Sustainability: The Next Step
Estimating the University of Wisconsin – Green Bay's Carbon Footprint

Chapter 4
Carbon Offsets – Carbon Sequestration

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Introduction

In the fall of 2007, Bruce Shepard, the Chancellor of the University of Wisconsin at Green Bay (UW-Green Bay), signed the American College and University Presidents Climate Commitment (ACUPCC). This commitment pledges UW-Green Bay to eliminate its campus's greenhouse gas emissions over time. One aspect of this effort is to produce a carbon inventory for the University. With over sixteen hundred acres of vegetative land, carbon sequestration could play a role in the inventory.

Definition

The net carbon sequestered in an ecosystem is calculated using several factors from the forest carbon cycle (Fig. 4.1) (Gower 2003). The uptake of carbon, called gross primary production (GPP), is the process where vegetation removes carbon dioxide (CO_2) from the atmosphere through photosynthesis and stores it in foliage, roots, and woody tissues. In photosynthesis, the CO_2 is converted into carbohydrates that plants use to create biomass. Plants respire CO_2 when they oxidize carbohydrates in order to grow, maintain, and repair tissue. In Figure 4.1, the sum of this respiration is labeled R_A for autotrophic respiration. The net primary production (NPP) is the difference between the GPP and R_A. In addition to the vegetation, the soil plays a role in this cycle. Soil organic content (SOC) is the carbon uptake of the soil (D) minus the respiration rates of the roots (R_R) and heterotrophs (R_H). The net ecosystem production (NEP) is the difference between the NPP and the heterotrophic respiration, which includes the vegetation and the soil. The NEP is considered the net carbon sequestered by an ecosystem and is labeled H in Figure 4.1. Uptake of CO_2 and allocation of carbon to respiration and biomass components (above-ground net primary production (ANPP) and below-ground net primary production (BNPP) is affected by water availability, nitrogen levels, temperature, stand age, and levels of atmospheric gases (Gower and Ahl 2006). Since the cycle is affected by many variables, the NEP can differ greatly within species, soil types, and geographic areas.

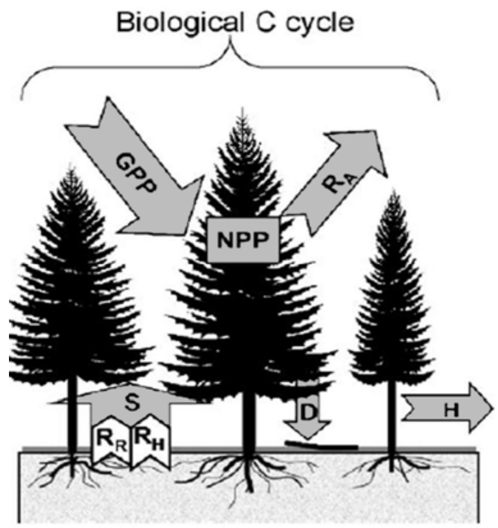

Figure 4.1 Diagram of the forest carbon cycle (Gower 2003).

Factors that affect carbon sequestration

As stated previously, the carbon that is sequestered by in an ecosystem is affected by water, nutrient, temperature, stand age, and atmospheric gases. The following are brief explanations of the effect these variables have.

Water

Water availability has been tied to NPP. The larger the amount of annual precipitation and soil water-holding capacity, the larger the leaf area index (LAI) (Fig. 4.2). The amount of foliage a plant has is directly proportional to its productivity. The scarcity of water will cause the plant to reduce its photosynthetic capability, reducing its carbon uptake. This will result in less carbon being sequestered (Gower 2001).

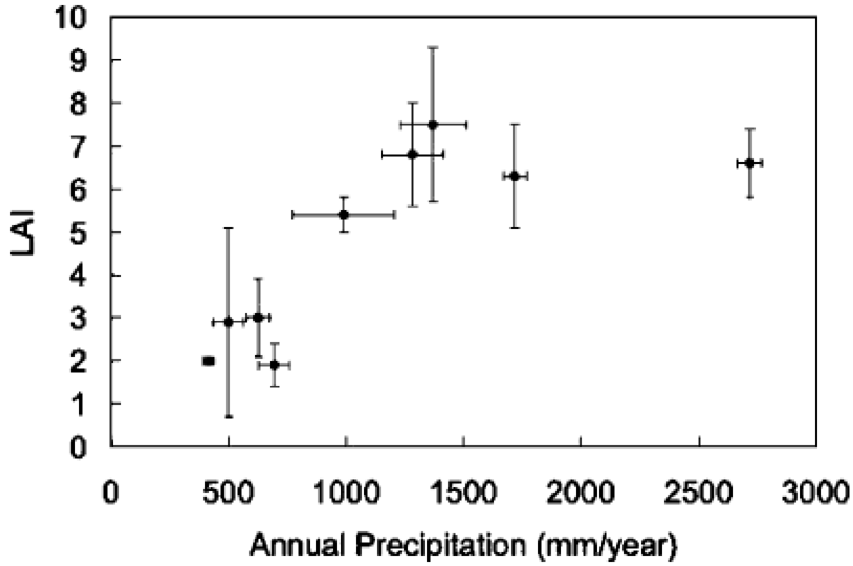

Figure 4.2 Relationship of average leaf area index (LAI) with annual precipitation (Gower 2003).

Nutrients

Foliage contains the largest amounts of nutrients in a plant. Plants tend to optimize carbon allocation to maximize carbon gain. With infertile soils, plants allocate more biomass to roots to increase nutrient uptake (Gower 2003). The highest levels of carbon sequestration can be observed with plants grown on fertilized land (Qian, et al. 2003).

Temperature

Increases in temperature have been demonstrated in empirical studies to increase soil heterotrophic respiration and decrease the amount of carbon the soil can uptake. This would reduce the soil's ability to be a carbon sink. Short-termed experiments have produced data, which don't support these models (Gower 2003).

Age

Carbon sequestration tends to decrease over the lifespan of a plant. It has been hypothesized this is due to a decline in NPP from nutrient limitations and hydraulic constraints (Gower 2003). This effect can be seen in several types of vegetation, forest (Fig. 4.3), and grasslands (Fig. 4.4). In addition to the decreased carbon sequestration rates, plants tend to allocate carbon to different tissue types (Howard, et al. 2004) (Fig. 4.5).

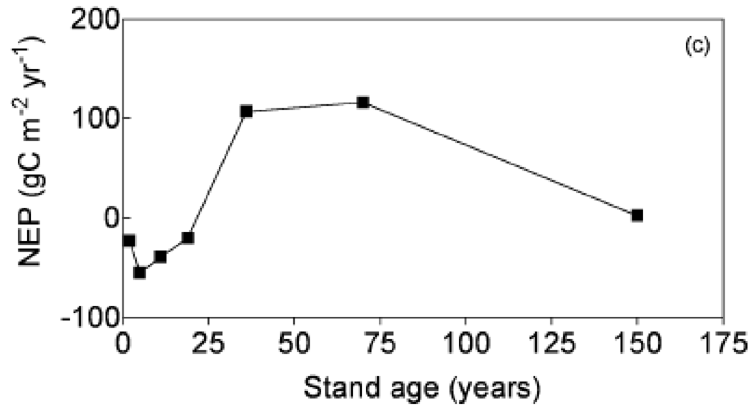

Figure 4.3 The net ecosystem production (NEP) for a well-drained boreal black spruce stand (modified from Gower 2003).

Atmospheric Gases

Recent studies in CO_2 and ozone, O_3, have shown these gases will affect carbon sequestration. Elevated atmospheric CO_2 levels allow more carbon to be available for plants to uptake. This has led to much research over the last decade as to how plants will allocate this resource. Short-term studies (King, et al. 2005), have shown an increase in NPP of approximately 20 percent. Along with increasing CO_2 levels, ground level ozone has also increased. When combined with ozone, NPP levels have decreased (Fig. 4.6).

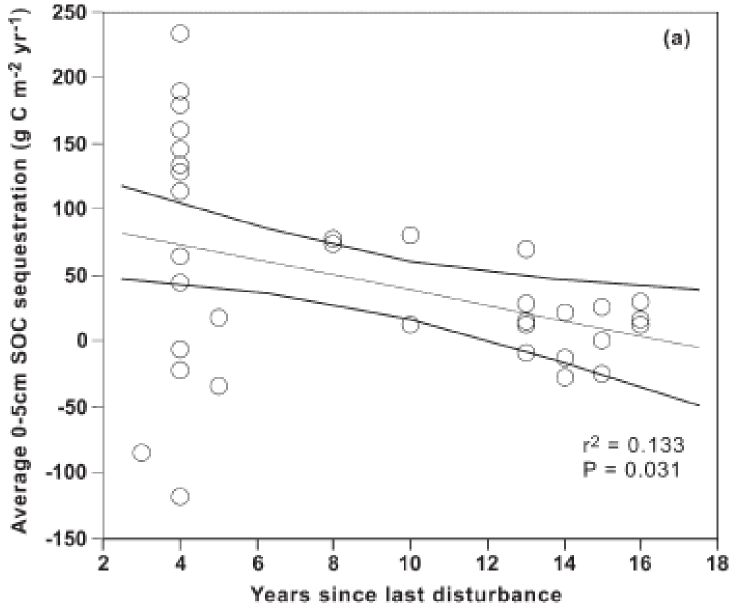

Figure 4.4 Changes in soil organic carbon (SOC) sequestration rate as a function of years since last disturbance. These prairies were planted on Alfisols and Mollisols. This graph shows the linear regression and the 95 percent confidence interval (modified from Kuckarik 2007).

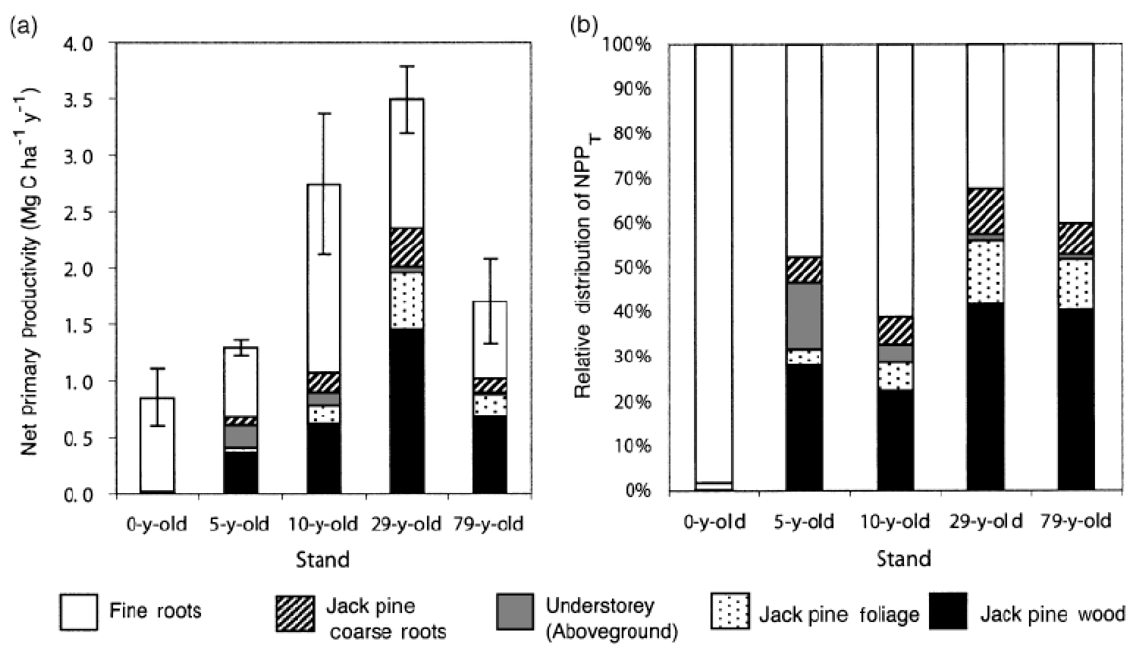

Figure 4.5 Allocation of carbon in (a) total NPP for stand and tissue type and (b) relative distribution of total NPP for tissue. These were from different aged jack pine stands in Saskatchewan, Canada (Howard, et al. 2004).

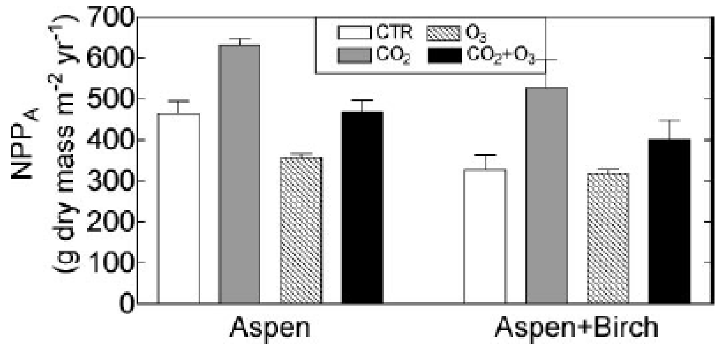

Figure 4.6 The NPPA for trees grown in ambient, elevated CO_2, elevated ozone, and elevated ozone and CO_2 FACE rings. (Data provided by Evan McDonald, U.S. Forest Service.)

Estimating vegetation type and area

Vegetation polygons of UW-Green Bay managed properties were delineated using photograph interpretation and the personal knowledge of senior instructional specialist Gary Fewless at UW-Green Bay and graduate student Wade Oehmichen. Using ESRI ArcGIS 9.2, polygons were characterized by dominant tree, brush, or grass species and polygon areas were calculated. Species were labeled using a slightly modified key from the Wisconsin Department of Natural Resources Managed Forest Law Vegetation Type Key **(**table 4.1). Layers utilized to aid in the photograph interpretation were from a variety of sources; Brown County Lands Department, UW-Green Bay, and the Wisconsin Department of Natural Resources. These layers included; aerial photos, topographical photos, hydrographical, and two foot contours. Refer to the chapter 4 appendix for individual maps of the UW-Green Bay managed properties.

Table 4.1 Vegetation type key

Code	Description	Tree Species
BH	*Bottomland Hardwoods*	Dominated by silver maple, river birch, elm, cottonwood, green ash
CH	*Central hardwoods*	Dominated by black walnut, black cherry, elm, white ash, and hack-berry and associated with red, white or black oak and hickory
NC	*Northern Conifer*	Dominated by red pine, white pine, and hemlock
NH	*Northern Hardwoods*	Dominated by sugar maple, yellow birch, basswood, rock elm, beech
SH	*Swamp Hardwood*	Dominated by black ash, red maple, American elm, Balm of Gilead
K	*Keg/marsh*	Used for Grass or High water table areas
KG	*Lowland grass*	Ground cover consisting of more than 50% of true grasses such as canary grass, bluejoint, big bluestem
LB	*Lowland Brush*	Mixed shrub/brush species
LBA	*Tag Alder*	More than 50% alder
LBD	*Dogwood*	More than 50% dogwood
LBW	*Shrub Willow*	More than 50% shrub willow
O	*Oak*	Dominated by red oak, white oak, or black oak, and associated with other hardwoods
PR	*Red Pine, Scotch Pine*	More than 50% pine with jack pine outweighing red and white pine
PRI	*Prairie Restoration*	Area restored to presettlement vegetation typically warm season grasses with native forbs
PW	*White Pine*	More than 50% pine with white pine outweighing red and jack pine
SC	*Swamp Conifer*	Predominately balsam fir, cedar, and spruce and assocaited with red maple and a variety of other hardwoods
SG	*Short Grass (mowed)*	Manicured grass
A	*Aspen*	More than 50% aspen

Source: Wisconsin Department of Natural Resources

Estimating sequestration rates

Since carbon sequestration rates are affected by many variables, it is difficult to determine the net ecosystem production (NEP) for a species. The sequestration rates used in this initial ACUPCC carbon inventory for UW-Green Bay utilized previously published data due to the timeline for the capstone exercise. In researching sequestration rates for various species and vegetation types that would be found on UW-Green Bay holdings, data published by Campbell, et al. (2004) was found to be useful. In the paper, soil organic content and carbon biomass were determined by creating a geospatial database. For soil, baseline soil organic content (SOC) stocks in forests were derived from the USDA Natural Resource Conservation Service (RCS) State Soil Geographic (STATSGO) database. Bulk density, rock content, layer thickness, and organic matter content were applied to soil carbon stocks calculations as explained in Johnson and Kern (2002). Campbell combined all of this data, resulting in SOC stocks and forest area by forest type for the years 1983, 1996, and 2001. The SOC stock was divided by the area to get millions of metric tons of carbon (MMTC) per hectare. A linear regression plotting this data against its year allowed for MTC/ha/yr to be determined (table 4.2).

Carbon biomass was estimated by combining the U.S. Forest Service Forest Inventory (FIA) volume data and utilizing carbon biomass conversions listed in Birdsey (1992). This resulted in carbon biomass and forest area by forest type for the years 1983, 1996, and 2001. Similar to the SOC data, the carbon biomass was divided by the area to get MMTC per hectare. A linear regression plotting this data against its year allowed for MTC/ha/yr to be determined (table 4.2).

Table 4.2 Total carbon sequestrated by forest type derived by linear regression

Forest Type	*SOC (MTC/ha/yr)*	*Biomass (MTC/ha/yr)*	*Total C Sequestrated (MTC/ha/yr)*
White-Red-Jack Pine	-0.02	0.7	0.68
Spruce-Fir	0.02	0.2	0.22
Oak-Hickory	0.03	0.7	0.73
Elm-Ash-Cottonwood	0.02	0.2	0.22
Maple-Beech-Birch	0.01	0.5	0.51
Aspen-Birch	0.09	0.3	0.39

Source: Campbell et. al. 2004

All of the rates for the vegetation types found on UW-Green Bay managed lands were not stated in Campbell, et al. (2004). Additional rates were found in a search of recently published peer-reviewed papers, with rates found in ecosystems similar that of UW-Green Bay. When a range of rates were given, the average was used. All units were converted to metric tons of carbon dioxide equivalents per hectare per year ($MTeCO_2ha^{-1}yr^{-1}$) (table 4.3).

Table 4.3 Carbon sequestration rates by vegetation type with the source the value was obtained from.

Vegetation Type	eCO_2 Sequestration ($MTeCO_2ha^{-1}yr^{-1}$)	Source
Agricultural	1.172	Johnson, et al. 2005
Brush, Bottomland	0.843	Ferguson 2003
Conifer, Northern	2.492	Campbell, et al. 2004
Conifer, Red Pine	2.492	Campbell, et al. 2004
Conifer, Swamp	0.806	Campbell, et al. 2004
Conifer, White Pine	2.492	Campbell, et al. 2004
Grasses, Mowed	2.931	Qian, et al. 2003
Grasses, Prairie	2.070	Kucharik, et al. 2006
Grasses, Uncut	2.107	Kucharik, et al. 2006
Hardwoods, Bottomland	1.869	Campbell, et al. 2004
Hardwoods, Maple	1.869	Campbell, et al. 2004
Hardwoods, Northern	1.869	Campbell, et al. 2004
Hardwoods, Oak	2.675	Campbell, et al. 2004
Hardwoods, Swamp	0.806	Campbell, et al. 2004
Marsh	0.916	Williamson 2001

Results

The UW-Green Bay has 677 hectares of managed properties that sequester carbon. The inventory of vegetation types by property is listed in table 4.4. The groups with the largest areas are: Northern Conifer, Uncut Grasses, Northern Hardwoods, and Mowed Grasses (fig. 4.7). The amount of eCO_2 sequestered each year was calculated by multiplying the area of each vegetation type (fig. 4.7) by the sequestration rate (table 4.2). Figure 4.8 illustrates the eCO_2 sequestered by vegetation type on UW-Green Bay. The total amount of eCO_2 sequestered by UW-Green Bay lands as 1403 $MTeCO_2\ yr^{-1}$. The range of eCO_2 was calculated by using the lowest sequestration rate found (0.476 MTeCO_2 $ha^{-1}yr^{-1}$) and the highest sequestration rate found (4.03 MTeCO_2 ha^{-1} yr^{-1}), and resulted in a range from 323 to 2730 MTeCO_2 yr^{-1}.

Table 4.4 UW-Green Bay inventory of area of vegetation types by managed property.

	Grasses, Uncut	Brush, Bottomland	Hardwoods, Northern	Grasses, Prairie	Hardwoods, Swamp	Conifer, Red Pine	Marsh	Conifer, Northern	Conifer, Swamp	Agricultural	Hardwoods, Bottomland	Hardwoods, Maple	Grasses, Mowed	Conifer, White Pine	Hardwoods, Oak
Property (ha)	**KG**	**LBW**	**NH**	**PRI**	**SH**	**PR**	**K**	**NC**	**SC**	**AG**	**BH**	**MAPLE**	**SG**	**PW**	**OAK**
Kingfisher	2.27	0.47	3.95	4.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Peninsula	24.52	0.00	5.99	0.00	27.63	5.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Point au Sauble	19.72	0.00	28.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Toff Point	33.55	0.00	11.40	0.00	0.00	0.00	54.73	165.61	25.57	0.00	0.00	0.00	0.00	0.00	0.00
UWGB	70.11	0.34	64.64	3.65	0.00	0.59	0.00	0.08	0.00	4.13	8.85	8.68	89.48	2.78	10.10
TOTAL HECTARES	**150.17**	**0.81**	**114.75**	**8.28**	**27.63**	**5.81**	**54.73**	**165.69**	**25.57**	**4.13**	**8.85**	**8.68**	**89.48**	**2.78**	**10.10**

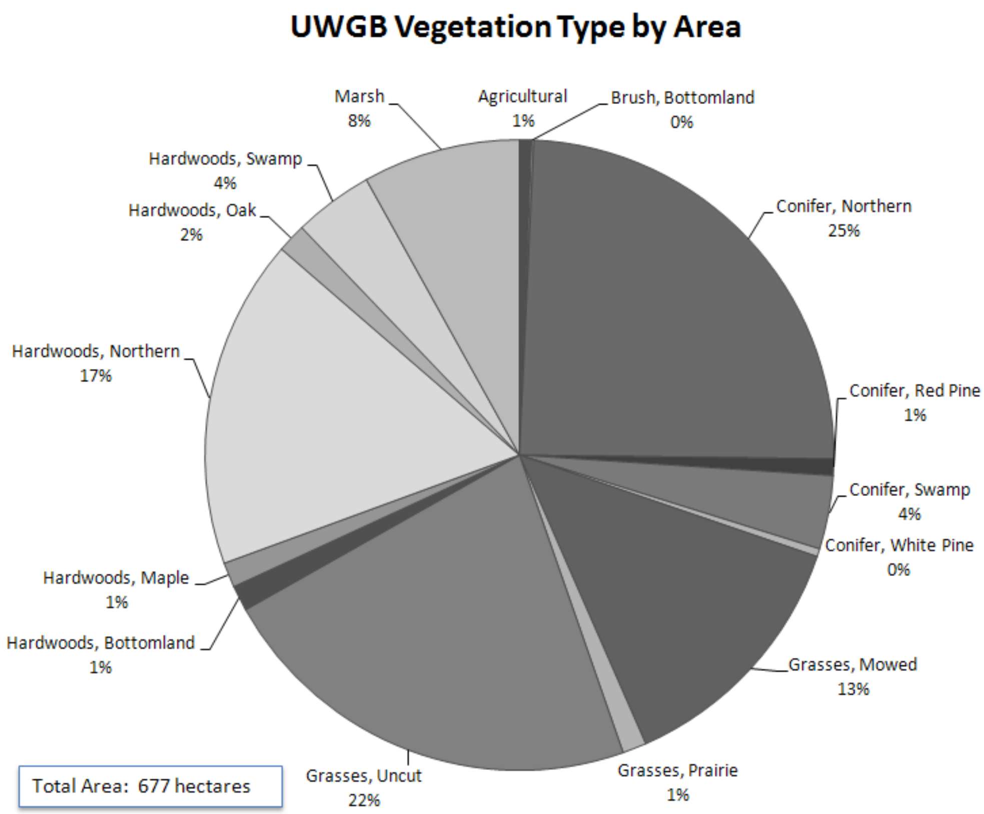

Figure 4.7 UW-Green Bay vegetation type by area

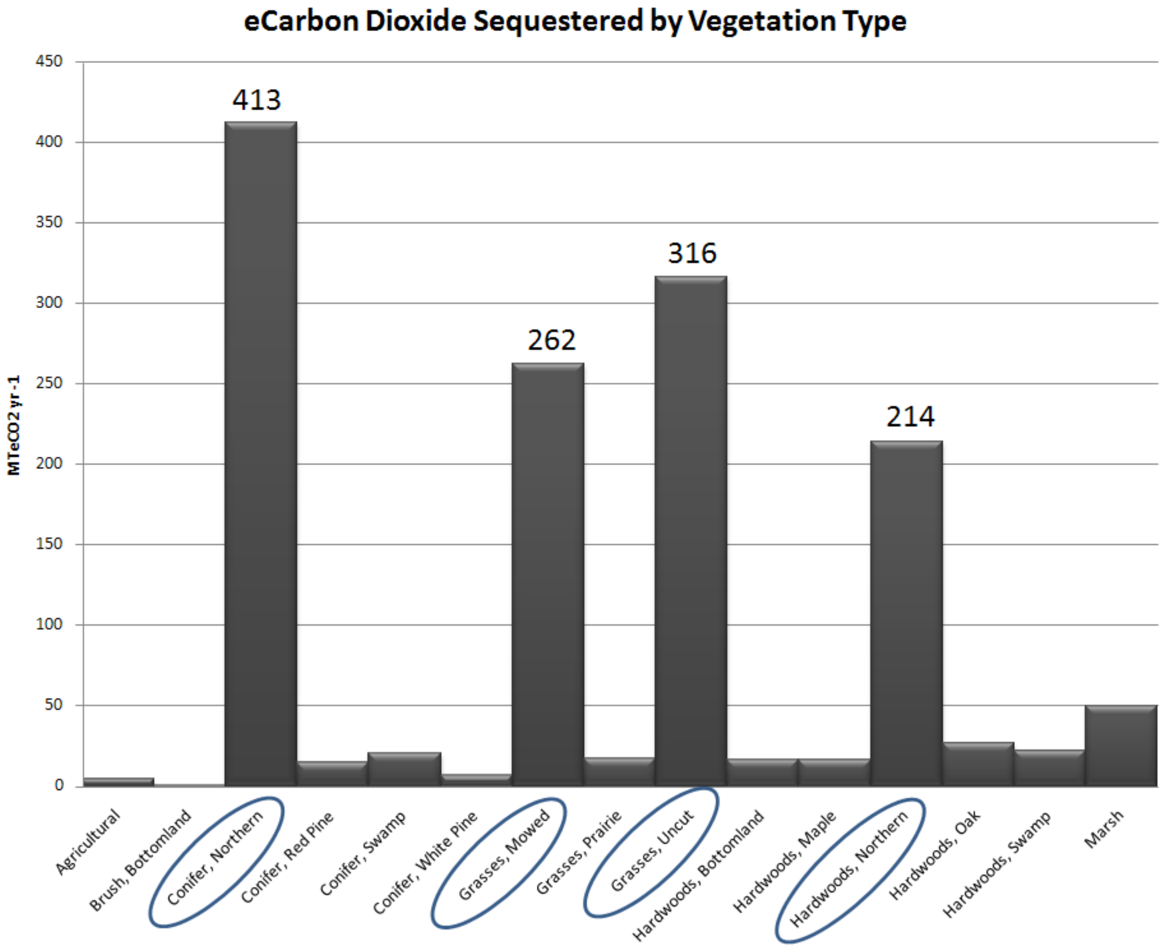

Figure 4.8 eCO_2 sequestered by vegetation type for UW-Green Bay managed properties

Conclusion

The applicability of management techniques for improved carbon sequestration is limited for the University of Wisconsin – Green Bay. Since less than 4% of the carbon footprint is offset by the University's managed properties; resources are better applied to reducing our footprint through conservation and efficiency improvements. However, improved sequestration management options should be considered when changes are considered for the managed properties. Mowed grass should be replaced with prairie or forest to eliminate the increased fossil fuel usage associated with maintaining mowed grass. If reforestation is to take place, species and practices to improve sequestration should be considered in the planning stage. Native species should be maintained on all properties and natural succession should be allowed to take place. It is imperative that the GIS layers of UW-Green Bay managed properties be maintained for future sequestration calculations. In conclusion, any changes to property management should include considerations for improved carbon sequestration.

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