Carbon Storage in the Acadian Forest: Estimating carbon storage and associated dynamics of a privately owned small woodlot in the Acadian Forest Region.

Dale Prest.
Environmental Programs, Dalhousie University
Halifax, NS.
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Abstract

Restoring carbon sinks in the Acadian Forest Region of Canada has the potential to reduce atmospheric carbon dioxide levels, subsequently mitigating the effects of anthropogenic climate change and increasing acidification of the oceans. By managing and receiving financial compensation for carbon storage, landowners and managers will by default restore degraded forests closer to an old-growth condition. These forests have the added value of providing more habitat types that are currently underrepresented in the Acadian Forest Region. For landowners to receive financial compensation for carbon storage, carbon dynamics, such as current carbon storage, must be quantified in an efficient and cost effective manner. This project quantified carbon storage in living and dead pools on a 20.8 hectare woodlot north of the village of Port Joli, NS. This was done by breaking the woodlot into four stand types based on dominant tree species and by using a representative, stratified random sampling method that estimated each of the carbon pools (with the exception of mineral soil carbon storage). It is estimated that, in total, that 3240 Mg carbon are stored in four different stand types on the entire woodlot. The potential correlation between depth of and amount of carbon in the organic layer was measured and found to be statistically significant. Given that sampling of the organic layer was by far the most time consuming and costly of the sampling methods, it is recommended that further investigation into this relationship be done to develop a prediction equation that could be used to easily and cost effectively estimate the amount of carbon in the organic layer. The data collected here can be used in the future to further investigate the carbon dynamics of woodlot carbon dynamics, such as monitoring changes in carbon storage with time and management practices, as well as used to calibrate national carbon budget models like the CBM-CFS3.

Acknowledgements

I would like to take this opportunity to acknowledge the generous support of the Port Joli Basin Conservation Society and Harrison Lewis Center. Without the support of either of these groups sampling of this property would not have been possible. I would like to thank Charles and Danielle Robertson for allowing me to use one of their woodlots as a study site and for taking time out of their lives to help me understand the history of the Douglas Property. The logistical support of Dr. Bill Freedman allowed for the thorough analysis of this woodlot that was required. His input and technical expertise were of the upmost importance and allowed for this project to be of the quality and calibre that it deserves. Thanks also go out to the Art and Dorothy Cooke Memorial Research Scholarship foundation for their significant support towards this project.

I would also like to particularly acknowledge the contribution of Dirk and Anne VanLoon. Their involvement in both the Port Joli Basin Conservation Society and Harrison Lewis Center require considerable commitments of both of them, and without their involvement this project would not have happened. For a summer they welcomed me onto their farm and into their lives’ and made it one of the best experiences of my life. Thank you both for everything!

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1.0- Introduction

1.1- Overview

The use of financial mechanisms to compensate landowners for the provision of ecosystem services has been identified as having the potential to augment conservation efforts (Barker et al. 1995, Macmillan 2002, O'Connor 2008, Freedman et al. 2009). Such compensation for maintaining or augmenting the ecosystem service of ecological carbon storage has the potential to allow landowners to receive a stream of revenue for managing their lands for conservation purposes, while at the same time helping to reduce atmospheric concentrations of carbon dioxide (Freedman et al. 2009). Recently, it has been shown that increasing concentrations of carbon dioxide and other greenhouse gases are 'very likely' to contribute to climate change (IPCC 2007), and they may be causing an acidification of marine waters (Fabry et al. 2008). Both of these phenomena carry risks of causing damage to the human economy and to natural ecosystems.

Forest ecosystems, particularly in temperate regions, have the potential to increase carbon stores under land management practices that encourage the accumulation and stabilisation of carbon pools (Birdsey 1992, Birdsey 1992, Cathcart et al. 2007, Montagnini and Nair 2004). This is true both of land that has been deforested (such as urbanized and agricultural areas) and of forests managed by the forestry industry (Freedman et al. 2009). In the Acadian Forest Region (AFR) of Atlantic Canada (Figure 3), it has been shown that late-successional red spruce (*Picea rubens*) dominated forests store larger amounts of carbon than do early-successional forests (Taylor et al. 2007, Taylor et al. 2008). This dynamic is supported by many other studies (Stinson and Freedman 2001, Freedman et al 1996, Freedman et al. 2009) including a socioeconomic analysis of protecting wilderness areas in Nova Scotia, commissioned by the Nova Scotia Department of Environment (Jacques Whitford Ltd. 2009).

The present study will quantify carbon storage on a 20.8-hectare (54 acre) property of private land near the village of Port Joli, Nova Scotia. This will be done by examining the amount of organic carbon that is stored in various pools of the woodlot. By establishing a methodology to achieve the objectives outlined in Section 1.2, this study has the potential to begin a dialogue about how landowners can quantify carbon storage at the woodlot level.

1.2- Objectives

The objectives of this study are threefold:

1. Estimate carbon stored in living and dead biomass on the case study property
2. Measure the potential correlation between depth of organic layer and carbon content
3. Provide a solid data set that can be used for future analysis of carbon dynamics

1.3- Relevance and Significance of this Study

The primary purpose of this study is to quantify carbon storage in living and dead biomass pools on a privately owned property in the Acadian Forest Region (AFR). However, the greater significance of this study is that it will serve to begin a dialogue on how land managers can efficiently quantify carbon woodlot storage. As will be discussed later on, paying landowners for carbon storage will help to reduce atmospheric carbon dioxide levels, while also encouraging landowners to maintain their woodlots in later-successional forest stages and thereby restoring a habitat that is currently rare in the AFR.

As will be discussed in the Section 2 of this report, almost all of the forest land in Nova Scotia is presently of a young age compared to what existed in pre-European times (Wilson and Colman 2001, Mosseler et al 2003). Such a widespread trend is a result of hundreds of years of settlement, timber harvesting, anthropogenic wildfires, and combinations of these influences. This is particularly true of coastal areas (Neily et al. 2003). The value of allowing more forests to age and undergo successional development (in addition to the potential for increased carbon storage) is to allow for the re-establishment of a number of biotic features that are only supported by late-successional forests. Such features include large standing dead trees that provide habitat for species of cavity dwelling fauna, such as the barred owl (*Strix varia*), pileated woodpecker (*Dryocopus pileatus*), and flying squirrel (*Glaucomys* spp.) (what constitutes an old forest in the AFR, and what those forests used to look like, will be explored in Section 2.). Mosseler et al. (2003) suggest that old-growth forests are also important for the maintenance of the genetic diversity of the forests. Genetic diversity plays a key role in maintaining the ability of a population to evolve and adapt in the face of environmental changes, such as in climate, as well as the introduction of invasive non-native species and diseases. During such environmentally turbulent times, the maintenance of genetic diversity in old-growth forests is particularly important.

The present study has the potential to contribute to efforts to reduce atmospheric concentrations of carbon dioxide and re-establish late-successional forests throughout Nova Scotia. Despite an extensive literature review, I did not find other studies looking at whole-system carbon storage, sequestration and potential storage in the AFR. This makes my study both timely and significant.

This study measured a potential correlation between depth of organic layer and mass of carbon found in the organic layer. This is because empirical sampling of the organic layer, as was done in this study, is both time and energy intensive. If a strong correlation exists between the depth of organic layer and amount of carbon that is contained (as is expected), then estimating carbon stocks by measuring the depth of the organic layer will greatly expedite the estimation of woodlot carbon storage.

The dataset produced by this study could also be used for future investigations related to woodlot carbon dynamics. Such investigations could include estimation of potential carbon storage, monitoring changes in carbon pools over time, or calibration of national or regional carbon budget models.

2.0- Review of Literature

2.1- Payment for Ecosystem Services

Ecosystem services are valuable functions that individuals, communities, and/or societies receive from ecosystems. They include, but are not limited to: natural resources, climate regulation, and cultural values. The beneficiaries of ecosystem services may be members of a local community, as is the case with subsistence hunters, or people that are spatially removed from the ecosystem providing the service, as is the case with climate-related services.

Payment for ecosystem service (PES) schemes arose as an attempt to incorporate their value into an economic model that has guided land-use planning and management (Jack et al. 2008). Sven Wunder (2007, p. 49) describes a PES scheme as the following: “A PES scheme, simply stated, is a voluntary, conditional agreement between at least one ‘seller’ and one ‘buyer’ over a well defined environmental service—or a land use presumed to produce that service.” There are a number of examples of the use of PES schemes to provide ecosystem services to customers (see (Macmillan 2002, Kane and Erickson 2007, Wunder 2007, Wendland et al. 2009, Corbera et al. 2009)). Recently, PES schemes have been used as a financial mechanism to support forest conservation projects around the world (Pagiola et al. 2002, Corbera et al. 2009).

2.2- **Carbon Storage via Tree-based Systems**

The strong link between forests and atmospheric carbon dioxide levels is well documented. As shown in Figure 1, annual oscillations are evident in atmospheric carbon dioxide levels in Mauna Lau, Hawaii. The downward part of the oscillation corresponds with and is due in part to the growing season of deciduous leaf litter in the northern hemisphere. The UNFAO (2003) estimated that since 1980, 25% of all carbon dioxide emissions associated with human activities was a result of tropical deforestation. Carbon sequestration and storage - via afforestation, reforestation, restoration of degraded forest lands, and through conservation of biomass and soil carbon in existing forests – is a low-cost way to reduce atmospheric carbon dioxide levels

(Montagnini and Nair 2004). The potential for carbon sequestration is based around the photosynthesis-respiration relationship (Nair and Nair 2003). Trees are composed of carbon-based molecules such as lignin and cellulose, and when they grow they use the carbon from atmospheric carbon dioxide (along with energy, water and important nutrients) to construct these molecules (ie. through the process of photosynthesis). Carbon is then contained within these molecules and is kept from re-entering the atmosphere. In many forests (such as those of the AFR) soil processes like dead-wood fragmentation and digestion by soil fauna results in some of those carbon based molecules being drawn deeper into the soil or becoming incorporated into the biomass of soil organisms (Brady and Weil 2002, Sayer 2004). This increases the amount of carbon stored in the soils. Carbon is returned to the atmosphere when those carbon based molecules are decomposed and the carbon is respired as carbon dioxide.

Following are a list of the pools of carbon as they exist in forest systems;

- live trees
- dead standing trees
- dead fallen trees and branches
- ground vegetation
- organic layer
- mineral soil carbon

It has generally been observed that mineral soil carbon does not change much with management practices (Durgin 1980, Huntington and Ryan 1990, Johnson 1992, Harvey et al. 1994). However, a recent study in the AFR suggests that clear-cutting can decrease carbon storage in the mineral soil (Diochon et al 2009). For the purposes of this study, it will be assumed that mineral soil carbon is not significantly changed by management practices, and thus mineral soil carbon will not be estimated. This is because of logistical constraints and because current national carbon budget models assume that mineral soil carbon is stable with different management practices (Kruz et al. 2009). As such, an estimation of mineral soil carbon storage is not applicable to calibrating the CBM-CFS3 model – which uses stand level information and management practices to project carbon storage into the future - nor will potential woodlot carbon storage estimation using the model reflect any potential changes in mineral soil carbon storage. It should be noted that if, as found by Diochon et al (2009), mineral soil carbon storage can be increased with management practices that specifically target increasing mineral soil carbon storage, increasing mineral soil carbon storage has the potential to securely store very large amounts of carbon.

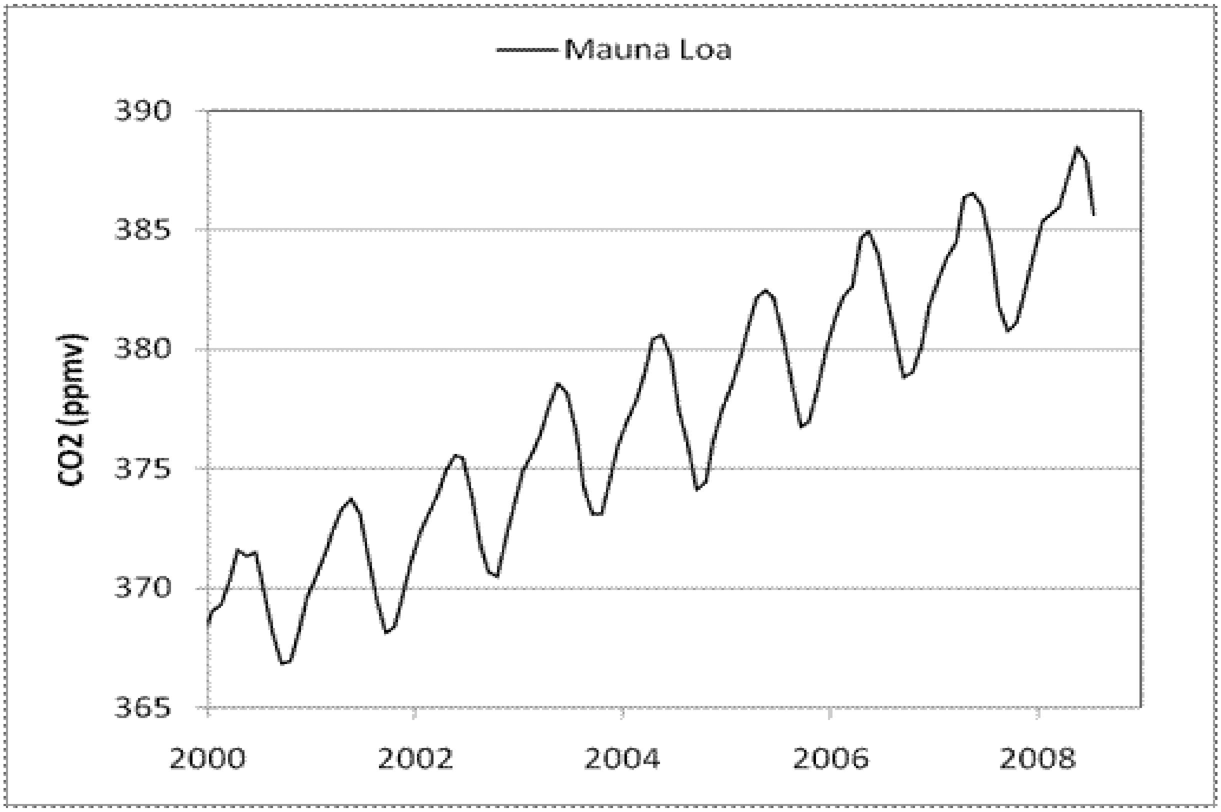


Figure 1- Atmospheric CO_2 concentrations as taken from Mauna Loa, Hawaii between 2000 and 2008 (Tans 2009).

The potential for increased forest based carbon storage depends on the forest type and soils being examined. Johnson et al (2004), for example, suggest that due to the relatively young age of forest soils of the northern hemisphere, they have a greater potential for carbon storage than those of tropical forests. Of those relatively young soils of the northern hemisphere, soils located in temperate, developed regions that have been exposed to human induced alteration of land cover have the ability to increase total carbon storage under proper management regimes that encourage the accumulation and storage of carbon (Birdsey 1992, Cathcart et al. 2007). This study will look at one such region, the Acadian Forest Region (AFR), whose characteristics will be described in the following section.

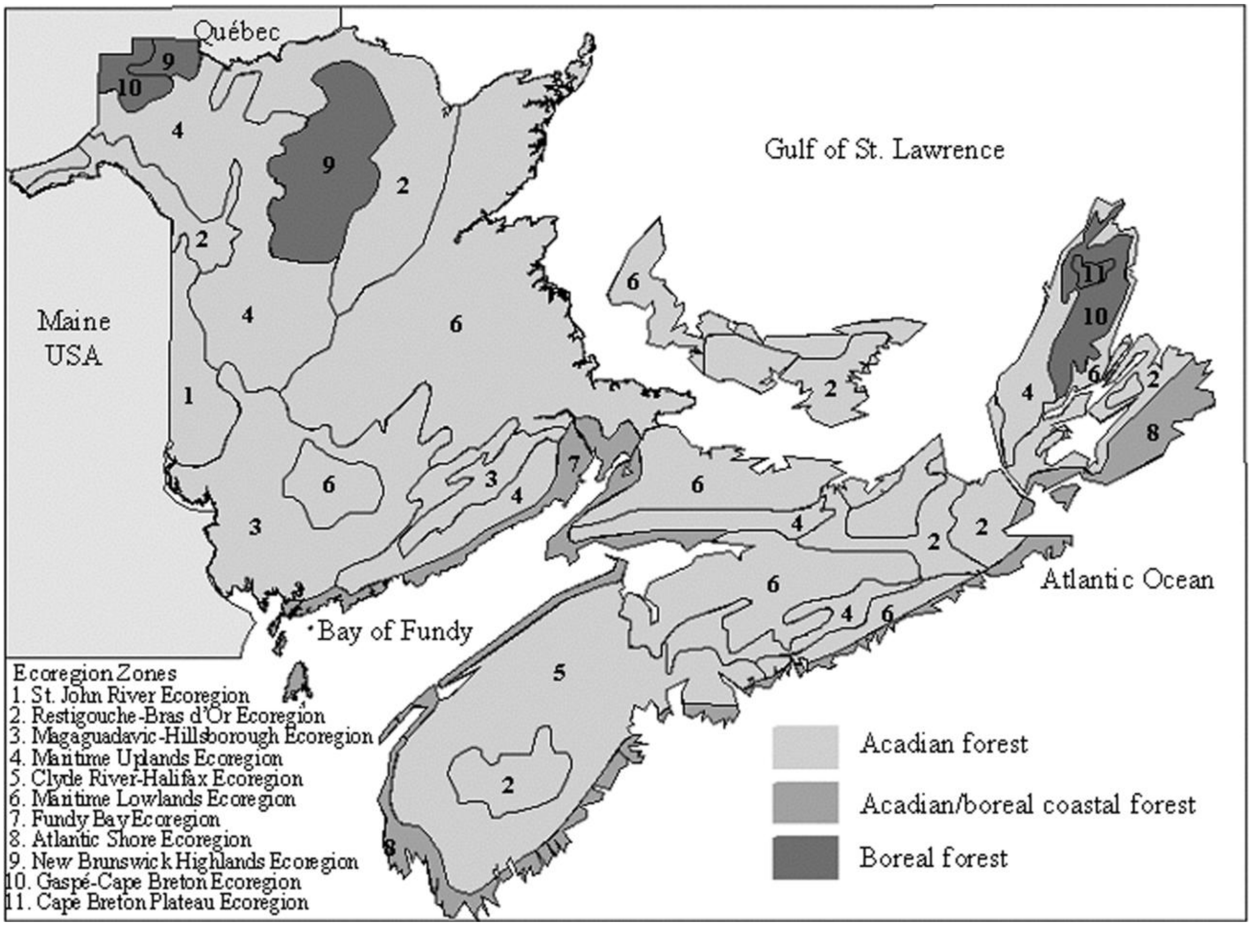


Figure 2- Acadian forest region of Canada's Maritime Provinces. Ecoregions and forest types are indicated within figure (adapted from (Loucks 1968) as found in (Mosseler et al. 2003)).

2.3- Acadian Forest Region (AFR)

Figure 2 shows a coarse classification of forest types of the Maritime Provinces. The Acadian forest region (AFR), so named after the historical French colonial region known as 'Acadie', extends into Maine and a small part of Quebec, covering approximately 11.3 x 10^6 ha in the Maritime Provinces (Loucks 1968, Mosseler et al. 2007). For a less coarse classification of forest types of the AFR, see Neily et al. (2003).

The AFR is characterised by the presence of shade tolerant red spruce (*Picea rubens*) growing in association with balsam fir (*Abies balsamea*), eastern hemlock (*Tsuga canadensis*), eastern white pine (*Pinus strobus*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*). These species, when left undisturbed, form late-successional forest types (Loucks 1968, Mosseler et al. 2007, Rowe 1972).

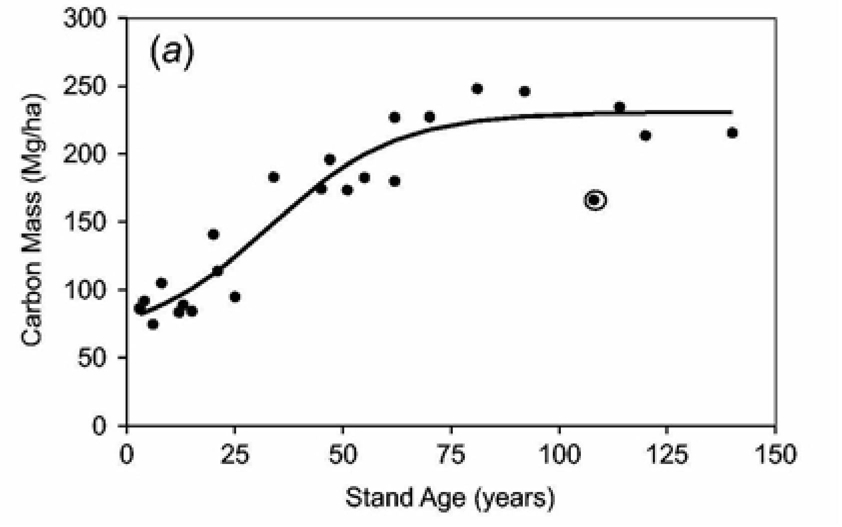


Figure 3- Total site carbon storage versus stand age. Sites were located in Central Nova Scotia, were red spruce dominated stands regenerating from clearcuts, had greater than 80% stocking and were not planted or treated with herbicides (adapted from (Taylor et al. 2007)).

Coastal forests, marked as 'Acadian/boreal coastal forest' in Figure 2, are characterised by moist forests resulting in associations of red spruce, black spruce (*Picea mariana*), and white spruce (*Picea glauca*) along with red maple (*Acer rubrum*) and white birch (*Betula papyrifera*).

Many of the forests of this coastal region are now dominated by white spruce after centuries of human induced disturbance. However, work performed by Hamburg and Cogbill (1988) in neighbouring New England suggests that these forests may once have been dominated by red spruce. The property of focus in this study is located on the border between the Acadian Forest and the Acadian/Boreal Coastal Forest as shown in Figure 2.

Disturbance regimes of the AFR are characterised by small, gap-phase disturbances. This is a result of the death of individual or small groups of trees due to senescence, insect disease or windthrow. These trees are replaced through a process known as gap-phase succession, by which openings in the dominant canopy are filled by smaller trees (Freedman et al. 1996) that compete for access to light resources. These small-scale gap openings favour the regeneration of shade-tolerant species (Mosseler et al. 2003). Mosseler et al. (2003) estimate that in the absence of large, stand replacing disturbances, such as fire and clearcutting, up to 85% of the AFR could have been dominated by late-successional species forming 'climatic climax forest associations (pg. 6)' (This estimate of 85% is recognised by Mosseler et al. as an overestimate of late-successional forest cover, as edaphic limitations in areas underlain, for example, with peat bogs, reduce this number.). These 'climatic climax forest associations', while site dependent, are often characterised by multi-aged, multi-species forests with various canopy levels (Mosseler et al. 2007). Palynological records from all three of the Maritime provinces suggest that these forest types (old, shade tolerant, multi-species, mixed-wood forests) have existed for several thousand years prior to European colonisation (see (Green 1987) for Nova Scotia, (Mott 1975) for New Brunswick and (Anderson 1980) for Prince Edward Island).

Natural forests of the AFR accumulate substantial biomass in the form of coarse woody debris (CWD) and plant detritus (Mosseler et al. 2007). This affects not only carbon storage, but also forest dynamics, as some climax tree species like eastern hemlock and yellow birch find favourable microclimatic conditions for regeneration on large downed, decaying CWD (D'Amato et al. 2009). As shown in Figure 3, the accumulation of living and dead biomass together with increased carbon on the forest floor results in greater levels of carbon storage in older red spruce dominated forests (Taylor et al. 2007). Currently, in Nova Scotia, less than 1% of forests are greater than 100 years old (Wilson and Colman 2001). This is echoed by Mosseler et al (2003) who suggest that the amount of old-growth forest is considerably less than 1% of forest land. Land-use management regimes that, where possible, encourage the restoration and maintenance of late-successional forests will result in greater levels of carbon storage than will management regimes encouraging young forests harvested on short rotations (Stinson and Freedman 2001) (also see Appendix 1). Recent work in temperate forests suggest that old-growth forests continue to sequester carbon even after old-growth stages are reached (Luyssaert et al. 2008). Thus there is considerable potential for the forests of Nova Scotia to increase their carbon storage by managing the forests closer to an old-growth condition.

2.4- Climate Change: an Uncontrollable Variable

The potential impacts of climate change on the AFR must be addressed as an uncontrollable and unpredictable variable that could have major consequences on the future dynamics of forests of the AFR. As mentioned above, palynological data has shown that the AFR has had a relatively stable forest type over the last 4000 or so years (Green 1987, Mott 1975, Anderson 1980). However, a change in climate, which is known to be occurring at a global scale (Walther et al. 2002, Hansen et al. 2006), has the potential to cause dramatic changes in the species composition, disturbance regimes and overall characteristics of forests of the Maritime Provinces. Land managers and planners around the world are preparing for this, and are trying to predict what those changes may look like (for example, see (Bachelet et al. 2001, Walther et al. 2002, Schmitz et al. 2003, McClean et al. 2005) . While the possible effects of climate change on the forests of the Maritime Provinces and the AFR are outside of the scope of this study, it is an important variable to acknowledge and consider. If the disturbance and climate regimes of the Maritime Provinces changes the carbon dynamics of the forests, as could happen if fire were to become a major disturbance in the region, it would change all together the relevance and validity of this study. This is an uncontrollable variable that, while recognised and acknowledged, will not be taken into account by this study.

2.5- Previous Forest Carbon Research in the AFR

The role of forests in storing carbon is well known (Birdsey 1992, Brunnert 1996, Freedman et al. 1996, Stinson and Freedman 2001,Montagnini and Nair 2004,). A number of studies were found that have looked at carbon storage dynamics of the AFR (Freedman et al. 1982, Freedman and Morash 1985, Fleming and Freedman 1998, Taylor et al. 2007, Taylor et al. 2008, Diochon et al. 2009). Recent studies have begun to measure carbon storage at the stand level (Taylor et al. 2007, Taylor et al. 2008, Diochon et al. 2009). However, none of these studies looked at total ecosystem carbon mass. Taylor (2007), while looking at the top 10cm of soil carbon, failed to examine both belowground biomass and soil carbon below 10cm. The findings of Diochon et al.

(2009), while looking at carbon in the upper 50cm of soil and not at aboveground biomass, suggested that soil carbon of the upper 50cm was sensitive to changes in management practices. This goes against the commonly held view that soil carbon below the forest floor is stable (Durgin 1980, Huntington and Ryan 1990, Johnson 1992, Harvey et al. 1994,). While the findings of Diochon et al. (2009) are far from conclusive evidence to the contrary, they do suggest that further work should be done to examine changes in soil carbon with changing management practices, particularly in the AFR.

Land units relevant to land managers are those that delineate property ownership. Property boundaries are not ‘natural’ or ‘ecological’ units, in that they do not recognise forest or soil types. As such, large properties can encompass a mix of stand and soil types, especially in the AFR. Previous studies looked at carbon storage at the stand level (Taylor et al. 2008, Taylor et al. 2007, Diochon et al. 2009). These aggregations were based on tree species composition and time since disturbance. This study will look to quantify carbon at the property level. This is advantageous to land owners and managers, as it translates into easily understandable quantities of carbon and possible revenues. By pulling together methodology from previous studies, and applying it at the property level, this study will begin to establish an accepted methodology for future property level quantification of carbon storage.

3.0 - Methods

The following section outlines the methods employed in this project.

3.1- Sample Design

Representative stratified random sampling methods were used throughout the study. However the specific sampling methods used varied slightly depending on the particular carbon pool of interest. These sampling methods are outlined in Section 3.3. The woodlot of focus was the Douglas Property at Port Joli, owned by Charles and Danielle Robertson. As mentioned in Section 2.7, the property level was chosen as the unit for study because it is relevant to land managers and owners. The Douglas Property was divided into four stand units (Figure 5) based on aggregations of land of similar forest type. Forest type was determined using a combination of data obtained from the NS Department of Natural Resources Ecological Land Classification system and ground proofing of stand delineations. Within each of these stand units, three random sample sites were chosen using ArcGIS. Stratified random samples were based on these random sample sites. Values for each of the pools of carbon were then calculated from data obtained from these sites.

3.2- Study Area

The Douglas Property is a typical coastal NS property, in that it runs inland over 2km from the south to north boundary lines and is only approximately 120 m wide. The Douglas Property is typical of many in the area, with its southern portions covered in softwood growth and its northern half dominated by hardwood species typical of the AFR. The age of the dominant canopy trees was estimated to be no greater than 80 years. There was evidence of a fire that burned the area prior to the establishment of the dominant age classes present now. This was more evident in the northern portion of the property, as the dominant red maples currently there were offshoots from the base of older, pre-existing trees. However, there was no local knowledge found that would support the suggestion of a fire approximately 80 years ago.

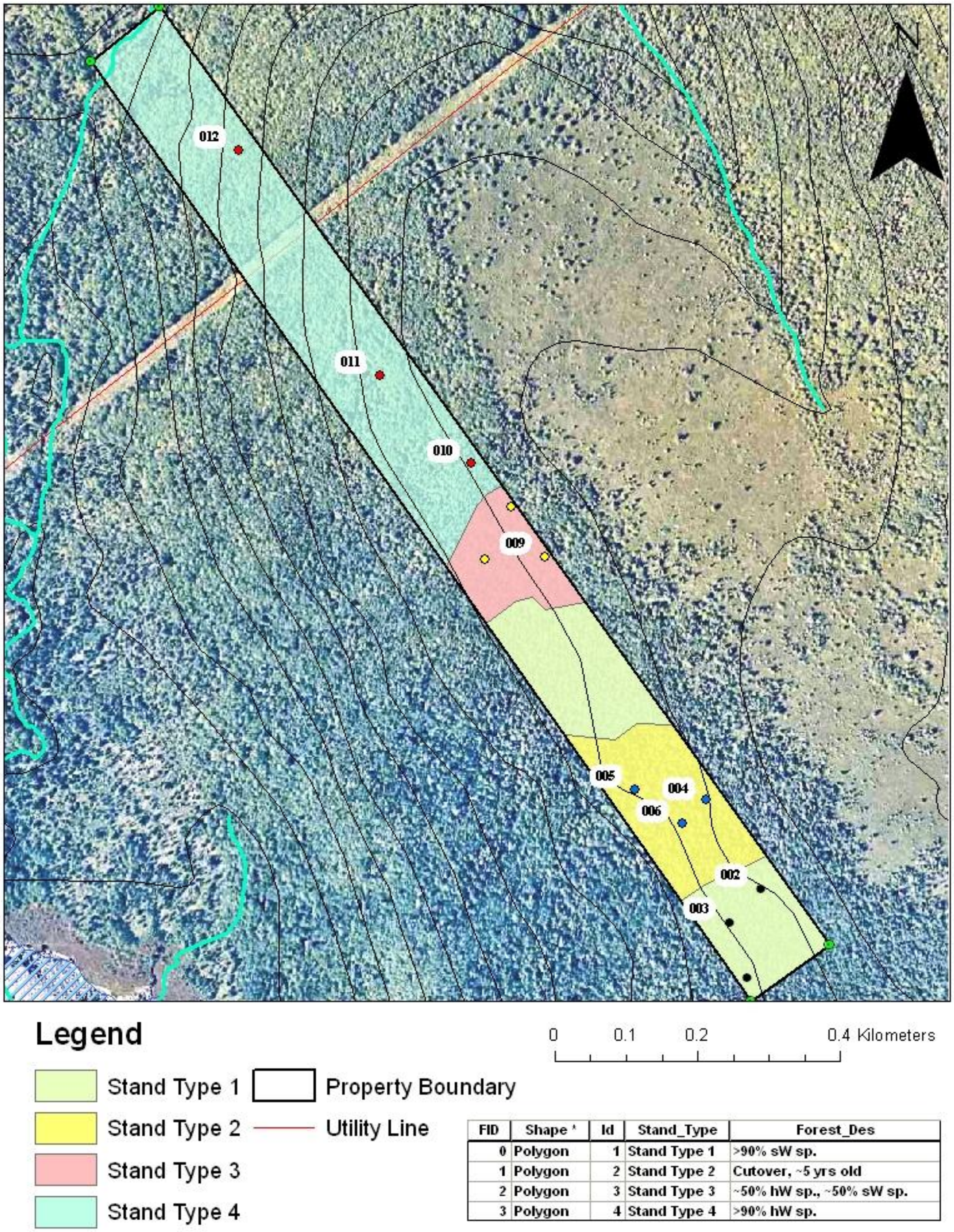
As mentioned above, four stand types were defined through a process of ground proofing NS Department of Natural Resources Ecological Land Classification units. These stand types, as shown in Figure 5, are as follows;

- Stand 1- This stand is dominated by a mixture or red spruce with black spruce, balsam fir and white pine mixed throughout. Stand 1 is 5.04 ha total in two distinct patches from the that are directly to the south and north of Stand 2. The dominant age class is approximately 75-85 years with scattered remnant red spruce, white pine and some red maple of an older age class. The balsam fir is largely over-mature and dying, which can be seen in the large number of dead stems measured in sample plots 002 and 003. Stand 1 is moderately well drained with local variations in topography resulting in some limited poor drainage.

- Stand 2- Stand 2 is a 3.32 ha patch that is the result of a clear-cut harvest that occurred approximately 5 growth seasons before sampling was undertaken in 2009. From remnant stumps and landowner testimonials this stand was compositionally the same as Stand 1 pre-harvest. Regeneration of softwood and hardwood species has proceeded exceptionally well in some areas with other areas not regenerating very well. This heterogeneity of regeneration was represented well by samples 004, 005 and 006. Drainage is similar to that of Stand 1. Harvesting left some coarse woody debris and litter.

- Stand 3- Stand 3 is in the middle of the lot to the north of Stand 1 (b). It is a transitional forest type between the softwood dominates stands to the south and hardwood dominated stands to the north. It is the smallest of the four stand types at only 1.91 ha. This stand is a equal mix of both softwood species such as red and black spruce and hardwood species like red maple and white birch. There is a substantial amount of witch hazel (*Hamamelis virginiana*) which grows in clumps and rarely reach greater than 4 meters in height. The drainage of this stand is moderate to poorly drained. More rhododendron grows in the understory in this stand than in Stand 1.

- Stand 4- The largest of the four stand types at 10.53 ha, Stand 4 is dominated by red maple with some white birch scattered throughout. A few yellow birch were found, but do not form a substantial part of the canopy at present. Stand 4 is moderate to well drained and has a brook, known locally as Douglas Brook, bisecting the northern portion of it. Very little regenerative growth was found, as the tight canopy of the dominant age-class appears to be preventing regeneration from becoming established.



FID	Shape *	Id	Stand_Type	Forest_Des
0	Polygon	1	Stand Type 1	>90% sW sp.
1	Polygon	2	Stand Type 2	Cutover, ~5 yrs old
2	Polygon	3	Stand Type 3	~50% hW sp., ~50% sW sp.
3	Polygon	4	Stand Type 4	>90% hW sp.

Figure 4- Map of study area. Port Joli is directly to the south of the map. Douglas Brook bisects the property in the north.

3.3- Sampling Methods

Vegetation Sampling

Standing Trees
Standing trees were defined as all live or dead trees standing ≥45˚ from the ground with a diameter at breast height (DBH=1.37 m from ground) ≥5cm. These were sampled using a 20m square plot for each sample point by recording DBH to the nearest millimetre using a diameter tape and by recording the species of each tree. While (Taylor et al. 2007)) used circular sample plots to estimate the same parameters, the square quadrats used here covered the same area (0.04 ha) and were used by Fleming (1996). Three 20m quadrats were used per stand type, allowing for the calculation of standard errors.

Coarse Woody Debris
Coarse woody debris was defined as all dead stems ≥5cm average diameter that were <45˚ from the ground. CWD was estimated using the same 20m quadrats mentioned above. Average diameters over 400cm lengths were estimated using a standard measuring tape. When possible the type of CWD was recorded distinguishing between softwood and hardwood. This method of sampling was used by Fleming (1996). Branches attached to downed trees were not measured.

Coarse Woody Litter
Coarse woody litter was defined as all stems ≥2cm average diameter but <5cm average diameter that were <45˚ from the ground. These were sampled using two 5m quadrats (located in opposite corners of the 2om quadrat mentioned above) per sample point, giving a total of six quadrats per stand type. Average diameter and length were recorded, along with whether it was from softwood or hardwood species. It is important to note that for sample points in stand 2, it was not possible to sample coarse woody litter in this manner. Therefore it was decided that forest floor samples would incorporate all woody litter that were within the 25cm quadrats.

Understory Vegetation
Understory vegetation was defined as all live and dead stems standing ≥45˚ from the ground ≥1cm 30cm from the ground but <5cm at the same height. Understory vegetation was sampled in the same two 5m quadrats per sample point as mentioned above. Diameter 30cm from the ground was taken and species was recorded. Fleming (1996) used the same nested sample design for measuring understory vegetation.

Ground Vegetation
Ground vegetation included non-woody vascular plants along with woody plants <1cm in diameter 30cm from the ground. Ground vegetation was sampled using four 1m x 1m quadrats for each sample point that all fell within the bounds of the larger 20m quadrat. Quadrats were harvested, and non-woody vegetation collected into paper bags and labelled.

Forest Floor Sampling

The forest floor was defined as everything below the ground layer, usually characterized by the top of the living moss layer, including roots of ground vegetation, down to, but not including, the Ae horizon. Coarse woody debris and litter were excluded, but litter <1cm average diameter was included. 25cm quadrats were excavated, with samples being stored in paper bags and labelled. Four quadrats were excavated in each of the sample points. This method was used by Taylor et al. (2007) to measure the same parameters. Depth of organic layer was recorded for each quadrat. As mentioned above, sample point in Stand 2 collected coarse woody debris in forest floor samples. These were treated in the same manner as the rest of the forest floor mentioned above.

3.4- Data Analysis

Biomass was estimated on a per hectare basis for each of the forest compartment whose sampling was described above.

Vegetation Estimation of Biomass

Standing Trees

Species-specific biomass prediction equations (Appendix 3) developed by (Freedman et al. 1982) were used to give estimates for dry weight of biomass. For some tree species, specific regression equations were not available, so generic biomass prediction equations (Appendix 3**)** were taken from (Freedman et al. 1984). For dead trees, biomass prediction equations that calculated the mass of only stem wood without bark or branches were used. While this may not be an accurate estimate of standing dead wood, it was the best method available given logistical constraints. Conversion of dry weight biomass to carbon used a 50% carbon per unit dry weight biomass calculation, as used by (Taylor et al. 2008, Taylor et al. 2007, Kurz et al. 1993, Freedman 2009).

The average dry weight of carbon per 20m quadrat was calculated for each stand type and multiplied by 25 to calculate weight of carbon per hectare ($20m*20m=400m^2$, $400m^2*25=10{,}000m^2$=1hectare). This number was then multiplied by the number of hectares per stand type to calculate total carbon storage in each of the stand types.

Li et al. (2003) developed regression equations to estimate underground root biomass using aboveground biomass for softwood and hardwood species. They are as follows;

Equation 1- $RB_s = 0.222AB_s$
Equation 2- $RB_h= 1.576AB_h^{0.615}$

RB and AB are aboveground biomass and belowground biomass, respectively and subscripts s and h denote softwood and hardwood species. As mentioned, aboveground biomass estimated were calculated using the equations found in Appendix 3.

For Stand 2, with no standing trees, stump diameters were measured and 3 cm were subtracted to account for butt flare. This estimate of DBH was used to calculate standing tree biomass, which was used for estimation of root biomass using equations 1 and 2.

Coarse Woody Debris and Litter

Volumetric estimates for coarse woody debris and litter were made using average diameter and length measurements. Fleming and Freedman (1998) developed estimates for density of deadwood by cutting discs from CWD samples, drying and weighing them. An estimate of 3.53.4 Mg/m^3 was used as calculated to calculate the weight of dead wood per quadrat. For the CWD estimate, weight per hectare for each stand type was calculated from average weight of CWD per quadrate which was multiplied by 25. For coarse woody litter, averages for each set of two quadrats were calculated within stand types, then multiplied by 200 ($5m*5m=25m^2$, $50m^2*200=10,000m^2=1ha$). Once again, 50% carbon per unit dry weight was used, and the amounts of coarse woody debris and litter for each stand were calculated by multiplying the kg/ha by the number of hectares in each stand.

Understory Vegetation

Generic biomass prediction equations (Appendix 3) for softwood, hardwood and shrub species, developed by Freedman (1984) were used to estimate dry weight biomass of understory vegetation. 50% carbon per unit dry weight was applied and quadrat averages were calculated for each stand type. Per hectare carbon was calculated by multiplying quadrat averages by 200. Stand type understory vegetation carbon was calculated by multiplying per hectare carbon by the number of hectares in each stand.

Ground vegetation

Collected ground vegetation samples were dried for 24-48 hours (depending on amount of woody vegetation, which required longer drying times) at 60˚ C. Each sample was weighed to the nearest 100th gram using a Scientec S500 scale. 50% carbon per unit dry weight was used to calculate carbon content. The four 1m quadrats per sample point were summed, and stand type averages were calculated. Per hectare ground vegetation carbon was calculated by multiplying stand type average weight of carbon by 2500 ($1m^2*4=4m^2$, $4m^2*2500=10,000m^2=1ha$). This number was multiplied by the number of hectares in each stand type to give the amount of ground vegetation carbon in each stand.

Forest Floor

Collected forest floor samples were dried for 48 hours at 60˚C, as done by Freedman and Morash (1985). These were then weighted to the nearest 100th g. 50% carbon per unit dry weight was used to calculate carbon content.

4.0- Results

Table 1- Stand area and per hectare carbon represented by respective pools. Standard errors are given in parentheses following MG/ha estimates.

Stand Type	Area (ha)	Standing Trees (Live and Dead) (Mg/ha)	Understory (Mg/ha)	Coarse Woody Debris (Mg/ha)	Coarse Woody Litter (Mg/ha)	Ground Vegetation (Mg/ha)	Organic Layer (Mg/ha)	Total (Mg/ha)
Stand Type 1	5.04	127.68 (18.30)	0.09 (0.09)	0.90 (0.81)	0.32 (0.04)	0.13 (0.04)	66.08 (4.13)	195.20
Stand Type 2	3.32	23.30 (8.99)	1.88 (0.08)	0.50 (0.20)	NA	1.94 (0.47)	83.67 (5.76)	111.29
Stand Type 3	1.91	81.78 (9.61)	0.98 (0.48)	0.55 (0.25)	0.32 (0.11)	0.20 (0.06)	83.47 (14.68)	167.28
Stand Type 4	10.53	82.10 (9.82)	0.81 (0.46)	0.63 (0.16)	0.19 (0.09)	0.60 (0.10)	62.81 (10.53)	147.13
Total (Average)	20.79	72.89	0.50	0.67	0.20	0.66	68.81	151.16

Table 2- Stand area and total carbon represented by respective pools.

Stand Type	Area (ha)	Standing Trees (Live and Dead) (Mg)	Understory (Mg)	Coarse Woody Debris (Mg)	Coarse Woody Litter (Mg)	Ground Veget-ation (Mg)	Organic Layer (Mg)	TOTAL (Mg)
Stand Type 1	5.04	643.24	0.45	4.53	1.59	0.66	332.88	988.40
Stand Type 2	3.32	77.37	6.24	1.67	N/A	6.44	277.98	373.03
Stand Type 3	1.91	156.03	1.87	1.05	0.62	0.38	159.27	321.13
Stand Type 4	10.53	864.55	8.51	6.68	1.99	6.32	661.11	1559.69
Total	20.79	1663.82	17.07	13.93	4.20	13.80	1431.24	3242.24

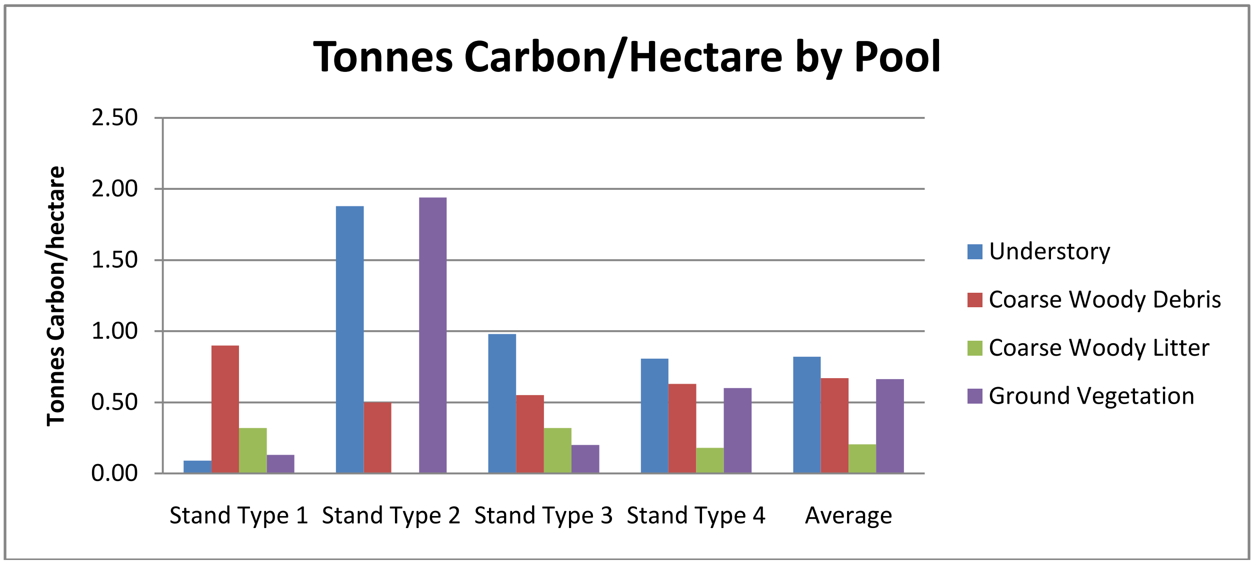


Figure 5- Mg Carbon / hectare for understory, CWD, CWL and ground vegetation.

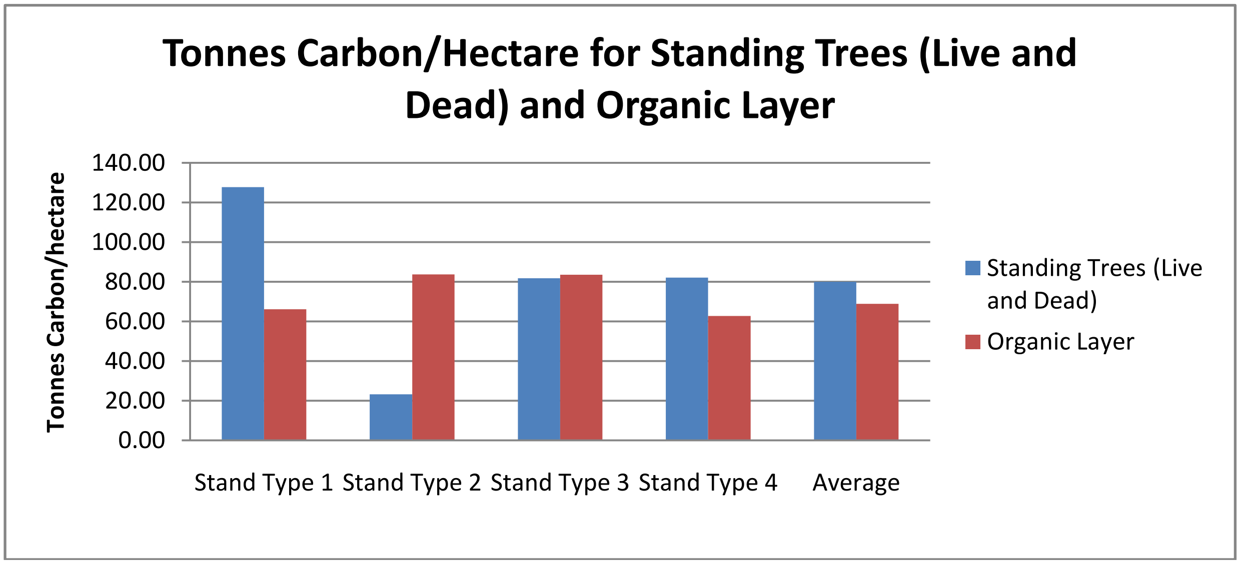


Figure 6- Mg Carbon/hectare for standing trees and organic layer.

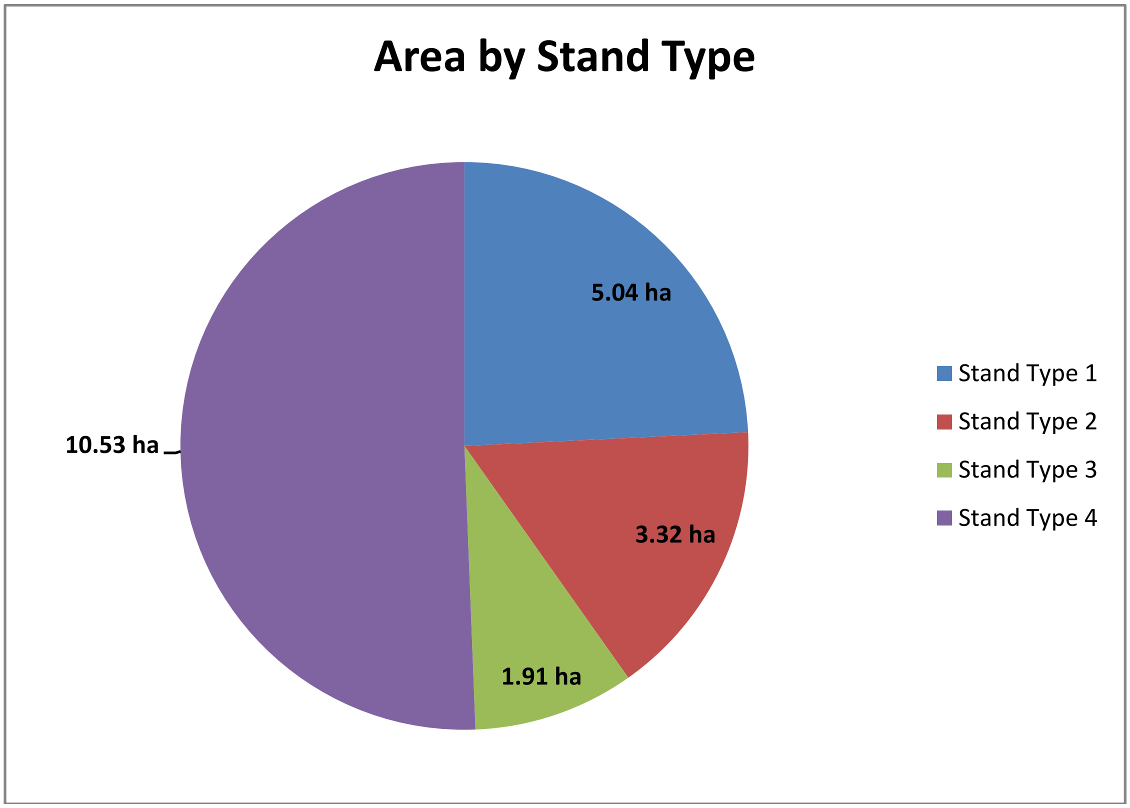


Figure 7- Area of each stand type.

4.1- Vegetation Biomass

Graphical representations of per hectare carbon weights and total, per stand carbon amounts can be found in Figures 8 and 9. Following is a short description of estimated carbon quantities.

Standing Trees

Stand 1 had the largest amount of carbon per hectare in standing trees at 127.68 Mg on each hectare (Table 1), while stands 3 and 4 similar per hectare amounts of carbon in standing trees, at 81.78 and 82.10 MG/ha respectively. However, due to its greater size, Stand 4 stored the largest amount of carbon in standing trees, with 864.22 Mg over 10.53 ha (Table 2).

Coarse Woody Debris

Stand 1 had the greatest amount of carbon storage per hectare with 0.90 Mg/ha (Figure 1), and had the second largest total amount of CWD carbon in the stand with 4.53 Mg/ha (Figure 2). Stand 4 had the second greatest amount of total and per hectare carbon storage while once again storing the greatest amount of carbon in CWD at 6.68 Mg/ha. Despite harvesting slash, Stand 2 had the least amount of carbon per hectare CWD carbon at 0.50 MG/ha.

Coarse Woody Litter

Coarse woody litter represented 0.21 MG carbon/ ha on average, with Stand 1 and Stand 2 having the greatest amount of CWL per hectare, at 0.32 MG/ha (Figure 1). Considering that Stand 3 is a mix of stands 1 and 4, its CDL was less than both Stands 1 and 4 at only 0.18 Mg/ha. This could have been a result of the location of samples.

Understory Vegetation

Stand 2 had the greatest amount of carbon represented in understory vegetation, with 1.88MG Carbon/ha (Table 1). Stand 4 had the greatest total amount of carbon stored in understory vegetation with 8.51 MG Carbon/ha stored. The name 'understory vegetation' is misleading in this sense, as in Stand 2 this class of vegetation is the regenerating age-class that is technically forming the only canopy on the site. Stand 1 had the least amount of both per hectare and total understory vegetation.

Ground Vegetation

Stand 2 had the greatest amount of ground vegetation per hectare with 1.94 MgC/ha (Table 1). Stands 1 and 3 had similar amounts of carbon in ground vegetation, with 0.13 and 0.20 MgC/ha each, while Stand 4 had substantially more at 0.60 MgC/ha.

4.2- Forest Floor

The organic layer was the largest pool of carbon in Stand 2 and Stand 3, which contained 83.67 and 83.47 Mg/ha respectively (Table 1). Stand 4 had the lowest amount of carbon in the organic layer at 62.81 Mg/ha. It was found that Stand 1 had 66.08 MgC/ha.

4.3- Overall Carbon Storage

Total carbon storage by stand type can be found in Table 2, while per hectare carbon storage by stand type can be found in Table XX. Total carbon storage was estimated at 3242.24 MgC across the whole property, while average per hectare carbon storage was 151.16 MgC/ha. Stand 1 had the greatest amount of carbon per hectare at 195.20 MgC/ha. Stand 2, which differed from Stand 1 only because it was harvested 5 years prior to sampling, stored the least amount of carbon per hectare at 111.29 Mg/ha.

4.4- Relationship Between Depth of Organic Layer and Amount of Carbon in Organic Layer

Figure 7 shows the correlation between depth of organic layer and organic carbon mass per plot. Stand 2, which includes coarse woody litter in with the organic layer, is plotted separately than Stands 1, 3 and 4. Both of the plot lines show a very strong correlation that has a strong statistical significance at 95%.

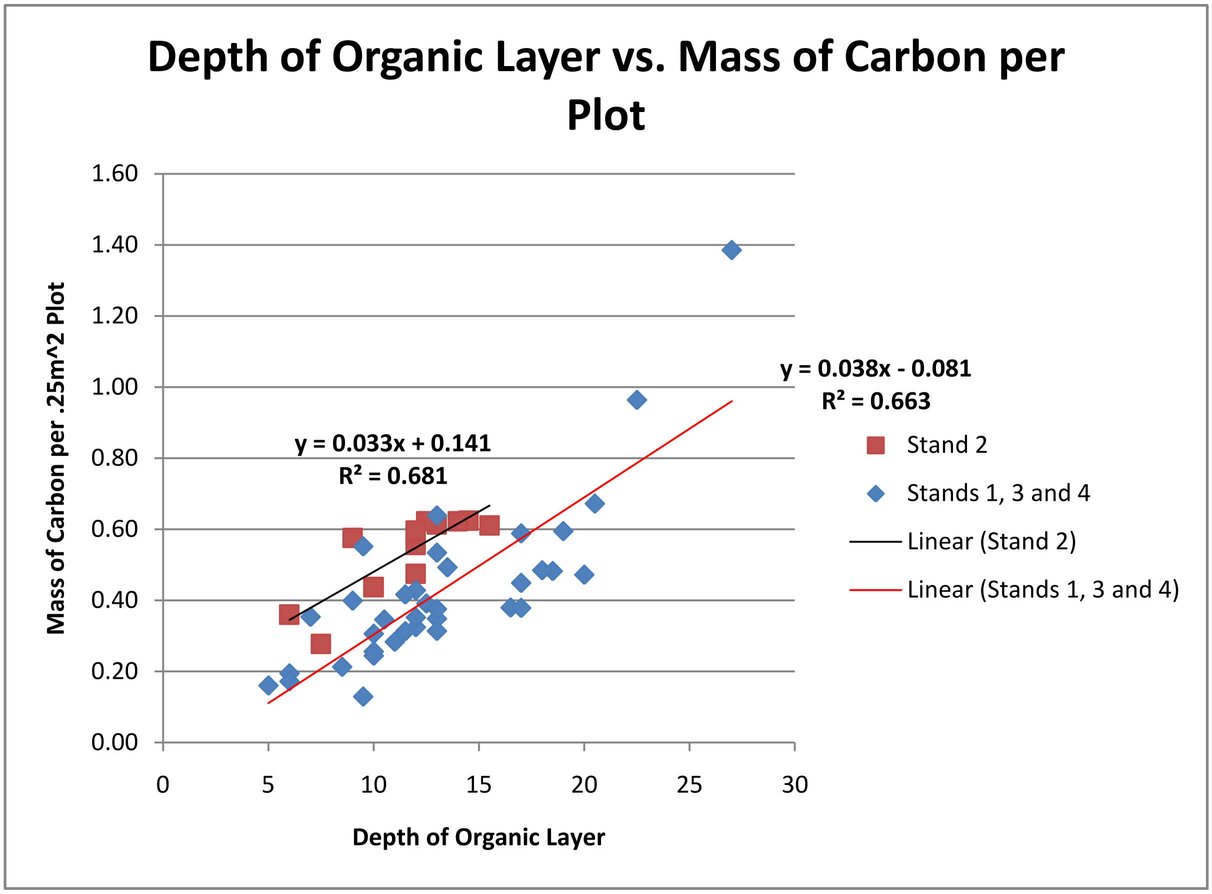


Figure 8- Depth of organic layer plotted against mass of carbon per plot. Regression equations and correlation coefficients are given next to the relevant trend lines.

5.0- Discussion of Results

5.1- Vegetation Biomass

Standing Trees

It was expected that Stand 1 would have the greatest amount of carbon represented in standing trees. Upon visual inspection it can be seen that Stand 1 had more dense trees that were on average taller than either Stand 3 or Stand 4. However, it was surprising that Stand 3 and Stand 4 were so similar. Considering that Stand 3 is a transition zone between Stand 1 and Stand 4, it would logically be expected that the amount of standing biomass would be somewhere between the two. The results given here suggest that there is no added benefit in delineating a unique Stand for transition zones between the softwood and hardwood dominated stands found here. Stand 1, at 127.68 MgC/ha, is within the range empirically estimated for red spruce dominated stands between 81 and 100 years by Taylor et al. (2007), who used a circular plot to measure the same parameters. This gives confidence to the results observed here.

Standard errors given in Table 1 are not always below the 10% of the mean target that was aimed for, but were close. Given more time and logistical support, more sampling could have reduced the standard errors more. Given the correspondence of this data with other similar biomass estimates, it is felt that these are accurate estimates of standing trees.

The standing tree estimate for Stand 2 is for root biomass is likely overestimated. This is because estimates for stump and root biomass is based on a biomass prediction equation for generic softwood and hardwood equations that use DBH to estimate dry weight. Given that the stumps at ground level were measured (not at DBH), 3 cm diameter was subtracted to account for butt flare. Also, given that biomass predictions were for live trees, decay of root biomass would have occurred resulting in an overestimate of biomass.

Coarse Woody Debris and Coarse Woody Litter

CWD and CWL estimates for Stand 1 were less than were expected. Taylor et al. (2007) observed approximately 25 and 20 MgC/ha (CWD+CWL) for red spruce dominated stands between 61-80 and 81-100 years respectively. This could be due to several factors. First, between site variation in tree health and species composition could have led to differences in tree senescence or coarse litter input. Second, locations in south-western Nova Scotia could have litter decomposition rates that are higher due to the climate and a warmer temperature. Third, the differences in observed results could be due to different sampling method, as Taylor et al. (2007) used a line intercept method for estimating CDW and CWL. It was observed that there was a lot of standing dead wood in Stand 1 (mostly dead balsam fir), which could over the next 10 years continue to decay and become fallen CWD and CWL.

No comparative sites for Stand 2, Stand 3 and Stand 4 were found. However, the observed values are within the range of expected values and follow trends found upon visual inspection. However, Stand 2, with the lowest of all of the CWD estimates could be reflective of the high amount of fibre utilisation of stems >5cm diameter. An estimate of 0.50 MgC/ha of CWD in Stand 2 is not surprising.

Understory Vegetation

Understory vegetation estimates were as expected. A lack of tree regeneration in Stand 1 was reflected with the estimate of 0.09MgC/ha, while the five year old regeneration in Stand 2 is shown with Stand 2 having the highest understory vegetation values. Stand 3 and Stand 4 each had greater amounts of witch hazel and rhododendron growth, which was reflected in their relatively high understory vegetation carbon estimates.

Ground Vegetation

The amount of ground vegetation in each of the stands was expected. Stand 2, being a cutover with lots of light reaching small vegetation had the greatest amount of carbon stored, with more than three times as much as Stand 4. Stand 4 had the second greatest amount of carbon stored in its ground layer, which likely reflects the extra amount of light that reached the ground in hardwood dominated stands. However, the relatively high standard errors of each stand suggest that greater certainty could be reached with more sampling. The small contribution of the ground vegetation to overall carbon storage, in all but Stand 2, is similar to that found by Taylor et al. (2007).

5.2- Forest Floor

The organic layer estimates calculated here are higher than that observed by Taylor et al. (2007) even though the same sample procedures were used. This could be due to variation between sites tested. Given the impacts of site specific drainage, it is likely that the amount of carbon represented in the organic layer is largely site dependent.

It was somewhat surprising that Stand 2 had the most carbon in its organic layer, as one may expect decomposition over the previous 5 years exposed to higher temperatures to have reduced the organic layer. However, with inputs from harvesting slash and the inclusion of CWL one may expect temporarily high inputs of organic material into the organic layer. It should be noted that even when the amount of carbon in CWL for Stand 1 is added to the organic layer, it is still substantially less than the organic layer of Stand 2. As mentioned above, site specific conditions, like drainage and slope aspect could have considerable impacts on the organic layer.

Decomposition of samples collected likely had reduced the weight of the samples at the time of drying and weighing. The time between collection and drying was, in some cases, four months. Fungi were observed growing in some of the samples, and considering that they were likely saprophytic fungi respiration could have resulted in a loss of mass. However, it isn’t believed that this loss would have been significant. When possible, quicker drying of samples and better storage conditions should be used.

5.3- Overall Carbon Storage

Stand 1, which is comparable with stands estimated by Taylor et al. (2007) of the same age, was estimated to contain slightly more carbon per hectare than those stands estimated by Taylor et al. (2007). However, Taylor et al. (2007) did not estimate belowground biomass, which was taken into account here. Therefore, for the 61-80 year age class that stored approximately 160 MgC/ha (without their estimation of mineral soil carbon) given by Taylor et al. (2007), it is believed that the difference between their estimates and the estimate given here for Stand 1 can be attributed to belowground biomass and differences in the organic layer. As mentioned above, differences in amount of carbon in the organic layer can be attributed to differences in site characteristics, including drainage or aspect.

Estimates for Stand 2, while being the lowest amount of carbon stored per hectare in this study, were significantly higher than that estimated by Taylor et al. (2007). This difference can be attributed to inclusion of root biomass that were not included in the estimation by Taylor et al. (2007) and to differences in the amount of carbon in the organic layer. It is unclear why the organic layers in this study contained so much more carbon than those estimated by Taylor et al (2007). However, this could be an indication of organic layer masses and depth being particularly site specific. This could be due to stand management history, local climactic regimes or some other site specific factor.

5.3- Relationship Between Depth of Organic Layer and Amount of Carbon in Organic Layer

Measuring the amount of carbon in the organic layer was by far the longest and most time consuming portion of the whole sampling regime. To expedite estimation of carbon at the woodlot scale (for economic and logistical reasons) it would be beneficial to develop a prediction equation allowing for estimation of carbon in the organic layer from simple depth measurements. These results suggest that the development of an accurate equation relating depth of organic layer and carbon content is possible. However, the results from this study are insufficient for the purpose of estimating organic layer carbon solely based on depth of organic layer. An expanded study specifically looking at this relationship is recommended.

Stands 1 and 2, when compared with similar sites investigated by Taylor et al. (2007), suggest that the amount of carbon in the forest floor (organic layer) is very site specific. This means that one cannot make accurate assumptions about the amount of carbon stored in the organic layer based on stand age, species composition or other pre-determined factors. Thus the development of a regression equation allowing for the estimation of carbon in the organic layer based on depth of organic layer is imperative for developing an efficient, economic method for determining woodlot carbon storage.

6.0- Conclusions and Recommendations

Total carbon storage on the Douglas Property, owned by Charles and Danielle Robertson of Port Joli, Nova Scotia was estimated experimentally to be 3242.24 MgC. This equates to an average of 151.16 MgC/ha. The greatest per hectare amount of storage was in Stand 1 with 195.20 MgC/ha, while the lowest was in Stand 2 at 111.29 MgC/ha. This difference is directly attributed to clearcut harvesting that took place approximately 5 years prior to sampling.

It was found that there was a statistically significant relationship between depth of organic layer and amount of carbon in the organic layer. It is suggested that further investigation into this relationship could produce a carbon prediction equation that could be used to speed up the sampling process. Sampling and determination of the amount of carbon in the organic layer was the most labour and time consuming part of the sampling procedure and currently represents an impediment to efficient and economical sampling of woodlot carbon storage.

Paying landowners for carbon storage has the potential to reduce atmospheric carbon dioxide concentrations and increase forest habitat that has become more and more rare in the Acadian Forest Region. For this to happen, land managers must be able to efficiently and economically quantify carbon storage at the woodlot property level. This study provides a template that can be followed to quantify carbon storage at the property scale while at the same time making recommendations that will make the process more efficient and practical. Future analysis can be carried out using this data. Such analyses include calibration of Canada's national carbon budget model, the CBM-CFS3 model, along with using this data as a baseline against which to measure future changes in carbon storage as a result of any given set of management techniques.

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Appendix 1

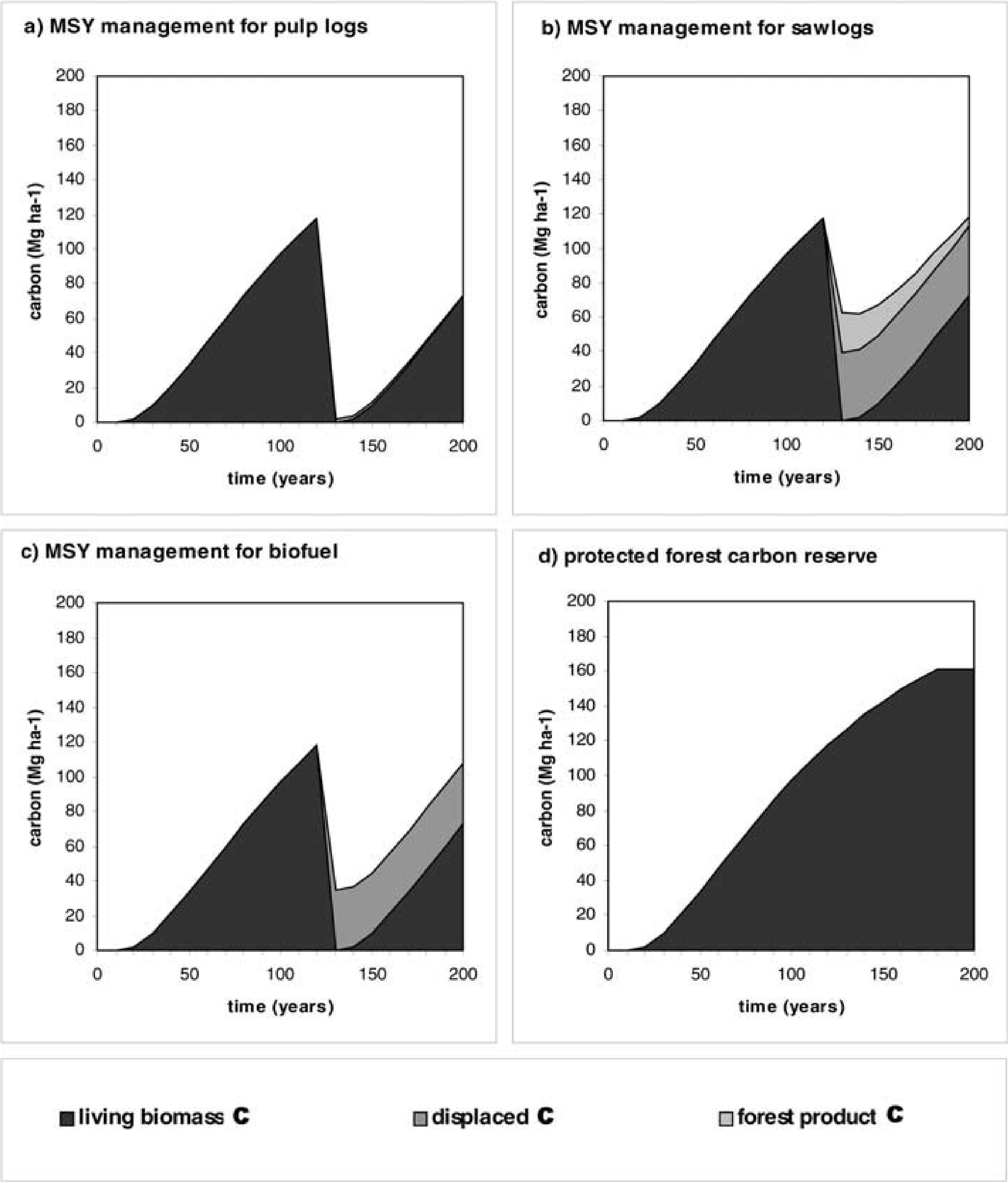

Figure 4. **Carbon storage in regenerating Acadian mixed tolerant hardwood forest under (a) maximum sustained yield (MSY) management for pulp logs, (b) MSY management for sawlogs, (c) MSY management for biofuel, and (d) protected forest C reserve management. Taken from Stinson and Freedman (2001), page 11.**

Appendix 2- Taken from (Neily et al. 2003), pages 71-72.

830 - South Shore Ecodistrict

The South Shore Ecodistrict extends about 160 km along the Atlantic coast of Nova Scotia from the Halifax peninsula to the mouth of the Clyde River and extends inland approximately 10 km. The Clyde River watershed is also used to define the eastern boundary of the Gulf of M aine (Kelly 1999). The coastline is irregular, with many bays, inlets, headlands and islands. The climate of the South Shore is probably influenced by the warmer waters of the Gulf Stream more so than the Eastern Shore (820), which is cooled by the colder waters of the Labrador current before it deflects out into the Atlantic Ocean. The South Shore also shares the same topography and geology as the adjacent inland ecodistricts (720, 740, 750, 760) but is separated from them due to the impact of the coastal climate on biodiversity. Its location on the Atlantic coast means that the South Shore is cooler in summer and milder in winter than the adjacent inland ecodistricts, and fog is more common along the coast. The total area of the ecodistrict is 1,020 km2 or 18% of the ecoregion.

The bedrock along the South Shore is mostly greywacke and granite. The soil is thin and moderately coarse-textured with imperfect to poor drainage. Sand beaches are common along the shoreline. Nearly 3% of the ecodistrict is covered with lakes and streams (3,056 ha). Because the coast was the first part of Nova Scotia settled by Europeans, the forests have been extensively harvested for a variety of products. Black and white spruce predominate the coastal forest with scattered occurrences of balsam fir. The coastal headlands receive the brunt of the Atlantic winds, which creates coastal forests of spruce where the trees are severely stunted. However, once the impact of this exposure is diminished either by shelter from established spruce or distance from the coast, other tree species will establish in the ecodistrict although the thin soil can be a serious impediment. The absence of red spruce, except for the most sheltered locations in the ecodistrict, is usually an indicator of the coastal influence of the Atlantic Ocean. This ecodistrict excludes the inner islands of Mahone Bay which for the most part are within the LaHave Drumlin ecodistrict. The vegetation of the forest ecosystems on many of these islands was studied recently (SRES 2002). Red spruce and white pine with scattered sugar maple, yellow birch and hemlock were reported which indicates that these islands are afforded some protection from the Atlantic Ocean.

Appendix 3- Biomass Prediction Equations

Table 1- Biomass prediction equations for total aboveground oven-dry weight of various tree species of the AFR. W stands for weight, while D stands for diameter at breast height, or 1.37m above ground. Adapted from Freedman et al. (1981).

Species	**Equation**	**n, R^2, s, c**
Balsam fir (*Abies balsamea*)	lnW = -2.2304 + 2.3263 ln D	30, 0.987, 0.1967, 1.02
White spruce (*Picea glauca*)	lnW = -1.8322 + 2.2413 ln D	24, 0.987, 0.2127, 1.02
Black spruce (*Picea mariana*)	lnW = -1.3371 + 2.0707 ln D	24, 0.983, 0.2270, 1.03
Red spruce (*Picea rubens*)	lnW = -1.7957 + 2.2417 ln D	37, 0.972, 0.3004, 1.05
Red maple (*Acer rubrum*)	lnW = -1.9702 + 2.3405 ln D	37, 0.992, 0.1756, 1.02
Sugar maple(*Acer saccharum*)	lnW = -1.8760 + 2.3924 ln D	36, 0.995, 0.1494, 1.01
Yellow birch (*Betula alleghaniensis)*	lnW = -2.1306 + 2.4510 ln D	24, 0.991, 0.1800, 1.02
White birch (*Betula papyifera*)	lnW = -2.0045 + 2.3634 ln D	37, 0.990, 0.2147, 1.02
Large toothed aspen (*Populus grandidentata*)	lnW = - 2.3200 + 2.3773 ln D	30, 0.995, 0.1557, 1.01
Trembling aspen (*Populus tremuloides*)	lnW = -2.3778 + 2.4085 ln D	26, 0.995, 0.1622, 1.01

Table 2- Biomass prediction equations for above-ground dead (wood, bark only on the merchanable stem) oven-dry weight of various tree species of the AFR. W stands for weight, while D stands for diameter at breast height, or 1.37m above ground. Adapted from Freedman et al. (1981).

Species	**Equation**	**n, R^2, s, c**
Balsam fir (*Abies balsamea*)	lnW = -3.7775 + 2.6635 ln D	22, .960, .1977, 1.02
White Birch (*Betula papyifera*)	lnW = -4.0550 + 2.9650 ln D	29, .984, .1666, 1.01
Black spruce (*Picea mariana*)	lnW = -3.7823 + 2.7403 ln D	19, .974, .1984, 1.02
Red spruce (*Picea rubens*)	lnW = -3.7858 + 2.8006 ln D	28, .972, .1909, 1.02
Red maple (*Acer rubrum*)	lnW = -3.0148 + 2.5932 ln D	26, .960, .1937, 1.02

Table 3- Aboveground dry weight biomass prediction equations for tree and plant aggregations. Adapted from Freedman and Morash, 1985.

Species Aggregations	**Equation**	**r^2, +/-**
Hardwood only	$\log_{10}DWT=(2.46+/-0.02)*\log_{10}DIAM-(1.01+/-0.02)$	0.982, 1.11
Softwood only	$\log_{10}DWT=(2.41+/-0.02)*\log_{10}DIAM-(1.01+/-0.02)$	0.988, 1.12
Shrub species (0.3-6.0 cm dia)	$\log_{10}DWT=(2.51+/-0.02)*\log_{10}DIAM-(1.23+/-0.02)$	0.979, 0.95

Appendix 4- Coarse woody debris density, taken from Flemming (1996).

Table 1- Coarse-woody debris (CWD) disc weights and dimenstions, averaged by diameter class. The weight-to-volume ratios were used to convert CWD volume data of the vegetation quadrats to biomass (kg). CWD biomass was then expressed as tonned of carbon per hectare. Taken from Flemming, 1996.

	Diamter Class (m)	N	Average Diameter (m)	Average Volume (m^3)	Average Weight (kg)	Conversion Factor (weight/volume ratio)
Reference Stands	0.05-0.10	12	0.071	0.0002	0.0799	399.5
	0.10-0.15	10	0.116	0.0005	0.1846	369.2
	0.15-0.02	9	0.164	0.0011	0.3351	304.6
	0.20-0.25	14	0.223	0.0019	0.4847	255.1
	0.25-0.30	6	0.278	0.0024	0.8958	373.3
	0.30-0.35	7	0.323	0.0037	1.1778	318.3
	0.35-0.40	9	0.368	0.005	2.329	465.8
	0.40-0.45	3	0.417	0.0096	3.2806	341.7
					Average	**353.4**