburn et al. 2005). This strategy aims to increase the ecological, economic, or social benefits and reduce the probability of loss of these benefits, while reducing acquisition costs. Benefit-cost-loss strategies recognize that acquiring properties that would be unlikely to convert to housing does not result in greater forest conservation than what would have been achieved without the acquisition. Cost and probability of loss are often correlated since properties that are more likely to be converted to housing also tend to be more expensive per acre. So in order to maximize benefit and reduce the probability of loss, the best strategy for new acquisitions is to purchase high benefit areas with medium cost and medium probability of loss, on average.

Overall, we found high variability in the forested context of Wisconsin's state forests. These diverse landscapes—some in highly forested regions and others in largely agricultural regions—demand diverse forest management strategies. Private lands in and around state forests face likely changes both from afforestation and from forest loss to cropland, development, and grasslands. Understanding these changes can help managers and planners better anticipate future challenges and allocate acquisition and outreach resources in ways that will be most effective and efficient.

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