Greenhouse Gas Emissions from Peat Extraction in Canada: A Life Cycle Perspective

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ABSTRACT

This study uses life cycle analysis to examine the net greenhouse gas (GHG) emissions from the activities of the peat industry in Canada for the period 1990 to 2000. GHG accounting is undertaken for (1) land use change, (2) peat extraction and processing, (3) the transport of peat to market by truck, train and ship, and (4) the *in situ* decomposition of extracted peat. The emission estimates were based on results from GHG accounting models using data derived from scientific literature, government and industry statistics, and the responses to a questionnaire sent to Canada's peat establishments. The questionnaire, designed to obtain information on peat extraction methods, land and fuel use, as well as the transportation of peat, had a response rate representing 69% of Canada's total peat production in the year 2000. Results indicate that 540 600 tonnes of greenhouse gases were emitted in 1990 and 893 300 tonnes were emitted in the year 2000 (emission figures are measured in CO_2 equivalents using a 100-year time horizon). Peat decomposition was by far the largest source of GHG emissions, averaging 70.6% of total emissions during the eleven-year period from 1990 to 2000. Greenhouse gases from land use change averaged 14.7%. An average of 10.4% of total emissions resulted from the transport of peat to market, while GHGs from extraction and processing averaged 4.3%. Predictions of the annual GHG emissions from the peat industry, assuming a "business as usual" context, were produced for the years 2001 to 2012. These figures were compared with those resulting from various greenhouse gas reduction scenarios.

RESUMÉ

Cette étude utilise l'analyse du cycle de vie pour étudier les émissions nettes de gaz à effet de serre (GES) résultant des activités de l'industrie de la tourbe au Canada entre 1990 et 2000. L'auteur comptabilise les émissions de GES résultant 1) du changement d'affectation des terres, 2) de l'extraction et de la transformation de la tourbe, 3) du transport de la tourbe jusqu'aux marchés d'écoulement par camion, train et bateau, et 4) de la décomposition *in situ* de la tourbe extraite. Les émissions estimatives reposent sur les résultats des modèles de comptabilisation des GES au moyen de données extraites de la documentation scientifique, des statistiques du gouvernement et du secteur privé et des réponses données à un questionnaire adressé aux établissements de tourbe du Canada. Ce questionnaire, dont le but était de recueillir des données sur les méthodes d'extraction de la tourbe, l'affectation des terres et la consommation de carburant, de même que sur le transport de la tourbe, a donné lieu à un taux de réponse qui représente 69 % de la production totale de tourbe du Canada en 2000. D'après les résultats, 540 600 tonnes de gaz à effet de serre ont été émis en 1990, et 893 300 en 2000 (les chiffres sur les émissions sont mesurés en équivalents CO_2 en utilisant un horizon temporel de 100 ans). La décomposition de la tourbe est de loin la plus importante source d'émission de GES, puisqu'elle représente en moyenne 70,6 % des émissions totales au cours des 11 ans qui se sont écoulés entre 1990 et 2000. Les émissions de gaz à effet de serre résultant du changement d'affectation des terres ont représenté en moyenne 14,7 %. En moyenne, 10,4 % des émissions globales sont attribuables au transport de la tourbe vers les marchés, alors que les GES émis par les activités d'extraction et de transformation se sont chiffrés en moyenne à 4,3 %. Les prévisions des émissions annuelles de GES de l'industrie de la tourbe, si l'on présuppose un scénario de « maintien du statu quo », ont été établies pour les années 2001 à 2012. Ces chiffres ont été comparés à ceux qui résultent de divers scénarios de réduction des gaz à effet de serre.

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CHAPTER ONE

INTRODUCTION

By clearing vegetation, draining peatlands and extracting peat, the peat industry has substantially altered the character of approximately 15 000 hectares of land in Canada. The appropriated substance, *Sphagnum* peat moss, prized for its porosity and its high water retention capacity, is processed, packaged, and shipped to markets within Canada and throughout the world. Although Canadian peat is destined for a wide variety of purposes, it is used most commonly in horticulture and gardening.

Canada, as the world's sixth largest peat industry, produced approximately 1.3 million tonnes of peat in the year 2000 (Statistics Canada 2001), and possesses the world's second largest peat resource, at 510 billion tonnes (Jasinski 2001). Global peat production was 28 million tonnes in 2000 (Jasinski 2001), with Canadian production responsible for approximately 5% of this amount. Similar to most economic activities, peat extraction has the potential to generate greenhouse gas (GHG) emissions that contribute to climate change.

Global climate change is an embodiment of the dubious distinction of human beings as the major agent of change on planet Earth. In order to address the impact of humans upon the climate, it has become increasingly necessary to account for GHG production, including the greenhouse gases generated by industries such as the peat extraction industry, that requires intensive land use and burns fossil fuels for some of its energy needs.

This study addresses GHG accounting at the scale of an industry. Accounting models are developed in order to estimate the annual net greenhouse gas emissions from peat extraction in Canada. This GHG contribution is composed of emissions from the disturbance of peatlands, the combustion of fossil fuels during the extraction, processing and transport of peat moss to market, and the decomposition of extracted peat. The results from this analysis will indicate the relative importance of each stage of the life cycle of peat extraction to the emission or uptake of greenhouse gases by the industry.

1.1 Objectives

The objectives of this study are to: (1) quantify the net annual greenhouse gas contribution of Canada's peat industry for the period 1990 to 2000; (2) compare the magnitudes of GHG emission from each of the four components of the life cycle of peat extraction (land use change, extraction and processing, transport of peat to market, and decomposition of the extracted peat); and (3) examine alternative scenarios by which the peat industry could reduce its overall greenhouse gas emissions.

1.2 Greenhouse Gas Accounting Framework

The boundaries of the GHG accounting framework used in this thesis are based upon the concept of life cycle assessment, and incorporates the greenhouse gases emitted from raw material acquisition through processing, transportation and use. The net greenhouse gases emitted through the disturbance and subsequent restoration of peatland ecosystems, the fossil fuels consumed during the extraction, processing and shipment of peat to market, and the change in the decomposition rate of the extracted peat over time, are included in the GHG accounting model for the life cycle of peat extraction (Figure 1-1). However, emissions originating upstream from peat extraction, including those associated with the production of fuel and electricity, the plastic packaging for the peat, the infrastructure and equipment used for extraction and processing, and the decomposition of non-peat waste, are beyond the scope of this study.

Separate methodologies are employed to calculate the GHG emissions generated during each stage of the life cycle of peat extraction, and vary with the type of data available. Throughout this study, it has been assumed that extracted peat has a 45% moisture content on a wet basis (Malkki and Frilander 1997; Nyronen and Oy 1996) and that half of the dry mass of peat consists of carbon (Mathur and Levesque 1980). The GHG emissions for each stage are expressed as tonnes of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), with CO_2 rounded to the nearest one hundred tonne, and both CH_4 and N_2O rounded to the nearest tenth of one tonne. Where specified, global warming potentials (GWP),[1] which estimate the relative potential of greenhouse gases to

[1] Over a 100-year time horizon, the GWP of CH_4 is 23, and the GWP of N_2O is 296 (in CO_2 equivalents) (IPCC 2001).

absorb infrared radiation in the atmosphere, are used to measure the total annual GHGs emitted in CO_2 equivalents through time. A 100-year time horizon is adopted to calculate GWP because this horizon is used for GHG accounting under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC 2001).

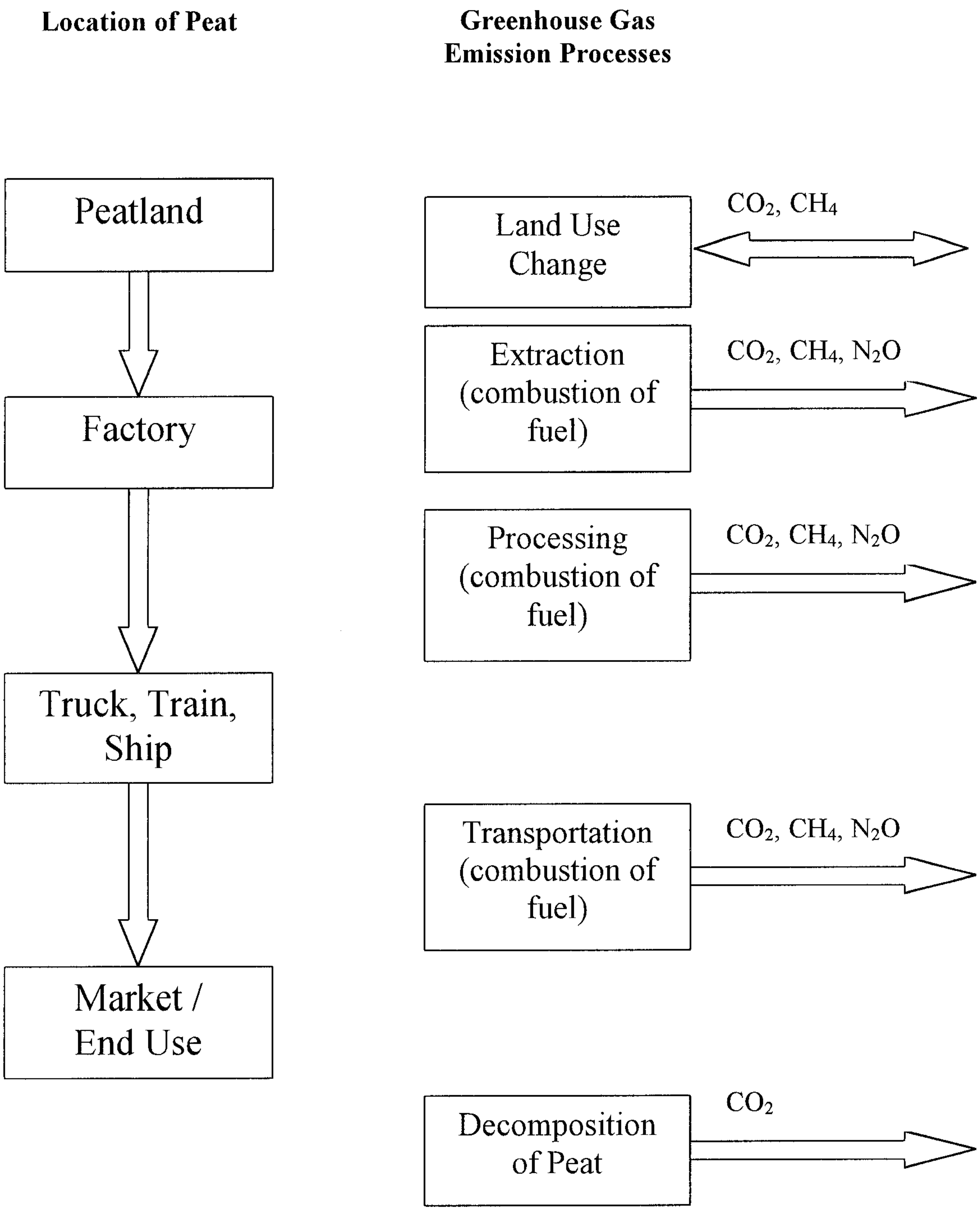

Figure 1-1. System Boundaries of the Greenhouse Gas Accounting Model for the Life Cycle of Peat Extraction in Canada

1.3 Sources of Information

Sources of information include scientific literature relating to GHG fluxes from undisturbed and cutover peatlands and on the decomposition rate of peat, as well as government and industry statistics on the extraction, transportation, processing and end uses of the product. The information gathered from responses to a questionnaire developed by the writer and sent to Canada's peat extraction establishments was also used in this study (*Appendix A: Questionnaire / Research Consent Form / Cover Letter; Appendix B: List of Peat Extraction Establishments Contacted [by Province]; Appendix C: Overview of Questionnaire Design and Results*).

1.4 Overview of Chapters

Chapter Two, entitled *Literature Review*, reviews the current state of knowledge on the contribution of the peat industry to greenhouse gas emissions. Much of the literature relevant to this study focuses on the definition of life cycle assessment methodology, the controls of carbon and methane fluxes in peatlands, and the restoration of harvested peatlands. Literature on the extraction, processing, and transport of peat, and on the decomposition rate of extracted material, is also examined. Little of the extant literature refers directly to the climate change implications of the activities of the peat industry.

The land use change component of this study (Chapter Three) addresses the GHG emissions from peatlands under extraction and restoration. The land use area data are derived from the responses received to the questionnaire sent to Canadian peat companies, and from a model designed by the author to estimate the area entering into production and taken out of production each year. The GHG fluxes (per unit area) that are deemed representative of each land use (undisturbed peatland, peatland under extraction, abandoned cutover peatland, and cutover peatland under restoration) are derived from published and unpublished data.

Chapter Four examines and accounts for the greenhouse gases emitted from the combustion of fuel during peat extraction and processing. The total GHG emissions from fuel use (not including transportation to market) are based upon annual Statistics Canada data on fuel consumption (by type of fuel) by Canada's peat industry for the period 1990 to 2000. The responses of the peat companies to the questionnaire are compared to the Statistics Canada data and provide an indication of the relationship between the amount of fuel used and the size of the peat extraction establishment.

Chapter Five, entitled *Transport of Peat to Market*, quantifies the use of fossil fuels to transport peat to market. The magnitude of greenhouse gas emissions from transportation varies with the distances between extraction sites and markets, as well as the mode of transport used. Peat export data from Statistics Canada and other data from the peat industry are used to quantify these GHG emissions. The methods used to calculate the median distances travelled by the extracted peat between the regions of extraction and consumption are described in *Appendix D: Transportation Distances*.

Chapter Six estimates the GHG emissions from the decomposition of peat after its extraction. It provides an overview of models that depict peat decomposition and reviews the scientific literature on the decomposition rates. A peat decomposition model appropriate for the conditions experienced by Canadian *Sphagnum* peat is applied to peat extraction data for the years 1941[2] to 2000 in order to estimate annual GHG emissions.

Chapters Three to Six each include a section entitled "Greenhouse Gas Reduction Scenarios" that proposes various measures that could be adopted in order to reduce GHG emissions from the peat industry, and explores the potential effectiveness of these measures.

Chapter Seven, entitled *Summary and Discussion*, estimates both the annual GHG emissions and the greenhouse gas intensity (GHGs emitted per unit of peat extracted) of the peat industry during the eleven-year period from 1990 to 2000. Future GHG emission scenarios for the peat industry are placed in the context of Canada's commitment under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), which calls for a 6% reduction of GHG emissions below 1990 levels by the commitment period between 2008 and 2012.

The *Conclusion* reviews the main findings of the thesis and suggests avenues of future research.

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[2] The year 1941 is used as the initial year of extraction because no more than a few thousand tonnes of peat per year were extracted in Canada before the 1940s (Warner and Buteau 2000; Swinnerton 1950). The Canadian peat industry grew rapidly during and after World War II due to the high demand for peat from the United States, a market that could not be satisfied by imports from Europe (Warner and Buteau 2000).

CHAPTER TWO

LITERATURE REVIEW

This study draws mainly from literature in the scientific and economic branches of geography. Most references in the literature relating to greenhouse gas emission from peat extraction focus on the subject of land use change, whereas there is a relative dearth of material relating to other aspects of the life cycle of extracted peat. Published literature that pertains to this study centers upon GHG accounting methodologies, the controls of carbon dioxide and methane fluxes in peatlands, the decomposition rate of peat, and GHG emissions resulting from fuel use. I am not aware of any published estimates of the greenhouse gas emissions of Canada's peat industry from a life cycle perspective.

2.1 Life Cycle Assessment

The life cycle of a product consists of raw material acquisition, manufacturing, use and disposition (Todd and Curran 1999; Graedel 1998; Curran and Young 1996). The methodology used to quantify the environmental impacts during a life cycle is known as a life cycle assessment (LCA), a process which "provides a framework, an approach, and methods for identifying and evaluating environmental burdens associated with the life cycles of materials and services, from cradle-to-grave" (Todd and Curran 1999). The emission of greenhouse gases due to human activity is commonly addressed in life cycle assessments.

While the initial development of life cycle assessment began as far back as the 1960s, interest in this topic within industry, government and academic circles became widespread only in the 1990s (Curran and Young 1996; Environment Canada 1995). The LCA has since become an important means of ensuring that actions taken to reduce environmental impacts at one stage of production do not result in upstream or downstream consequences which would produce a negative outcome overall (Brady 2000; Environment Canada 1995).

Greenhouse gas accounting from a life cycle perspective differs significantly from that articulated under the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. The latter method is not used for comparisons between industries or establishments since it addresses GHG emissions on the basis of national boundaries (Houghton *et al.* 1997).

Both the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI) (2001) have noted that there exists no generally accepted accounting and reporting practices for corporate greenhouse gas emissions. Consequently, these two organizations have proposed a corporate accounting and reporting standard that addresses the organizational and operational boundaries of the system of interest, the identification of direct and indirect GHG emissions, and the question of quality control (WBCSD and WRI 2001).

To date, Malkki and Frilander (1997) and Uppenberg *et al.* (2001), have produced the only published environmental life cycle assessments of the use of peat for energy production, with the latter study concentrating only on greenhouse gas emissions. Both studies estimated the net GHG emissions that would result from different peat extraction scenarios based upon peatland type and form of restoration (Uppenberg *et al.* 2001; Malkki and Frilander 1997).

Malkki and Frilander (1997) delineated peat utilization into eight stages: (1) peatland ditching; (2) peatland preparation and profiling; (3) peat production; (4) peat stockpiling (including the transportation of peat from fields to stockpiles); (5) peatland restoration; (6) energy peat combustion; (7) manufacture of auxiliaries; and (8) transportation. Much of this classification system cannot be used in the Canadian context, since Canadian peat is not used for energy production within Canada nor by any of the nations that import peat extracted in this country.

2.2 Land Use Change

Approximately one-quarter of the anthropogenic emissions of carbon dioxide to the atmosphere during the past 20 years has resulted from land use change, especially deforestation (IPCC 2001). In examining the published literature, little interest would seem to have been shown in the study of greenhouse gas emissions from peatlands prior to the 1990s. Peatland restoration only became a popular subject of research within the last twenty years (e.g., Lavoie and Rochefort 1996; Joosten 1995; Famous *et al.* 1991), along with the long-term impact of climate change on the carbon reservoir in peatlands (e.g., Kettles and Tarnocai 1999; Gorham 1991; Clymo 1984).

A number of scientific papers have examined the greenhouse gas emissions from the land use activities of the peat industry. Roulet (2000), by extrapolating values from previously published data, produced an estimate of the GHG emissions that resulted from land use changes in Canada's peatlands. Uppenberg *et al.* (2001), Crill *et al.* (2000), Malkki and Frilander (1997), and Rodhe and Svensson (1995) have produced GHG estimates of a similar nature for Sweden and Finland, also based upon a review of literature on this subject.

There is a consensus in the literature that a baseline level of GHG emissions from natural peatlands must be taken into account when producing an estimate of GHG emissions from land use activities by the peat industry (e.g., Schilstra 2001; Roulet 2000; Malkki and Frilander 1997). It is the change in emissions from this baseline level that represents the actual GHG emissions generated from land use activities (IPCC 2001). Unfortunately, baseline net GHG emission levels for peatlands have not yet been developed for land use change under the Kyoto Protocol.

Literature on Canada's peatlands concludes that more peat accumulates naturally than is currently extracted (Daigle and Gautreau-Daigle 2001). Schilstra (2001) does not believe that such an observation can be used to claim that a peat industry is sustainable. She argues that signatories of the United Nations Framework Convention on Climate Change (UNFCCC) should not be allowed to claim undisturbed peatlands as carbon sinks in order to offset the carbon removed through peat extraction because undisturbed peatlands are natural carbon sinks. According to Schilstra (2001), the claim of sustainability necessitates the resequestering of the extracted carbon by the same site that underwent extraction. Although there is agreement in the literature that a peat extraction site may eventually resequester carbon, the time period over which GHG neutrality is achieved is an issue that requires much further examination. This topic has been broached by Malkki and Frilander (1997), who estimated that it would take approximately 2000 years to resequester the amount of carbon dioxide emitted through peat extraction from one site.

2.3 Greenhouse Gas Emissions from Fuel Combustion

In their joint report on corporate GHG inventories, the World Business Council for Sustainable Development and the World Resources Institute (2001) state that it is rare for companies to take direct measurements of their GHG emissions. While this could be accomplished by monitoring exhaust gas concentration and flow rate, both the WBCSD and WRI (2001) observe that the most common method used to calculate greenhouse gas emissions has been to multiply published emissions factors by activity factors such as fuel use and vehicle distance travelled. Such a method is outlined in the IPCC Guidelines for National Greenhouse Gas Inventories, which was adopted by those countries that are signatories to the UNFCCC. This method of estimating domestic GHG emissions is based on the fuel supply multiplied by agreed emissions factors (IPCC 1997).

2.4 Peat Extraction and Processing

Scientific literature on the subject of peat extraction and processing is largely descriptive, with few studies exploring the magnitude of greenhouse gases released during the various stages of extraction and processing. Although the literature reflects the fact that the vacuum harvesting method of peat extraction is more common than the block cut method (e.g., Robert *et al.* 1999; Lavoie and Rochefort 1996), no sources discuss the reason why the block cut method has fallen out of favour with Canada's peat industry.

2.5 Transport of Peat to Market

Peat is transported to market by truck, rail and ship, with trucking being the most common method used. Numerous studies have highlighted the sensitivity of the price of peat to transport cost (e.g., Atlantic Provinces Transportation Commission 1992; Physical Distribution Advisory Service 1984). In light of this price sensitivity, much market-oriented research has been undertaken to explore the transportation needs of the peat industry in Canada, often focusing on the province of New Brunswick. This research provides insight into the economic and logistical issues relating to peat transportation that peat companies need to address in order to maintain or increase profits. Several studies allude to the influence of transport cost on the chosen location of peat extraction sites. None of the studies, however, including those by the Atlantic Provinces Transportation Commission (1992), Three-D Geoconsultants (1992), Physical Distribution Advisory Service (1984) and Gagnon *et al.* (1980), address environmental concerns and greenhouse gas emissions.

The WBCSD and WRI (2001) have identified both a fuel-based and a distance-based approach in order to calculate GHG emissions from transportation. The former approach requires aggregated fuel consumption data, which are then multiplied by a GHG emission factor. The latter approach, based upon distance travelled, is necessary if fuel consumption data are not available, although this method introduces a considerably higher level of uncertainty (WBCSD and WRI 2001). For the transportation of freight, fuel consumption statistics, derived emissions factors and commodity origin/destination surveys have all been used to calculate GHG emissions for Canada's transportation sector (Transportation Table: National Climate Change Process 1998).

As already noted, greenhouse gas accounting for transportation using the LCA methodology differs significantly from accounting under the IPCC framework. The IPCC framework excludes the GHG emissions associated with international marine and air transport for national emission totals, although these emissions are reported separately for information purposes (Olsen *et al.* 2002; IPCC 1997).

2.6 Decomposition of Extracted Peat

Life cycle assessments should include the environmental ramifications of the disposal of the product under study (Graedel 1998; Curran and Young 1996). Both Roulet (2000) and Malkki and Frilander (1997) have stressed the importance of including the decomposition of extracted peat when calculating the net GHG emissions from the peat industry. In a similar vein, some greenhouse gas accounting studies from the forestry sector have also attempted to take into account the GHGs emitted from the decomposition of wood products (e.g., Brown *et al.* 1999; Heath *et al.* 1996). In the LCA of peat extraction in Finland by Malkki and Frilander (1997), all the peat studied was used as a fuel for energy production. Thus, the decomposition of extracted peat was assumed to be 100% at the time of combustion. This is not the case for Canadian peat, as none is used for fuel.

To quantify the rate of carbon dioxide emission to the atmosphere resulting from peat extraction, one is required to know the decomposition rate of extracted peat, which in turn, depends on its end use. In this regard, there seems to be a consensus in the literature that the rate of peat decomposition is dependent upon water and oxygen availability, temperature, and the proportion of lignin in the peat (e.g., Mathur and Lévesque 1980). Although there are numerous examples of laboratory and field studies of peat decomposition, very few of them possess long-term decomposition values.

CHAPTER THREE

LAND USE CHANGE

Northern peatlands have accumulated peat over thousands of years, naturally taking up atmospheric carbon through photosynthesis and emitting greenhouse gases from peat decomposition (Whiting and Chanton 2001; Crill *et al.* 2000; Gorham 1991; Clymo 1984). Peat extraction disturbs the natural process of peat accumulation and alters the net greenhouse gas emissions from peatlands, tending to increase emissions of carbon dioxide (CO_2) and reduce emissions of methane (CH_4) (Roulet 2000; Sundh *et al.* 2000). The primary objective of this chapter is to estimate the potential change in net greenhouse gas emissions from those peatlands in Canada that have been extracted by the peat industry. This cannot be accomplished by direct measurement. It requires the application of knowledge of peatland carbon dynamics to the past, present and future conditions of peatland ecosystems affected by peat extraction. Land use and GHG flux data from undisturbed peatlands, peatlands under extraction, as well as those cutover peatlands both abandoned and under restoration, were used to estimate net greenhouse gas emissions.

3.1 Site Selection and Preparation for Extraction

Those peatlands that have an average minimum depth of two metres of commercially extractable peat are generally deemed suitable for extraction (Daigle and Gautreau-Daigle 2001). Nilsson *et al.* (1990) observed that it is common to leave the bottom one metre of a peat deposit intact in order to protect the extraction equipment from potential damage due to the prevalence of an irregularly formed mineral substrate.

To prepare a peatland for extraction, the selected bog must be drained, cleared of vegetation and levelled (Daigle and Gautreau-Daigle 2001; Robert *et al.* 1999; Lavoie and Rochefort 1996; Gottlich *et al.* 1993; Aiken *et al.* 1983). It is common for a drainage ditch to be dug around the perimeter of the selected site. This perimeter ditch then connects to a settling pond downstream from the bog (Committee of Peat Producers of the Acadian Peninsula 2001). The drainage of the site facilitates peat extraction by reducing the moisture content of the *in situ* peat (Schouwenaars 1995). This phase takes from one to six years, depending on the spacing and depth of the drainage ditches (Uppenberg *et al.* 2001; Malkki and Frilander 1997). The vegetation, consisting of trees, shrubs and living moss, is removed during this period.

The preparation of a peatland for extraction alters greenhouse gas emissions in two ways. First, the drainage of the site increases the decomposition rate of the *in situ* peat, since decomposition becomes less limited by oxygen, which was scarce before the site was drained (Waddington *et al.* 2002; Sundh *et al.* 2000; Martikainen 1996). The greater oxygen availability increases carbon dioxide emissions and reduces methane emissions. Second, by removing the living biomass from the peatland surface, the gross ecosystem production falls to zero (Waddington and Warner 2001; Aiken *et al.* 1983).

3.2 Methods of Peat Extraction and Change in Use over Time

Historically, there have been two main methods of peat extraction in Canada: (1) vacuum; and (2) block cut (Washburn & Gillis Associates Ltd. 1982; Swinnerton 1950). Other methods, such as mechanical dredging (the hydraulic method), never entered into widespread use in Canada (Swinnerton 1950). Swinnerton (1950), in his overview of Canada's peat extraction industry, observed that the usual method of peat extraction at the time was the block cut method and cited only one operation in Canada that used a hydraulic method. He also noted that one peat operation in British Columbia designed and operated a machine that vacuumed the peat from the surface and delivered it into paper bags.

The proportion of peat production that was block cut by hand or with machines was reduced greatly, beginning in the early 1960s (G. Hood, pers. comm., 2003 01 10). In general, the block cut method has been largely abandoned due to its higher labour costs than the vacuum method (G. Hood, pers. comm., 2003 01 10). This was the case, even though block cutting produced higher yields per unit area (Aiken *et al.* 1983). I have estimated that peat extraction by the vacuum method was negligible before 1960, but was used to extract 60% of Canadian peat in 1970, 90% in 1980, 95% in 1990 and 97.1% in 2000. These estimates are based upon the results from the questionnaire (*Appendix C: Overview of Questionnaire Design and Results* - Table A3) as well as consultation with a representative of the Canadian peat industry (G. Hood, pers. comm., 2003 01 10). Figure 3-1 applies these percentages to the annual peat extraction totals (Statistics Canada / Dominion Bureau of Statistics 2000-2002; 1996-1999; 1980-1991; 1942-1979; Energy, Mines and Resources Canada / Natural Resources Canada 1992-1996) to illustrate the shift in extraction methods used by the peat industry.

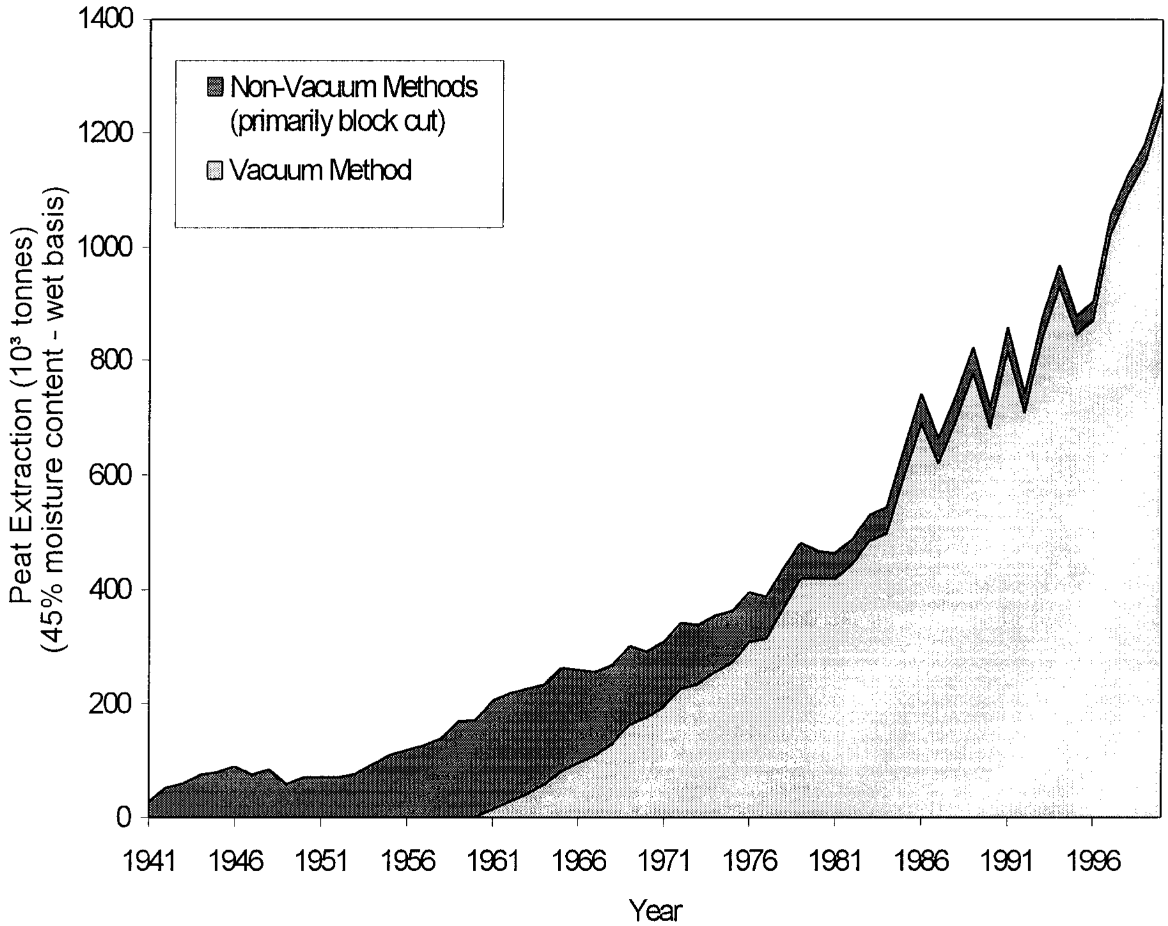

Figure 3-1. Annual Non-Fuel Peat Extraction and Extraction Method, 1941-2000

As referred to earlier, the popularity of the vacuum method of peat extraction in Canada may be explained by the lower cost of extraction when compared to that of the block cut method (G. Hood, pers. comm., 2002 09 13). Of equal importance is the fact that there is greater market demand for low cost peat of lesser quality (characteristic of the vacuum method of extraction) than for more expensive peat with longer fibres, generally produced through the block cut method (G. Hood, pers. comm., 2002 09 13).

3.2.1 Vacuum Method

The vacuum method of peat extraction is a two-fold operation that includes the milling of the peatland surface and the vacuuming of the milled peat. The milling of the uppermost one to two centimeter thick layer of peat breaks capillary flow within this layer (Daigle and Gautreau-Daigle 2001), allows the peat to dry to a 35-55% moisture content (wet basis) and facilitates its vacuuming (Malkki and Frilander 1997; Nyronen and Oy 1996). This milled peat is then collected by mobile vacuum harvesters, stockpiled and transported to a factory where it is screened and packaged (Daigle and Gautreau-Daigle 2001). This process may be repeated between 12 and 25 times during the extraction season (summer), depending upon the season's length and the weather (Nyronen and Oy 1996). Unlike the block cut method, the vacuum method is very weather dependent since vacuum harvesting machines are unable to remove milled peat under very wet conditions. The responses to the questionnaire show that the average annual yield of peat from vacuum harvested sites in Canada was 100 t/ha, assuming a 45% moisture content - wet basis (*Appendix C: Overview of Questionnaire Design and Results*).

3.2.2 Block Cut Method

The block cut method of peat extraction is distinguished by the use of a cutting disk or digging machine (Nyronen and Oy 1996). Each year, sods of peat are extracted from trenches with dimensions of one metre width by one metre depth that are spaced approximately five metres apart (R. Mecking, pers. comm., 2003 01 17). The extracted sods are left on the field to dry and later collected (Malkki and Frilander 1997). Over time, the entire upper layer of the peatland may be extracted, revealing another layer in which new trenches may be dug and additional sods removed.

3.3 Restoration of Cutover (Post-Extraction) Peatlands

Once peat companies no longer find it economically profitable to continue extracting peat at a particular site, the cutover site may be abandoned, restored back to a peatland, or converted to other land uses such as forestry or agriculture. The objective of peatland restoration is to restore the botanical composition of the surface, as well as to return the cutover peatland to a state of peat accumulation once again.

The restoration of cutover peatlands is usually accomplished by the raising of the water table, the seeding of the surface with moss fragments and other plants, and the addition of a surface cover, such as straw (Quinty and Rochefort 1997). The water table is raised by blocking the drainage ditches or by filling them though peat slumping (Waddington and Warner 2001). The purpose of this action is to increase the availability of water at the surface, necessary for *Sphagnum* growth, and suppress the aerobic decomposition of the *in situ* peat. The added surface cover conserves soil moisture and protects the vulnerable plants from the elements (Quinty and Rochefort 1997). The moss fragments are commonly obtained from the surface cover removed from peatlands entering into production (Committee of Peat Producers of the Acadian Peninsula 2001).

Cutover peatlands lack vegetation and have substantially altered hydrological and thermal conditions that have proven to be significant impediments to restoration. The peat remaining in these sites is highly decomposed, has smaller pores, a low hydraulic conductivity, high seepage losses and a lower specific yield (Price 1996). These characteristics produce increased fluctuations in the level of the water table (Waddington *et al.* 2002) and result in a surface that is prone to drought even after the drainage ditches are filled in (Money 1995). Unfortunately, the regrowth of *Sphagnum* can be limited by periodic desiccation (Money 1995). Substantial variations in soil temperature are another concern. Price (1996) contended that average soil temperature gradients are greater in cutover peatlands than in undisturbed ones, and Waddington *et al.* (2002) observed that the average range of summer temperatures was lower in cutover peatlands than in natural sites.

The growth of the vegetation community on the surface of a cutover peatland affects peat decomposition through the roots of vascular plants, such as cotton grasses (*Eriophorum vaginatum*), that transport methane past the oxidation zone by molecular diffusion and pressurized ventilation (Martikainen 1996; Bubier and Moore 1994). The root systems of these first generation plants also transport oxygen into the soil and release exudates that create a high microbial oxygen consumption within the root vicinity (Segers 1998). These roots tend to cause higher methane emissions overall (Segers 1998).

However, these methane emissions fall as the cotton grass is replaced with *Sphagnum* moss.

Several studies have shown that the restoration of vacuum harvested sites tends to take longer than that of block cut ones (Bérubé and Lavoie 2000; Lavoie and Rochefort 1996; Rochefort *et al.* 1995). Peatlands extracted by using the vacuum method have a level surface that lack *Sphagnum* diaspores (Robert *et al.* 1999; Rochefort *et al.* 1995). Block cut sites consist of mined trenches separated by ridges and are often left with some intact surface vegetation, which is more advantageous for the reestablishment of *Sphagnum* moss (Charman 2002; Robert *et al.* 1999). A greater number of nearby seed banks also contributes to the speed of restoration of block cut sites.

3.4 Categories of Land Affected by the Peat Industry

For this study, the general characteristics of the various peatland types have been defined as follows:

- Undisturbed peatland: naturally high water table and full vegetation cover;
- Peatland under extraction: low water table, no vegetation cover; with peat near the surface having a higher degree of decomposition than that in undisturbed sites;
- Abandoned cutover peatland: low water table and little or no vegetation cover;
- Cutover peatland under restoration: artificially high water table, increasing vegetation cover; addition of mulch (e.g., straw) to the surface.

The area of peatlands removed from production may not be equivalent to the area requiring restoration, since peatlands adjacent to those under production may also be disturbed. Although not addressed in the final GHG estimates for land use change, the drainage of peatlands for extraction purposes may inadvertently affect the greenhouse gas emissions of adjacent peatlands by lowering their water tables as well. Studies have shown that the moss on the surface of those pristine areas adjacent both to peatlands under extraction and to cutover sites, tends to become more prone to desiccation, while the decomposition rate of the peat substrate increases (Rodhe and Svensson 1995; Nyström 1992). Moreover, the growth of shrubs and other woody vegetation is no longer suppressed by the high water table. Rodhe and Svensson (1995) included the effect of drainage on adjacent areas for their estimate of GHG emissions from peat extraction, but assumed that it only increased the rate of peat decomposition. Nyström (1992), on the other hand, also looked at its positive effect on the growth of vegetation and estimated that the adjacent area affected may vary from 50% to 130% of the area under extraction.

Figure 3-2 illustrates the vertical profiles of undisturbed peatlands, as well as those affected by peat extraction, and the direction of GHG fluxes for each. The existence of surface vegetation is required for carbon sequestration. As is evident in the illustration, the height of the peatland under restoration is not equivalent to that of the undisturbed peatland. The peatland under restoration also has less peat available to decompose, and, other things being equal, should therefore produce lower levels of net GHG emissions.

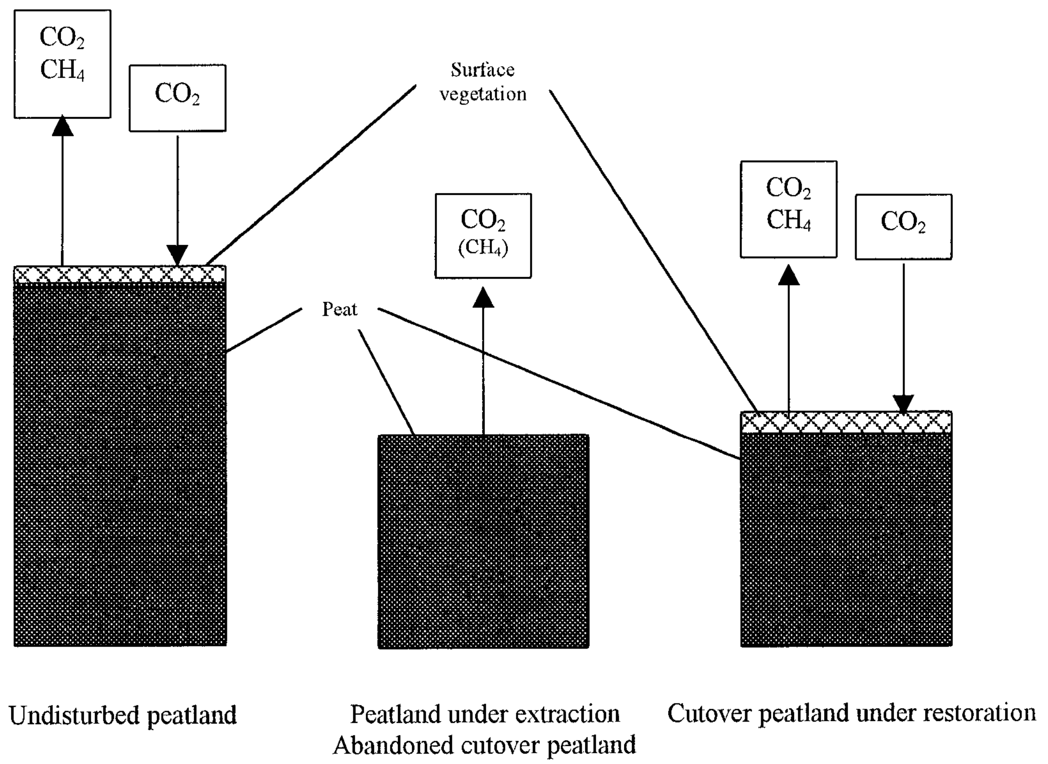

Figure 3-2. Vertical Profile of Peatland Types and the Direction of Greenhouse Gas Fluxes for Each Type. [Note: Methane (CH_4) emissions from peatlands under extraction or from abandoned peatlands may be present, but are of a very small magnitude].

3.5 Methodology of GHG Accounting for Land Use Change

In order to estimate the change in net greenhouse gas emissions from land use change by the peat industry in Canada, the following steps were taken:

- the areas of land affected by the peat industry were identified; and

- an average annual GHG flux per unit area was assigned to each category of land (including undisturbed peatlands), based upon estimates in the scientific literature, as well as unpublished data.

The following equation was then used to estimate the net GHG emissions from land use change:

Equation 3-1

$$GHG_{LUC} = A_{PUE} * F_{PUE} + A_{ACP} * F_{ACP} + A_{CPR} * F_{CPR} - (A_{PUE} + A_{ACP} + A_{CPR}) * F_{UDP}$$

where A_{PUE} represents the area of peatland under extraction; A_{ACP} signifies the area of abandoned cutover peatland; and A_{CPR} represents the area of cutover peatland under restoration. F_{PUE} represents the average annual per unit area GHG flux of peatland under extraction; F_{ACP} represents that of an abandoned cutover peatland; F_{CPR} signifies the GHG fluxes from a cutover peatland under restoration and F_{UDP} represents the average annual GHG flux per unit area of an undisturbed peatland.

Few studies have provided flux values for nitrous oxide emissions from peatlands (Crill *et al.* 2000; Martikainen 1996). The emissions from undisturbed peatlands are very low, with some sites known to consume the gas. The drainage of peatlands tends to increase nitrous oxide emissions, although this increase seems to take place in nutrient rich fens more than in ombrotrophic bogs (Martikainen 1996). Other studies have discounted the importance of nitrous oxide emissions from peatlands under extraction (Malkki and Frilander 1997; Rodhe and Svensson 1995).

3.6 Area Subject to Land Use by the Peat Industry

Canadian peatlands comprise a total area of approximately 123 million hectares, storing an estimated 155 Gt C[1] (Kettles and Tarnocai 1999). The current area of peatlands under extraction, 12 500 hectares (G. Hood, pers. comm., 2001 10 18), is a tiny fraction of this total (0.01%). Land use area data is derived from responses to the questionnaire sent to Canadian peat companies, from estimates made by the Canadian

[1] 1 Gt C = 10^9 tonnes of carbon

Sphagnum Peat Moss Association (CSPMA), and from a model designed to estimate the peatland area that enters into production and is removed from production each year.

3.6.1 Land Use Results from Questionnaire

Table 3-1 shows estimates of the land use of Canada's peat industry in the year 2000, extrapolated from the responses to the questionnaire (See also *Appendix C: Overview of Questionnaire Design and Results* – Table A2). These estimates were generated by dividing the land use area data by the fraction of Canadian peat extraction represented by the responses to the questionnaire (0.69). Greater than 99% of the peatland holdings harvested in the past were located in the holdings of peat establishments that used the vacuum method of peat extraction.

Table 3-1. Types of Land Use by Canada's Peat Industry in the Year 2000

Land Use	Estimates extrapolated from questionnaire responses
	hectares
Total peatland holdings†	79 577
Peatland holdings under extraction	13 096
Peatland holdings harvested in the past (Cutover peatlands)	1 272
Peatland holdings never harvested (Undisturbed peatlands)	65 210
Peatland holdings under natural restoration (Cutover abandoned peatlands)	975
Peatland holdings under active restoration (Cutover peatlands under restoration)	296

† Peatland holdings is the total area of peatland in Canada that peat companies are currently entitled to harvest.

G. Hood of the CSPMA (pers. comm., 2001 10 18) estimated that there were 8 300 hectares of peatland under extraction in the year 1990, increasing to 12 500 hectares in the year 2000. Although Daigle and Gautreau-Daigle (2001) have estimated that less than 17 000 hectares of land are currently under extraction in Canada, the results from the questionnaire (13 096 hectares – Table 3-1) would seem to substantiate the lower estimate of 12 500 hectares given by the CSPMA.

3.6.2 Model of Area of Land Used by the Peat Industry from 1941 to 2000

The land use figures obtained from the questionnaire and from the CSPMA were insufficient to generate estimates of the annual GHG fluxes from peatlands both currently and formerly under extraction, nor were they able to provide insight into the future land use patterns of the peat industry. A model defined by equations 3-2 to 3-7 was designed to address this gap in information. The model uses non-fuel peat extraction statistics for the years 1941 to 2000, derived from reports on the peat and non-metal mining industries by Statistics Canada / Dominion Bureau of Statistics (2000-2002; 1996-1999; 1980-1991; 1942-1979) and Energy, Mines and Resources Canada / Natural Resources Canada (1992-1996). Little peat was extracted before the 1940s, amounting to only a few thousand tonnes per year (Daigle and Gautreau-Daigle 2001; Swinnerton 1950). Since there is a substantial contrast in the annual yields of peat per hectare using the vacuum versus non-vacuum methods, it was deemed necessary to differentiate the land use calculations between these two categories of extraction. The proportions of annual peat production resulting from the vacuum and non-vacuum methods of extraction, shown in Figure 3-1, were used in the land use model.

The following equation (3-2) was used to estimate the area extracted via the vacuum method:

Equation 3-2

$$VPUE_{yr} = VExt_{yr} / Y_V$$

where $VPUE_{yr}$ represents the vacuum harvested peatlands under extraction in a given year (hectares); $VExt_{yr}$ represents the peat extracted by the vacuum method in a given year (tonnes); and Y_V represents the average annual yield of peatlands under extraction per hectare by the vacuum method (100 tonnes of peat per hectare).[2]

Equations 3-3 and 3-4 were used to estimate the area entering into production and the area removed from production, on an annual basis:

[2] The responses to the questionnaire indicate that an average of 100 tonnes of peat was extracted per hectare in the year 2000 by using the vacuum method (peat is assumed to have a 45% moisture content - wet basis).

Equation 3-3

$$VPEP_{yr} = \begin{cases} (VPUE_{yr} - VPUE_{yr-1} + VPRP_{yr}), \\ (VPUE_{yr} - VPUE_{yr-1} + VPRP_{yr}) <= 0 \\ 0, (VPUE_{yr} - VPUE_{yr-1} + VPRP_{yr}) > 0 \end{cases}$$

Equation 3-4

$$VPRP_{yr} = \sum_{t=yr-50}^{yr-20} VPEP_t / 31$$

where $VPEP_{yr}$ represents the vacuum harvested peatlands entering into production in a given year (hectares) and $VPRP_{yr}$ represents those removed from production (hectares).

Equation 3-3 indicates that the area entering into production in a given year is equal to the increase in peatlands under extraction over the previous year added to the peatlands removed from production. It is assumed that, once entering into production, peatlands under extraction cannot be removed from production until all of the commercial peat is extracted.

Equation 3-4 calculates the annual amount of peatlands removed from production and assumes that vacuum harvested peatlands under extraction have a life span of between 20 and 50 years (35-year average life span). This assumption is consistent with Nyronen and Oy's (1996) observations and is confirmed by the CSPMA (G. Hood, pers. comm., 2003 01 08). Therefore, with an average annual yield of 100 tonnes of peat per hectare over 35 years, 3 500 tonnes of peat would be extracted from one hectare of the average peatland. According to the Peat Decomposition Model by Frolking *et al.* (2001), a one-hectare bog with a depth of approximately 2.3 metres contains 3 500 tonnes of peat.

Equations 3-5, 3-6 and 3-7 were used to produce estimates of the area of non-vacuum harvested peatlands under extraction, entering into production and removed from production:

Equation 3-5

$$NVPUE_{yr} = NVExt_{yr} / Y_{NV}$$

Equation 3-6

$$NVPEP_{yr} = \begin{cases} (NVPUE_{yr} - NVPUE_{yr-1} + NVPRP_{yr}), \\ (NVPUE_{yr} - NVPUE_{yr-1} + NVPRP_{yr}) <= 0 \\ 0, (NVPUE_{yr} - NVPUE_{yr-1} + NVPRP_{yr}) > 0 \end{cases}$$

Equation 3-7

$$NVPRP_{yr} = NVPEP_{yr-2}$$

where $NVPUE_{yr}$ represents the non-vacuum harvested peatlands under extraction in a given year (hectares); $NVExt_{yr}$ represents non-vacuum harvested peat extraction in a given year (tonnes); Y_{NV} represents the average annual yield of peatlands under extraction per hectare by non-vacuum methods (1 750 tonnes of peat per hectare: 45% moisture content – wet basis); $NVPEP_{yr}$ represents the non-vacuum harvested peatlands entering into production in a given year (hectares); $NVPRP_{yr}$ represents the non-vacuum harvested peatlands removed from production in a given year (hectares) and $NVPEP_{yr-2}$ represents the non-vacuum harvested peatlands removed from production in year $_{yr-2}$ (hectares). It is assumed that the vast majority of peatlands that were not extracted by the vacuum method used the block cut method.

In order to estimate the area of non-vacuum harvested peatlands entering into production, Equation 3-5 assumes that the non-vacuum methods of extraction have an annual yield of 1 750 tonnes of peat per hectare (962.5 t/ha of dry peat), or 17.5 times that of the vacuum method. Assuming a mean dry peat bulk density of 0.11 t/m^3 (Lévesque and Mathur 1979), the annual yield of block cut sites results in a trench 0.88 m^2 in cross-sectional area. The annual yield of 1 750 tonnes of peat per hectare is in close agreement with the observations of the block cut peat extraction company, Heveco Ltd. This company states that approximately 3 feet (0.914 metres in depth) of peat is extracted from a three foot wide trench in a block cut site each year ("Heco Quality Growing Media" pamphlet), resulting in a trench with a cross sectional area of 0.84 m^2.

Equation 3-6 duplicates Equation 3-3 except that the figures representing non-vacuum methods of extraction are used in place of those representing the vacuum method of extraction. Equation 3-7 shows that the non-vacuum harvested peatlands removed from production are equal to those that entered into production two years previously.

The estimates of non-vacuum harvested (primarily block cut) peatlands entering into production and removed from production possess significant uncertainty. Some of this uncertainty derives from the fact that many block cut sites were converted to the vacuum method of extraction in the 1960s (R. Mecking, pers. comm., 2003 01 17). In addition, it is characteristic of the block cut method to shift production to another location before all of the peat remaining in the area under extraction is removed (G. Hood, pers. comm., 2003 01 10). The time taken until the lower layers of peat are block cut is dependent on the size of the site. This erratic extraction pattern creates difficulties in the production of accurate estimates of the dates in which block cut sites are removed from production. The estimate of two years for an area to be removed from production is based on the assumption that one 1.15 metre deep harvest occurs each year from one trench. Therefore, two years may be considered the minimum length of time required for a site to be removed from production.

Although the report of Swinnerton (1950) does not provide the total land use figures for peat extraction in Canada, it would seem to indicate that the land use model used in this study significantly underestimates the area of peatland under extraction in the 1940s.[3] This is to be expected since the areas adjacent to those under extraction are not included in the estimates generated by Equation 3-5, even though they might have been under extraction in a previous year and could still be again. Block cut sites, for example, are often perceived as including both the trenches and the adjacent ridges or baulks.

For the years 1941 to 2000, the model, based upon equations 3-2 to 3-7, calculates that a total of 15 164 hectares of peatlands are or have been under production and 2 743 hectares have been removed from production (1 250 ha vacuum harvested and 1 493 ha non-vacuum harvested). The modelled estimate of the area under extraction in the year 2000 (12 421 ha) is similar to that of the CSPMA (12 500 ha) (G. Hood, pers. comm., 2001 10 18) and to the estimate extrapolated from responses to the questionnaire (13 096 ha) (Table 3-1). The modelled estimate of the total area of vacuum harvested peatlands removed from production by the year 2000 (1 250 ha) is consistent with the findings extrapolated from the responses to the questionnaire (1 272 ha). The results from the model for the years 1990 to 2000 are shown in Tables 3-2 and 3-3.

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[3] Swinnerton's (1950) report provides the areas of several peat bogs under extraction in the 1940s.

Table 3-2. Modelled Data of Peatland Area under Extraction, Entering into Production, and Removed from Production, 1990-2000

Year	Area under Extraction	Area Entering into Production	Area Removed from Production
		Hectares	
1990	6 820	11	72
1991	8 177	1 432	74
1992	7 080	7	83
1993	8 366	1 377	90
1994	9 294	1 017	89
1995	8 443	14	105
1996	8 692	356	107
1997	10 189	1 612	115
1998	10 898	834	125
1999	11 454	707	151
2000	12 421	1 109	143

Table 3-3. Modelled Data of Peatlands Harvested in the Past by Vacuum and Non-Vacuum Methods, 1990-2000

Year	Total Cutover Peatland (Vacuum Method)	Total Cutover Peatland (Non-Vacuum Methods)	Total Area Harvested in the Past
		Hectares	
1990	283	1 378	1 660
1991	345	1 390	1 735
1992	418	1 400	1 818
1993	492	1 416	1 908
1994	574	1 422	1 997
1995	662	1 440	2 102
1996	761	1 448	2 209
1997	862	1 462	2 324
1998	980	1 469	2 449
1999	1 115	1 486	2 600
2000	1 250	1 493	2 743

Table 3-4 shows estimates of the total vacuum harvested cutover peatland, both abandoned and under restoration. The estimates of these cutover peatlands under restoration between 1990 and 2000 are based upon the land use data obtained from the responses to the questionnaire (see Table 3-1), and information provided by G. Hood of the Canadian Sphagnum Peat Moss Association (pers. comm., 2003 03 17).[4] In Table 3-4, the total abandoned cutover peatland is equal to the total cutover peatland area

[4] G. Hood suggested that 100 hectares of cutover peatlands were restored in 1999, with another 200 hectares in 2000.

(vacuum method) displayed in Table 3-3 minus the total cutover peatland under restoration.

Table 3-4. Estimated Area of Cutover Vacuum Harvested Peatlands, Abandoned and Under Restoration in Canada, 1990-2000

Year	Total Abandoned Cutover Peatland (Vacuum Method)	Total Cutover Peatland Under Restoration (Vacuum Method)
	hectares	
1990	283	0
1991	345	0
1992	418	0
1993	492	0
1994	574	0
1995	662	0
1996	761	0
1997	862	0
1998	980	0
1999	1 015	100
2000	950	300

3.7 Greenhouse Gas Fluxes Per Unit Area

A baseline level of greenhouse gas emissions from undisturbed peatlands must be determined in order to estimate the change in GHG emissions attributable to land use. The net greenhouse gas emissions from undisturbed peatlands vary with their specific biogeochemical, hydrological and climatological conditions. Some peatlands are net sources of carbon while others are net carbon sinks (Belyea and Clymo 2001). A baseline level of net GHG emissions may be based on short or long-term estimates in the scientific literature or could be estimated by measuring the net GHG emissions from each site before it undergoes extraction. The latter method is not appropriate for the provision of long term rates of peat accumulation in undisturbed peatlands.

Gorham's (1991) carbon accumulation rate of 23 g C/m^2/yr, was used to represent undisturbed peatlands in Canada suitable for peat extraction. Gorham (1991) has estimated an annual emission of 5.3 g CH_4/m^2/yr (4 g of C) from northern peatlands with 99 g CO_2/m^2/yr (27 g of C) removed from the atmosphere. These estimates fall within the range of temperate and boreal peatland carbon accumulation rates of 20 to 50 g C/m^2/yr suggested by Moore (2001) and 10 to 35 grams suggested by Ovenden (1990).

Gorham's (1991) carbon dioxide uptake estimate is substantially higher than in some studies while the methane estimate is lower. For undisturbed bogs in Sweden, Uppenberg *et al.* (2001) estimated that 58 g $CO_2/m^2/yr$ is removed from the atmosphere and 21 g $CH_4/m^2/yr$ is emitted. For undisturbed bogs in Finland, Malkki and Frilander (1997) estimated that 73 g $CO_2/m^2/yr$ is removed from the atmosphere and 9.3 g $CH_4/m^2/yr$ emitted to it.

Net CO_2 and CH_4 fluxes from bogs affected by peat extraction were measured in Rivière-du-Loup (Québec) in 1999 and 2000 and Shippagan (New Brunswick) in 2001 (Moore *et al.*, unpublished data). As one of very few projects concerned with the measurement of GHG fluxes from harvested and restored peatland sites, it is assumed to be representative of the fluxes from peatlands under extraction and restoration throughout Canada, though this assumption needs to be tested. The cutover peatlands in Rivière-du-Loup began to be restored immediately after extraction was completed, whereas those in Shippagan were abandoned for 11 years before restoration was undertaken.

Table 3-5 displays the data collected from the sites in Rivière-du-Loup (Québec) and Shippagan (New Brunswick), obtained by an identical methodology and the same equipment. The figures in Table 3-6 were derived by taking the mean of the CO_2 and CH_4 data for each type of site.

Table 3-5. Estimated May to October Emissions of CO_2 and CH_4 from Sites in Rivière-du-Loup, Québec (1999 and 2000) and Shippagan, New Brunswick (2001)†

Site	Rivière du Loup		Shippagan	
	CO_2 flux	CH_4 flux	CO_2 flux	CH_4 flux
	g/m²			
Peatland Under Extraction	733	0.9	990	2.1
Cutover Peatland Under Restoration (<2 years)	917 - 1 833	3.6	843	0.4
Cutover Peatland Under Restoration (2-4 years)	1 100 - 1 833	1.9	220 - 733	0.8 - 4.1
Abandoned Cutover Peatland (Vacuum Method) (25-30 years)	1283	2.1	587	0.7

† Source: Moore *et al.*, unpublished data

Table 3-6. Mean CO_2 and CH_4 Fluxes for the Season

Site	Mean CO_2 flux	Mean CH_4 flux
	g/m²	
Peatland Under Extraction	862	1.5
Cutover Peatland Under Restoration (<2 years)	1 109	2.0
Cutover Peatland Under Restoration (2-4 years)	972	2.2
Abandoned Cutover Peatland (Vacuum Method) (25-30 years)	935	1.4

Annual flux estimates need to be produced since the length of the season over which the measurements took place represented approximately 45% of the year (May-October). Snow cover and reduced temperatures in winter decrease microbial activity in soils (Mast *et al.* 1998; Oechel *et al.* 1997). Fluxes of methane in the winter have been observed to vary from 4% to 43% of the annual flux measurements (Dise 1992; Whalen and Reeburgh 1988). Mast *et al.* (1998) observed that average winter carbon dioxide fluxes varied from 8% to 23% of the gross annual fluxes from a subalpine wetland. For this study, winter flux measurements for both CO_2 and CH_4 were assumed to be 15.5% of the annual emissions. Table 3-7 shows the results from applying these assumptions to the GHG flux numbers.

Table 3-7. Mean CO_2 and CH_4 Fluxes for the Year

Site	Mean CO_2 flux	Mean CH_4 flux
	g/m²	
Peatland Under Extraction	1 020	1.8
Cutover Peatland Under Restoration (<2 years)	1 312	2.4
Cutover Peatland Under Restoration (2-4 years)	1 150	2.6
Abandoned Cutover Peatland (Vacuum Method) (25-30 years)	1 106	1.7

Other studies have produced estimates of GHG fluxes from peatlands under extraction similar to those shown in Table 3-7. Malkki and Frilander (1997) assumed fluxes of 917 g $CO_2/m^2/yr$ and 9.3 g $CH_4/m^2/yr$ from peatlands under extraction, with Uppenberg *et al.* (2001) estimating 1000 g $CO_2/m^2/yr$ and 2.1 g $CH_4/m^2/yr$, and Crill *et al.* (2000)[5] estimating 1 060 g $CO_2/m^2/yr$ and 6.7 g $CH_4/m^2/yr$.

[5] The estimates by Crill *et al.* (2000) include emissions during the stockpiling of peat.

The carbon dioxide fluxes of cutover peatlands under restoration from Moore *et al.* (unpublished data) tend to be higher than those found in other studies, while the methane fluxes tend to be lower. Waddington and Price (2000), observed that a block cut peatland under restoration showed losses of both carbon dioxide (623 g $CO_2/m^2/yr$) and methane (0.3 g $CH_4/m^2/yr$). Other studies have claimed that cutover peatlands under restoration sequester carbon. For example, Uppenberg *et al.* (2001) estimated that cutover peatlands under restoration take up between 0 and 123 g $C/m^2/yr$ (equivalent to 451 g $CO_2/m^2/yr$). Malkki and Frilander (1997) assumed that 64 g $CO_2/m^2/yr$ is removed from the atmosphere from cutover peatlands under restoration. The higher levels shown in Table 3-7 may be explained, in part, by the decomposition of the straw added to the surface of the cutover peatland which is not included in the estimates by Uppenberg *et al.* (2001) and Malkki and Frilander (1997).

The GHG flux from the abandoned cutover peatland, shown in Table 3-7, is similar to that found in other studies. Waddington *et al.* (2002) observed emissions at abandoned cutover peatlands (2 to 8 years since abandonment) varying from 323 to 1 463 g CO_2/m^2 from early May to late August in 1998 and 1999. The older sites and wetter seasons tended to produce lower carbon dioxide emissions than the younger sites and drier seasons. At the same cutover peatland sites, Waddington and Price (2000) observed methane emissions ranging from 0.3 to 1.2 g CH_4/m^2 during the summer of 1998, described by Waddington *et al.* (2002) as a relatively dry season.

Although scientific studies indicate that the microtopography of block cut sites favour carbon accumulation in the trenches and losses of carbon from the ridges (Tuittila *et al.* 1999), they vary widely in their carbon flux findings. Moore *et al.* (unpublished data) found that abandoned block cut sites had carbon fluxes that were higher than those of cutover vacuum harvested sites. Tuittila *et al.* (1999) observed that the trenches sequestered as much as 64.5 g C/m^2 per year with some drier areas emitting 38.3 g C/m^2 per year.

It is assumed that there are no net GHG emissions[6] from cutover peatlands that were extracted via non-vacuum, primarily block cut (manual and mechanical) methods,

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[6] These cutover peatlands are assumed to be GHG neutral. Therefore, for each hectare of cutover peatland that was extracted by using non-vacuum methods, 99 g $CO_2/m^2/yr$ is not removed from the atmosphere, and 5.3 g $CH_4/m^2/yr$ is not emitted to the atmosphere.

most of which were abandoned before 1970. This assumption is based upon several factors. The current land use of these cutover peatlands is uncertain. While some of these cutover sites may be growing *Sphagnum*, others may be forests, agricultural fields or used otherwise. Many of these cutover sites are no longer part of the current holdings of peat companies in Canada since numerous operations no longer exist, with those on the lower mainland of British Columbia being prominent examples. In addition, the responses to the questionnaire indicated that almost all of the cutover sites in the holdings of the peat industry were from companies that extracted peat using the vacuum method.

Table 3-8 shows the GHG emission estimates per hectare (t/ha) used for each type of land use. The GHG fluxes for peatlands under restoration were derived by taking the average of the fluxes from the recently restored (<2 year) and restored (2-4 year) sites from Rivière-du-Loup and Shippagan.

Table 3-8. Greenhouse Gas Flux Estimates Used for Each Type of Land Use

Type of Land Use	Source	GHG Flux	
		CO_2	CH_4
		Tonnes emitted per hectare	
Undisturbed Peatland	Gorham (1995)	-0.99	0.053
Peatland Under Extraction	Moore *et al.* (unpublished data)	10.20	0.018
Abandoned Cutover Peatland (Vacuum Method)	Moore *et al.* (unpublished data)	11.06	0.017
Cutover Peatland Under Restoration	Moore *et al.* (unpublished data)	12.31	0.025

3.8 Results

The gross GHG flux estimates for land use were produced by multiplying the GHG flux data displayed in Table 3-8 by the areas affected by the peat industry, shown in Tables 3-2, 3-3 and 3-4. These estimates are displayed in Table 3-9.

Table 3-9. Gross Greenhouse Gas Emissions from Land Use by Canada's Peat Industry, 1990-2000

Year	Peatlands Under Extraction		Peatlands Harvested in the Past		Gross GHG Emissions	
	CO_2	CH_4	CO_2	CH_4	CO_2	CH_4
	tonnes					
1990	69 600	122.8	3 100	4.8	72 700	127.6
1991	83 400	147.2	3 800	5.9	87 200	153.1
1992	72 200	127.4	4 600	7.1	76 800	134.5
1993	85 300	150.6	5 400	8.4	90 800	159.0
1994	94 800	167.3	6 300	9.8	101 100	177.0
1995	86 100	152.0	7 300	11.3	93 400	163.2
1996	88 700	156.5	8 400	12.9	97 100	169.4
1997	103 900	183.4	9 500	14.7	113 500	198.1
1998	111 200	196.2	10 800	16.7	122 000	212.8
1999	116 800	206.2	12 500	19.8	129 300	225.9
2000	126 700	223.6	14 200	23.6	140 900	247.2

In order to calculate the change in greenhouse gas emissions from land use, the emissions of undisturbed peatlands are subtracted from the gross GHG emissions of peatlands affected by peat extraction. The results are shown in Table 3-10.

Table 3-10. Net Change in GHG Emissions due to Land Use by Canada's Peat Industry, 1990-2000

Year	Area affected by peat industry	Baseline GHG emissions		Gross GHG emissions		Net Change in GHG Emissions	
		CO_2	CH_4	CO_2	CH_4	CO_2	CH_4
	hectares	tonnes					
1990	8 481	-8 400	449.5	72 700	127.6	81 100	-321.9
1991	9 912	-9 800	525.3	87 200	153.1	97 000	-372.3
1992	8 898	-8 800	471.6	76 800	134.5	85 600	-337.0
1993	10 275	-10 200	544.6	90 800	159.0	100 900	-385.6
1994	11 291	-11 200	598.4	101 100	177.0	112 300	-421.4
1995	10 545	-10 400	558.9	93 400	163.2	103 900	-395.7
1996	10 901	-10 800	577.8	97 100	169.4	107 900	-408.4
1997	12 513	-12 400	663.2	113 500	198.1	125 800	-465.1
1998	13 347	-13 200	707.4	122 000	212.8	135 200	-494.6
1999	14 054	-13 900	744.9	129 300	225.9	143 200	-518.9
2000	15 164	-15 000	803.7	140 900	247.2	155 900	-556.5

Note: When the CO_2 emission estimates show a negative sign, the peatland acts as a sink for CO_2. When the CH_4 emission estimates show a negative sign, the disturbance of the peatland causes CH_4 emissions to be reduced.

3.9 Size of Peat Reserves in Canada

The following assumptions were made to estimate the current mass of Canada's peat reserves that the peat industry is entitled to extract, based upon the responses received to the questionnaire:

- the peatlands under extraction (13 096 hectares) and peatland holdings never harvested (65 210 hectares), extrapolated from the questionnaire responses, is representative of reality;
- the average amount of commercial peat in undisturbed peatland holdings is 3 500 tonnes per hectare; and
- the average amount of commercial peat in peatland holdings under extraction is 1 750 tonnes per hectare.

By taking these assumptions into account, an estimate of 160 million tonnes of peat (45% moisture content – wet basis) is produced. At the rate of peat extraction in the year 2000, these reserves will last approximately 125 years. However, assuming a 5% annual growth rate and using the peat extraction level in the year 2000 as the baseline, Canada's peat reserves will only last until the year 2040.

3.10 Sustainability of Peat Extraction

Peat extraction in Canada is not sustainable over time scales of centuries or less. Assuming that Gorham's (1991) figure[7] was representative of the carbon fluxes of the 12 421 hectares of peatlands under extraction before they were disturbed, it would have taken approximately 123 years to accumulate the peat extracted in year 2000[8] alone. Approximately 1 918 years would be needed to accumulate the peat extracted over the period from 1941 to 2000,[9] assuming that 15 164 hectares of peatlands had undergone extraction. However, it is unlikely that Gorham's (1991) carbon flux estimate is truly representative of the average flux over the thousands of years of peatland development,

---

[7] 23 g C/m²/yr

[8] Extraction in the year 2000 was 1 277 000 tonnes of peat, equivalent to 351 175 tonnes of carbon (assuming a 45% moisture content – wet basis, and that 50% of dry peat is carbon).

[9] Extraction over the period from 1941 to 2000 was 24 323 555 tonnes of non-fuel peat, equivalent to 6 688 978 tonnes of carbon (assuming a 45% moisture content – wet basis, and that 50% of dry peat is carbon).

especially since the rate of peat accumulation decreases with the height of the accumulated peat (Clymo 1984).

Models of peatland growth show changes in carbon sequestration through time. These models may be categorized into two broad views: (1) the allogenic model, and (2) the autogenic model (Charman 2002; Hilbert *et al.* 2000). The allogenic model views external factors, such as climate, as the major control of peatland growth whereas the autogenic model perceives internal factors, such as peatland depth, as the dominant control (Charman 2002; Hilbert *et al.* 2000).

In his autogenic model, Clymo (1984) assumes that net primary production and the depth of the water table remain constant. The model differentiates between the processes that take place in the acrotelm (aerobic layer) and the catotelm (anaerobic layer). Although the depth of the acrotelm is constant, the depth of the catotelm grows at an ever-decreasing rate until the rate of addition equals the combined losses at all depths. At this point, the mass of peat reaches a steady state.

The Peat Accumulation Model (PAM), designed by Hilbert *et al.* (2000), produces results similar to those of Clymo (1984), but considers both internal and external controls of peatland dynamics and shows that equilibrium peat accumulation and water table depth depend on the net water input to the peatland. Hilbert *et al.* (2000) proposed that a peatland can reach two equilibrium states, (1) deep and dry, and (2) shallower and wet, over a range of water balances. The existence of more than one equilibrium state is attributed to the effect of water level on net primary production (NPP). If the water table is too low, the lack of water limits NPP, if it is too high, NPP is also restricted.

For ombrotrophic bogs, Clymo (1984) and Hilbert *et al.* (2000) indicate that a younger peatland with a smaller catotelm has a faster rate of peat accumulation than a peatland with a thicker catotelm. Figure 3-3 displays the results of a PAM simulation of carbon accumulation in a peatland over thousands of years, assuming a mean annual rate of precipitation of 900 mm (Hilbert *et al.* 2000).

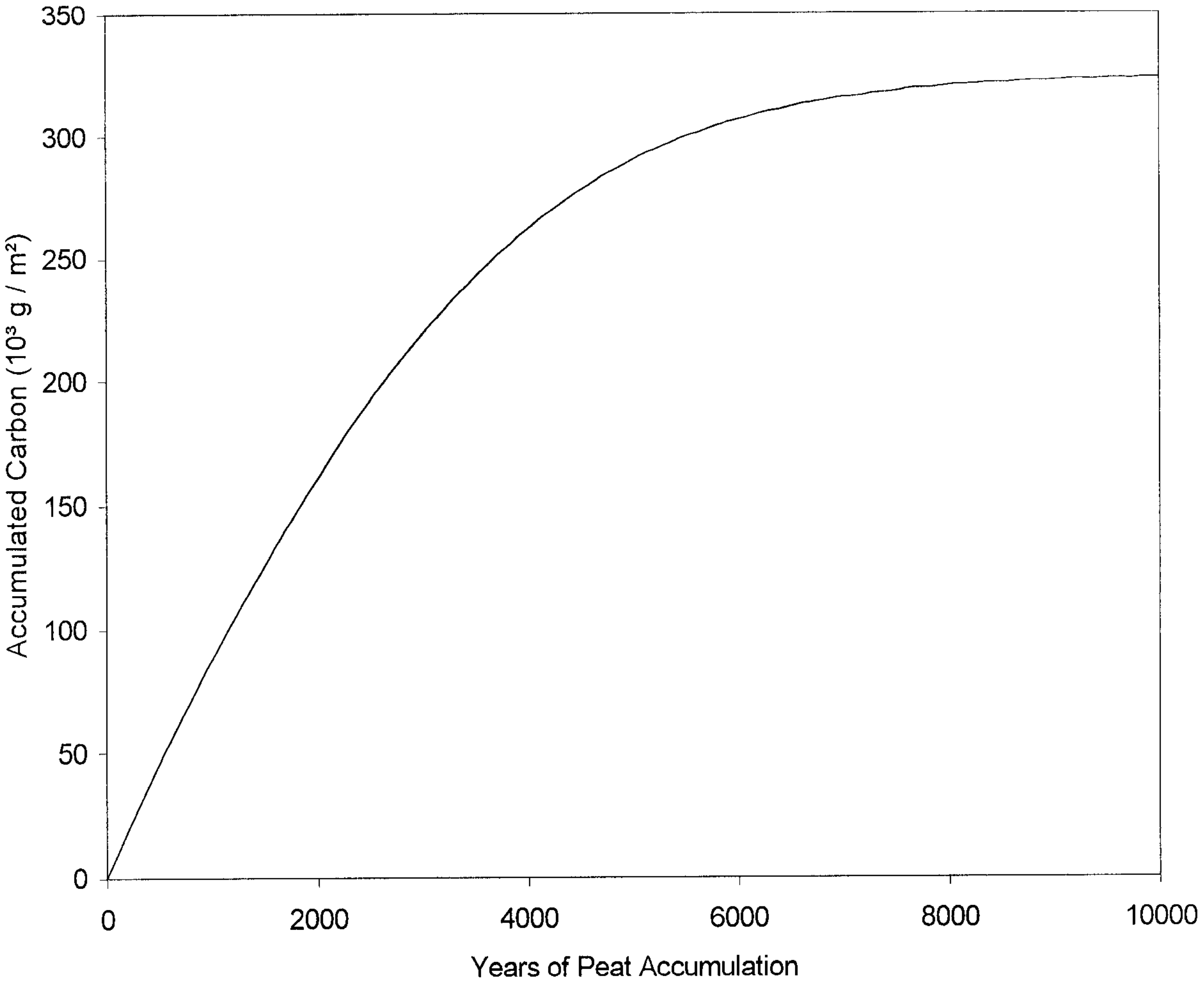

Figure 3-3. Accumulation of Carbon in a Peatland [Peat Accumulation Model (Hilbert *et al.* 2000) Simulation, Assuming a Mean Annual Precipitation of 900 mm]

The carbon balances of three peatland disturbance scenarios are modelled in order to estimate: (a) the time it takes to sequester the carbon emitted due to land use; and (b) the time it takes to sequester both the carbon extracted and the carbon emitted due to land use. Each disturbance scenario is presumed to take effect as soon as the peatland enters into production. The scenarios are defined as follows: (1) a site under restoration[10] that was extracted by using either the vacuum method or the block cut method; (2) an abandoned site that was harvested using the block cut method; and (3) an abandoned site that was extracted using the vacuum method.

[10] The restoration of a site is generally characterized by the raising of the water table, the spreading of mulch on the surface and the seeding of the surface with moss fragments.

There exist no long-term studies of carbon fluxes from cutover peatlands. Empirical carbon flux data from older abandoned sites (up to 30 years since abandonment) and peatlands newly restored (<5 years since the water table was raised) have shown that annual fluxes vary between 100 and 500 g/m^2, with perhaps an average of 300 g/m^2/yr (Moore *et al.* unpublished data; Waddington *et al.* 2002). The carbon fluxes for the three scenarios are loosely based upon this empirical data. The scenarios also take into account some of the factors that affect peatland restoration time, which were addressed in Section 3.3. It should be noted that scenarios two and three assume that abandoned cutover sites will eventually become carbon-sequestering peatlands. This will not occur unless the water table eventually returns to a level that is near the surface.

The first scenario assumes that a peatland emits 300 g C/m^2/yr for the first 50 years from the time it enters into production, and takes another 50 years to reach a net flux of –90 g C/m^2/yr (linear decrease).[11] The second scenario assumes that a block cut peatland that has an initial 50-year period in which its carbon flux remains at 300 g C/m^2/yr, requires another 100 years to reach a net flux of –90 g C/m^2/yr (linear decrease). Scenario three assumes that the carbon fluxes from abandoned sites extracted via the vacuum method remain at 300 g C/m^2/yr over the first 100 years and reach a level of –90 g C/m^2/yr after 200 years (linear decrease). Once the net flux reaches –90 g C/m^2/yr, the numbers produced by the Peat Accumulation Model[12] by Hilbert *et al.* (2000) for the annual accumulation of peat carbon on a peatland with one metre of peat, are applied. Figure 3-4 provides a graphical representation of the first 200 years of carbon fluxes characteristic of each peatland disturbance scenario.

[11] The Peat Accumulation Model by Hilbert *et al.* (2000) produces a carbon flux estimate of approximately 90 g C/m^2/yr from a peatland with a depth of one metre.

[12] Assuming that the cutover peatland receives a mean annual rate of precipitation of 900 mm.

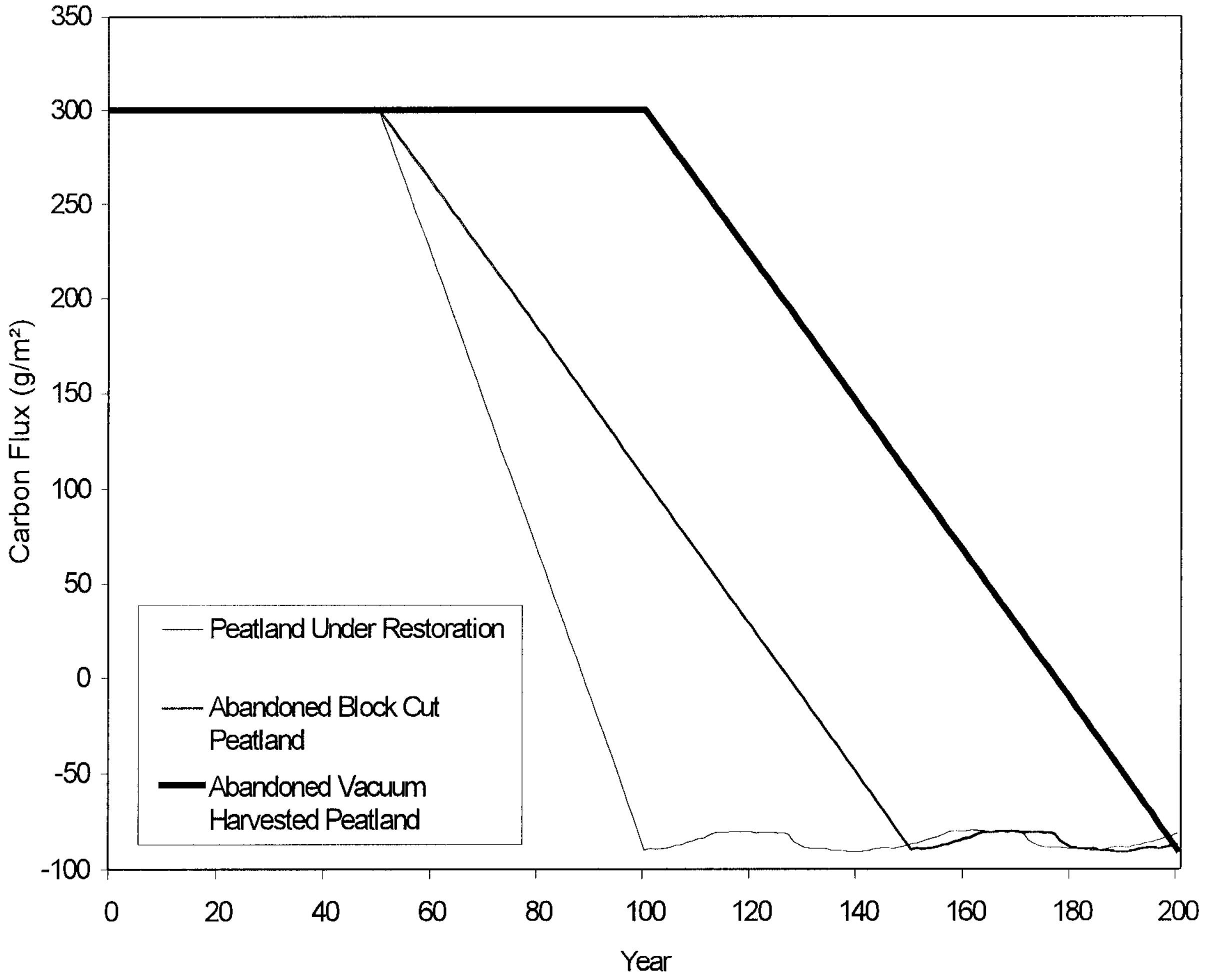

Figure 3-4. Carbon Fluxes per m^2 from a Peatland Under Restoration, an Abandoned Block Cut Peatland, and an Abandoned Vacuum Harvested Peatland

The results for each scenario, shown in Table 3-11, demonstrate that it could take thousands of years to resequester the carbon emitted due to land use[13] and the extraction of peat. The results also reveal the important role of peatland restoration to reduce carbon emissions from cutover sites over long periods of time.

[13] The carbon emissions resulting from land use do not include carbon sequestration that would be forgone.

Table 3-11. Carbon Emissions from a Peatland Under Restoration, an Abandoned Block Cut Peatland and an Abandoned Vacuum Harvested Peatland, and Years to Resequester the Carbon

Peatland Disturbance Scenario	Carbon Emissions	Time to resequester the carbon emitted from land use	Time to resequester both the carbon extracted and the carbon emitted from land use
	g/m^2	years	
Scenario One: Peatland Under Restoration	20 900	602	2 012
Scenario Two: Abandoned Block Cut Peatland	26 700	794	2 258
Scenario Three: Abandoned Vacuum Harvested Peatland	41 700	1 251	2 911

In this study, it has been assumed that 96 250 g C/m^2 are extracted (3 500 tonnes of peat per hectare) from an average peatland for commercial peat. The results from the three peatland disturbance scenarios show that between $2.1*10^4$ g C/m^2 (760 tonnes of peat per hectare) and $4.2*10^4$ g C/m^2 (1500 tonnes of peat per hectare) are lost from the peatlands as carbon dioxide and methane emissions due to the disturbance resulting from peat extraction. This is equivalent to approximately 22% to 44% of the carbon removed as commercial peat.

3.11 Greenhouse Gas Reduction Scenarios

The emission of greenhouse gases resulting from peatland disturbance is an unavoidable effect of peat extraction. It can nevertheless be reduced in magnitude. Uppenberg *et al.* (2001) recommended that undisturbed peatlands with high methane emission rates should be favoured for extraction over those with lower emission rates due to the greater reduction in methane emissions once the peatland is drained.

It is possible to reduce the area under extraction by increasing the annual amount of peat extracted per unit area. It would have required the complete extraction of approximately 6 950 hectares of peatlands to acquire the 24 323 555 tonnes of non-fuel peat extracted between 1941 and 2000, assuming that the average peatland contained 3 500 tonnes of peat per hectare. Since the area of peatland under extraction at any one time depends upon the demand for peat and the annual yield per unit area of peatland, the land used for extraction has necessarily been much higher than 6 950 hectares.

Carbon emissions may be reduced by attempting to restore cutover sites to carbon-sequestering peatlands as soon as extraction has ceased. The scenarios examined in Section 3.10 have illustrated that a substantial amount of additional carbon can remain sequestered if the time it takes to harvest and restore a cutover peatland is minimized. Moreover, additional peat can be extracted per unit area since there is less time for the peat to decompose *in situ*.

CHAPTER FOUR

PEAT EXTRACTION AND PROCESSING

The Canadian peat industry uses machinery and equipment powered by fossil fuels and electricity to extract, process and "add value" to its product. In the period from 1990 to 2000, the industry has used diesel fuel, liquefied petroleum gases, gasoline, light fuel oil, heavy fuel oil, natural gas and kerosene, as well as electricity,[1] in its operations (Statistics Canada 1991-1999; 2000-2002). This chapter addresses the greenhouse gases emitted to the atmosphere from the use of fossil fuels during the extraction and processing of peat.

While early peat extraction depended largely on human labour and hand tools, machinery has now come to dominate all phases of modern operations (Charman 2002). Backhoes, bulldozers and levellers prepare the peatland for extraction by digging trenches for drainage, removing the surface vegetation and levelling the peatland (Gottlich *et al.* 1993; Aiken *et al.* 1983). Tractors then harrow or mill the uppermost layer of peat, later followed by large vacuum harvesters that collect it (Daigle and Gautreau-Daigle 2001). In the case of the block cut method, the peat is cut from the prepared ground. Within the factory, machines may dry, sift, mix, compact and bag the peat. Forklifts are used to load the material onto trucks that transport the peat to market, a railway terminal or port, or to another location for further processing.

4.1 Greenhouse Gas Accounting Methodology

The following equation was used to calculate the GHG emissions from peat extraction and processing (GHG_{E+P}), the results of which are presented in Table 4-1:

Equation 4-1

$$GHG_{E+P} = \sum_{i=1}^{n} Q_{F_i} * GHG_{F_i}$$

[1] Electricity is not considered a source of GHG emissions in this life cycle assessment because the GHG emissions from the production of electricity originate "upstream" from the peat extraction process.

where Q_{F_i} represents the quantity of fuel used, per fuel type (Table 4-2), GHG_{F_i} represents the mass of GHG emissions per unit of fuel consumed, and n represents the number of fuel types – in this case, n = 7.

Table 4-1. Greenhouse Gases Emitted during Peat Extraction and Processing, 1990-2000

Year	Total GHG Emissions		
	CO_2	CH_4	N_2O
	tonnes		
1990	20 700	2.0	3.3
1991	23 300	2.1	3.9
1992	21 600	1.7	3.3
1993	23 400	1.7	3.5
1994	29 000	1.9	4.6
1995	36 000	2.7	5.1
1996	32 100	2.0	4.6
1997	30 400	2.1	4.6
1998	34 800	2.2	5.6
1999	34 500	2.2	5.7
2000	34 900	2.1	5.7

Table 4-2. Consumption of Fuels Purchased by Canada's Peat Industry, 1990-2000

Year	Fuel Consumption						
	Natural Gas	Gasoline	Kerosene	Diesel	Light Fuel Oil	Heavy Fuel Oil	Liquefied Petroleum Gases
	10^3 litres						
1990	8	1 842	2	4 502	55	105	2 464
1991	10	1 762	6	5 559	31	111	2 472
1992	3	1 442	0	4 654	72	202	3 272
1993	3	1 257	0	5 121	543	172	3 078
1994	4	1 294	0	6 898	306	302	3 697
1995	4	2 113	0	7 326	376	348	6 180
1996	4	1 381	0	6 968	147	0	6 517
1997	6	1 541	0	6 947	9	0	5 441
1998	4	1 455	0	8 625	155	0	5 111
1999	7	1 540	0	8 746	29	0	4 779
2000	6	1 281	0	8 806	36	0	5 362

Sources: Statistics Canada, 1991-1999, *Non-metal mines*, (Ottawa: Statistics Canada), Catalogue no. 26-224. Statistics Canada, 2000-2002, *Non-metallic Mineral Mining and Quarrying*, (Ottawa: Statistics Canada), Catalogue no. 26-226.

The annual quantity of fuel consumed for peat extraction and processing was obtained from Statistics Canada data on the consumption of fuel by the peat industry collected from its annual *Census of Manufactures* (Table 4-2).[2]

The GHG conversion tables from *Canada's Emissions Outlook: An Update* contain figures that state the amount of CO_2, CH_4, and N_2O that is emitted from the combustion of various fossil fuels (Analysis and Modelling Group, National Climate Change Process 1999). Table 4-3 displays the figures used for GHG_{Fi} in Equation 4-1.

Table 4-3. Mass of Greenhouse Gases Released from Fuel Combustion (GHG_{Fi})[3]

Fuel	Greenhouse Gas		
	CO_2	CH_4	N_2O
	t/ML	kg/ML	kg/ML
Natural gas	1.88	4.3 - 4.8 (4.6)	0.02
Gasoline	2.36	0.25 - 1.3 (0.78)	0.046 - 0.58 (0.31)
Kerosene	2.55	0.006 - 0.26 (0.13)	0.07
Diesel	2.73	0.05 - 0.15 (0.1)	0.1 - 1.1 (0.6)
Light Fuel Oil	2.83	0.01 - 0.3 (0.16)	0.013 - 0.07 (0.042)
Heavy Fuel Oil	3.09	0.03 - 0.3 (0.16)	0.013 - 0.40 (0.21)
Liquefied Petroleum Gases	1.11 - 1.76 (1.44)	0.03	0

Source: Analysis and Modelling Group, National Climate Change Process, 1999, *Canada's Emissions Outlook: An Update*, (Ottawa: Analysis and Modelling Group, National Climate Change Process).

By extrapolating the fuel use data from the questionnaire to the entire industry,[4] peat extraction and processing was shown to produce 20 104 tonnes of GHGs (in CO_2

[2] The scope of the consumption of purchased fuel and electricity data has been defined as follows: "The data consists of all purchased fuel and electricity consumed by the establishments both in their manufacturing and non-manufacturing operations, and covers amounts used by the establishment in vehicles of all descriptions, plant and office operations and any ancillary units which comprise this accounting entity. Values reported include transportation, duties, etc. which form part of the laid down cost at the establishment." (Statistics Canada. 1984. *Concepts and definitions of the census of manufactures*. 31-528 Occasional).

[3] For those instances in which there is a range of emission factors for the combustion of a particular fuel, the median value is used (displayed within parentheses).

[4] Equivalent to peat extraction in the year 2000 divided by the proportion of the industry (based on this extraction statistic) that responded to the questionnaire.

equivalents – 100 year time horizon) in the year 2000. This figure differs significantly from the estimate produced from the Statistics Canada data, which was 36 603 tonnes.

There are several possible explanations for this discrepancy between the data obtained from the questionnaire and that from Statistics Canada. The fuel consumption data from the questionnaire represented only 45% of peat production in Canada in the year 2000, less than the 69% total response rate, because some of the respondents did not provide their fuel consumption data. These results represented a smaller sample of Canadian peat production than the information obtained from Statistics Canada's *Census of Manufactures*, which sampled virtually all peat establishments in Canada. Those companies that did not respond to the questionnaire may have consumed a substantially higher amount of fuel per unit of peat extracted.

The fuel consumption data acquired from the *Census of Manufactures* may be of a larger scope than the data collected from the responses to the questionnaire. The definition of the scope of the Statistics Canada fuel consumption data, quoted in footnote two of this chapter, indicates that the fuel purchased by an establishment for transportation purposes is included in this data. However, the results extrapolated from the questionnaire have shown that very few peat establishments own[5] the trucks used to ship peat to market. This extrapolation indicates that there are approximately 20 trucks owned by peat establishments, that travel an average of 43 000 km/yr (*Appendix C: Overview of Questionnaire Design and Results*). Therefore, although there may be some double counting of GHG emissions from transportation, the overestimate of total GHG emissions should not reach more than 1 000 tonnes of CO_2 equivalents (100-year time horizon) per year.

4.2 Types of Fuels Used, 1990-2000

As of the year 2000, the peat industry used diesel, liquefied petroleum gases, gasoline, light fuel oil and natural gas in its operations (Statistics Canada 2002). Between 1990 and 2000, the use of kerosene and heavy fuel oil were phased out (Figure 4-1).

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[5] Peat companies generally hire shipping firms to transport peat to market and do not directly purchase the fuel used to operate the vehicles (Fred Kennedy & Associates 1997).

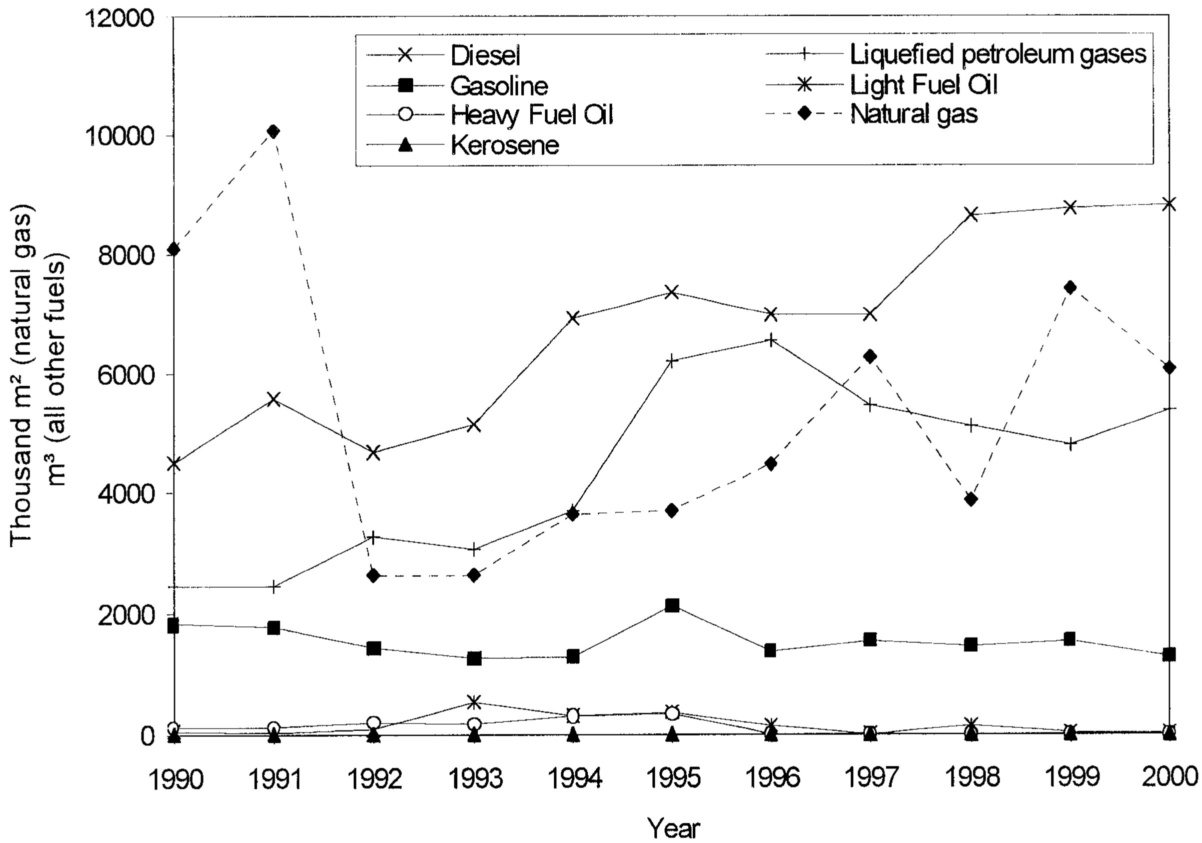

Figure 4-1. Consumption of Fuels Purchased by Canada's Peat Industry, 1990-2000. Sources: Statistics Canada, 1991-1999, *Non-metal mines*, (Ottawa: Statistics Canada), Catalogue no. 26-224. Statistics Canada, 2000-2002, *Non-metallic Mineral Mining and Quarrying*, (Ottawa: Statistics Canada), Catalogue no. 26-226.

The proportion of greenhouse gases emitted from the combustion of diesel fuel during extraction and processing operations increased by approximately 10% of total GHG emissions from 1990 to 2000, while that of gasoline fell by a similar amount (Figure 4-2). Diesel produces 17.8% more greenhouse gas (in CO_2 equivalents – 100 year time horizon) during combustion than the same amount of gasoline, based on the figures shown in Table 4-3. Therefore, the apparent substitution of diesel for gasoline has further increased the GHG emissions from fossil fuel combustion during peat extraction and processing. As this study does not take into account GHG emissions generated upstream from peat extraction, the possible differences in the magnitude of GHGs emitted during the production of diesel and gasoline have not been estimated.

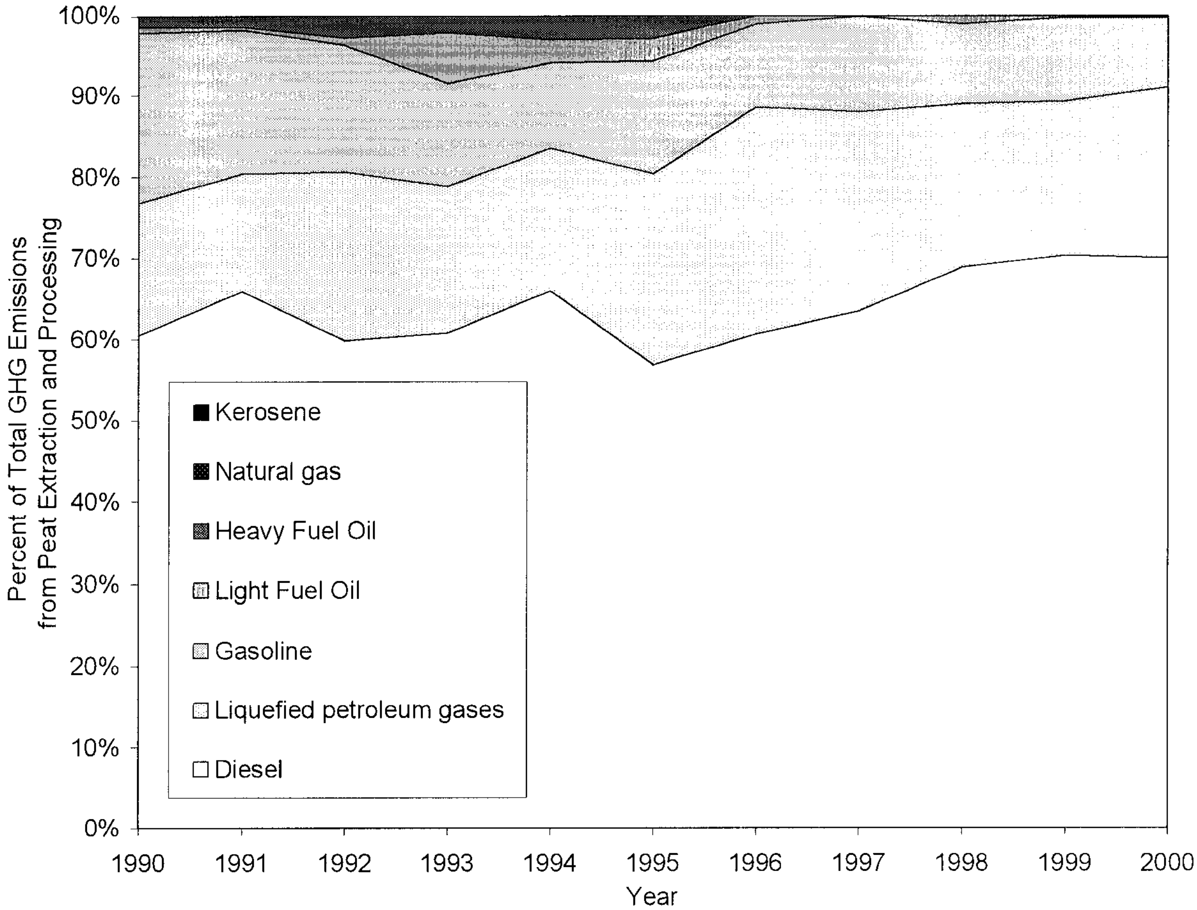

Figure 4-2. Percentage Contribution of Fossil Fuel Types to GHG Emissions from Extraction and Processing, 1990-2000. [Note: the contributions of natural gas and kerosene to GHG emissions during peat extraction and processing are so small that they cannot be seen in this graph.]

4.3 Price of Fuel and GHG Intensity

Although the prices of the most important fuels used for peat extraction have increased significantly from 1990 to 2000, there does not appear to be any conclusive evidence that the price of fuel has affected the GHG intensity[6] of peat extraction and processing. Data from Statistics Canada show that there were peaks in fuel prices in 1990, 1996, 1997 and especially the year 2000 when the GHG intensity of the peat industry was relatively low (Figure 4-3). In general, the years with the lowest GHG intensity (1991, 1993, 1997 and 1999) do not coincide with these peaks (Figure 4-4).

[6] Defined in this study as the amount of greenhouse gases emitted per unit of peat production.

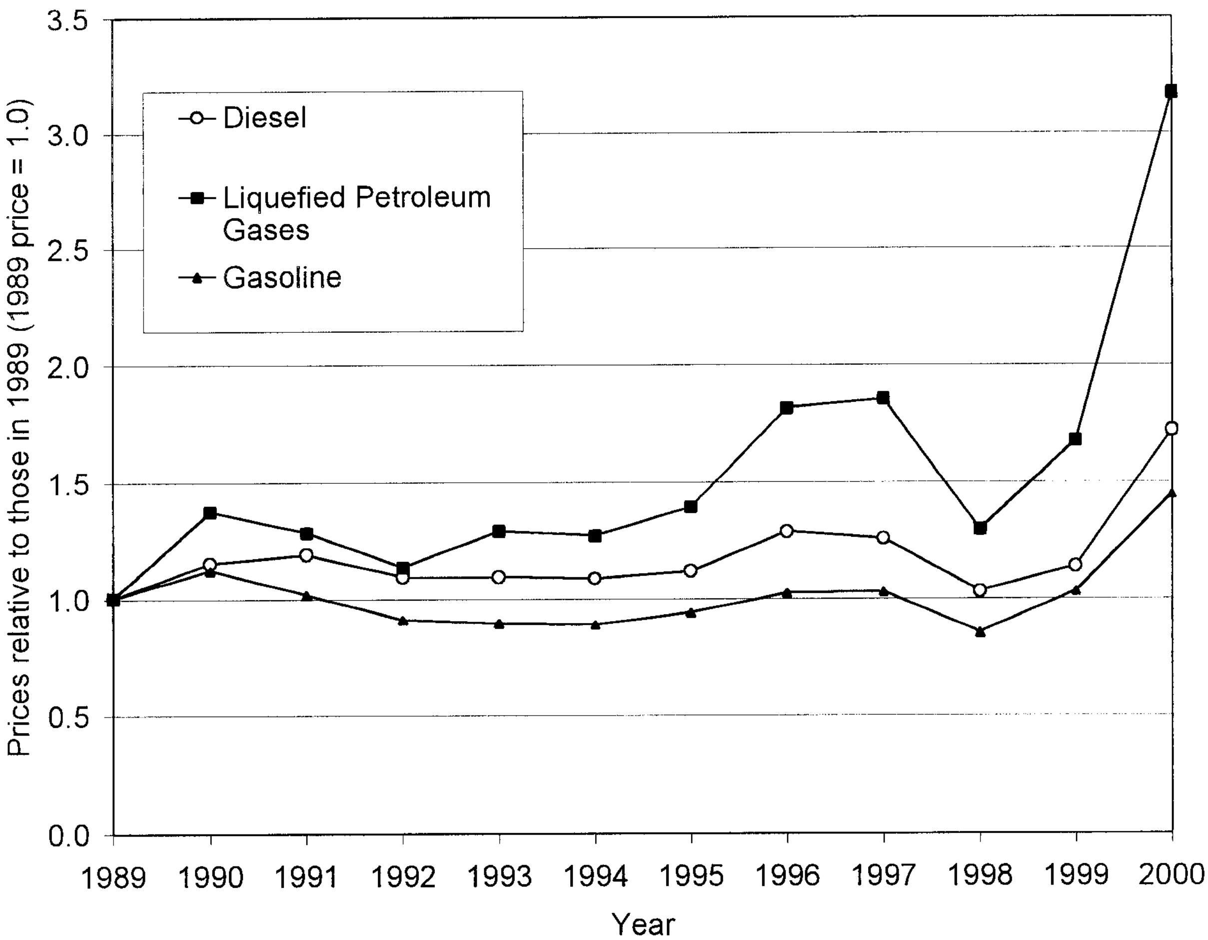

Figure 4-3. Annual Change in Prices of Diesel, Liquefied Petroleum Gases and Gasoline Relative to 1989 Prices, 1989-2000. Source: Statistics Canada, 1991-2001, *Industry price indexes*, (Ottawa: Statistics Canada), Monthly Reports, Catalogue no. 62-011 Monthly, ISSN 0700-2033.

4.4 Fuels Used during Each Stage of Peat Production

The questionnaire was used to collect data on the types of fuel consumed during the following stages of peat extraction and processing: (1) digging of drainage ditches; (2) extraction of peat; (3) stockpiling the peat; (4) moving the peat to the factory; (5) sifting the peat; and (6) bagging (Table 4-4). The questionnaire also left room for the respondent to name all of the stages of peat processing relevant to the particular establishment, and the fuels used during each of these stages of production.

Table 4-4. Fuels Consumed during Each Stage of Peat Production

Stage of Peat Production	Fuels Consumed
Digging of drainage ditches	Diesel, light fuel oil
Extraction	Diesel, light fuel oil
Stockpiling	Diesel, light fuel oil
Moving the peat to the factory	Diesel, light fuel oil, gasoline
Sifting the peat	Electricity, diesel, light fuel oil
Bagging	Electricity, diesel, light fuel oil, "human"
Other (peat drying, distribution to customer, storage, loading, and electricity generation)	Diesel, liquefied petroleum gases, gasoline, light fuel oil

Diesel fuel is traditionally used to power equipment involved in peat extraction. However, some establishments use natural gas or liquefied petroleum gases (LPG) to heat the workplace or dry the peat before baling it, while gasoline is used in forklifts and other equipment within the plant (G. Hood, pers. comm., 2001 10 19).

4.5 Greenhouse Gas Intensity of Peat Extraction and Processing at the Scale of the Industry

Figure 4-4 displays the greenhouse gas intensities of peat extraction and processing for the entire peat industry from 1990 to 2000. The results in this figure indicate that there is no discernible trend toward increased efficiency in fuel consumption by the peat industry during extraction and processing from 1990 to the year 2000.[7] The GHG emissions per tonne of extracted peat were highest in 1995, and lowest in 1993. Over the 1990s, the GHG intensities ranged from 0.02810 (1993) to 0.04286 (1995) tonnes of GHG per tonne of peat extracted. The greenhouse gas intensities were calculated by dividing the GHG emissions (in CO_2 equivalents – 100 year time horizon) by the amount of peat extracted in a particular year (extraction data presented in Figure 3-1).

[7] One respondent to the questionnaire claimed that the consumption of fuel by his peat extraction establishment, per unit of peat, had decreased greatly over the past decade.

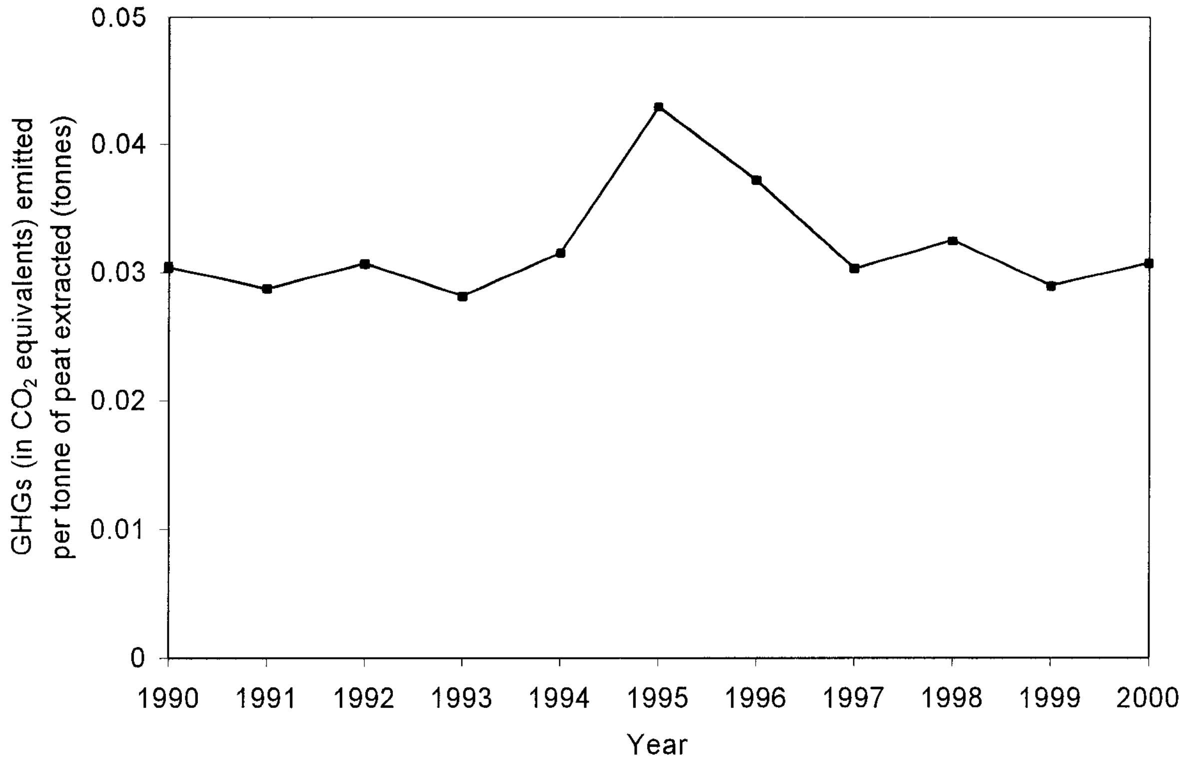

Figure 4-4. Greenhouse Gas Emissions from Peat Extraction and Processing, Per Tonne of Peat Extracted, 1990-2000

4.6 Greenhouse Gas Intensity of Peat Extraction and Processing at the Scale of the Establishment

The results from the questionnaire were used to estimate the respondents' fuel use per tonne of peat extracted. These estimates provide an indication of the range of GHG intensities within Canada's peat extraction industry that may affect the role and potential effectiveness of carbon trading permits for the peat industry. If there is little variation in GHG intensities among peat establishments, the potential for carbon trading may be lower than if the variation in greenhouse gas intensities is high.

There are preliminary indications that a carbon trading system could succeed in reducing GHG emissions from the peat industry. Responses to the questionnaire show that there is substantial variation in the GHG intensities of Canada's peat establishments, ranging from 0.00452 to 0.0302 tonnes of GHG (CO_2 equivalents – 100 year time horizon) per tonne of extracted peat (Figure 4-5). This is to be expected due to geography, climate and other differences between extraction sites, as well as differences in the types of peat products generated at each establishment. A detailed audit of the industry is required in order to identify whether the variation in GHG intensity is related to the types of equipment employed or the geography and climatic characteristics of the peat extraction sites.

4.7 Fuel Use and the Size of the Peat Operation

Webber (1984) contended that large factories tend to be more efficient than smaller ones due to their additional division of labour (increased specialization). Although larger peat extraction establishments may possess lower labour and other economic costs per unit of extracted peat, they do not necessarily use less fossil fuels. Responses to the questionnaire appear to show that fuel use, per unit of production, is not determined by the size of the peat production establishment (Figure 4-5).

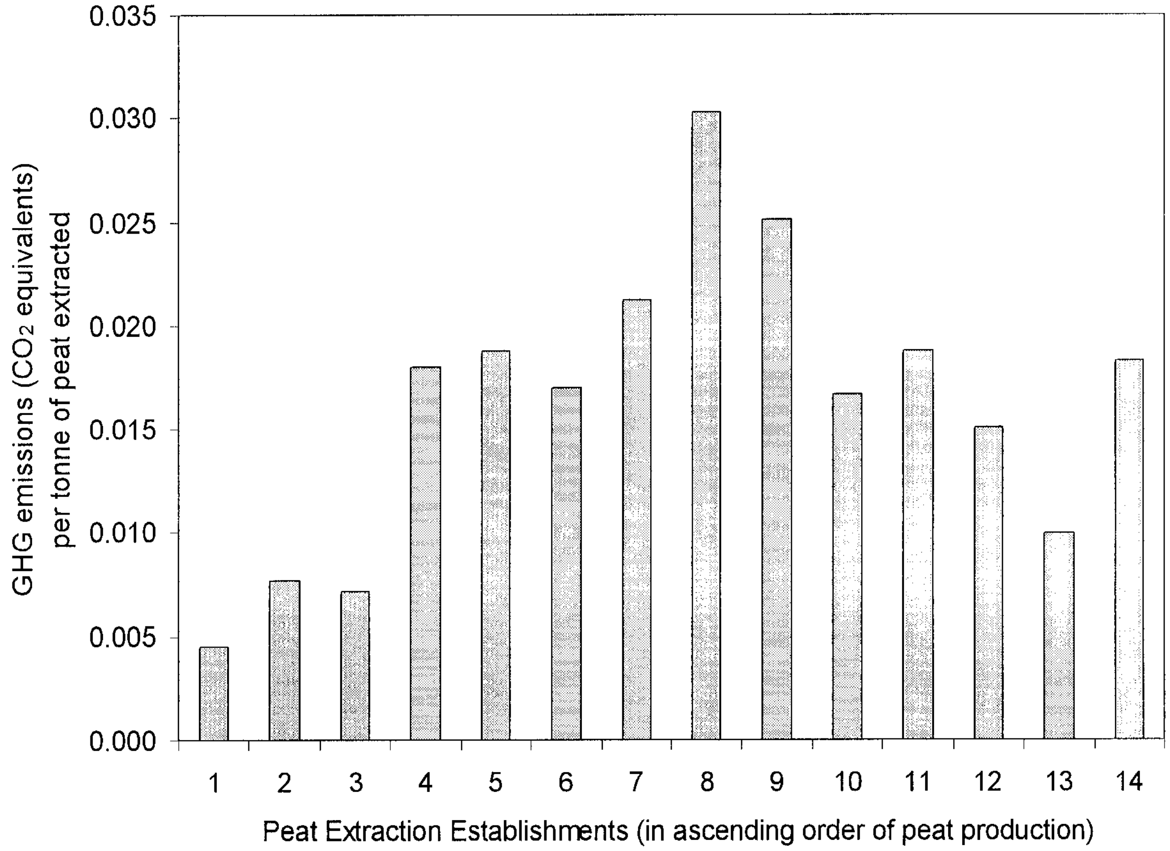

Figure 4-5. Greenhouse Gas Emissions from Peat Extraction and Processing for Each Establishment, Per Tonne of Peat Extracted (Year 2000). [Note: The establishments listed in this chart represent 14% of Canada's peat production. Questionnaire responses that represent more than one establishment are not included in this sample.]

4.8 "Business As Usual" Greenhouse Gas Emissions

The relationship between annual peat extraction and the greenhouse gas emissions resulting from peat extraction and processing is used to predict GHG emissions into the future. An x-y scatter diagram was produced that displays points representing the GHG emissions from peat extraction and processing (in CO_2 equivalents – 100 year time horizon) versus annual peat extraction data, from 1990 to 2000 (Figure 4-6). A linear relationship was extrapolated from the data.

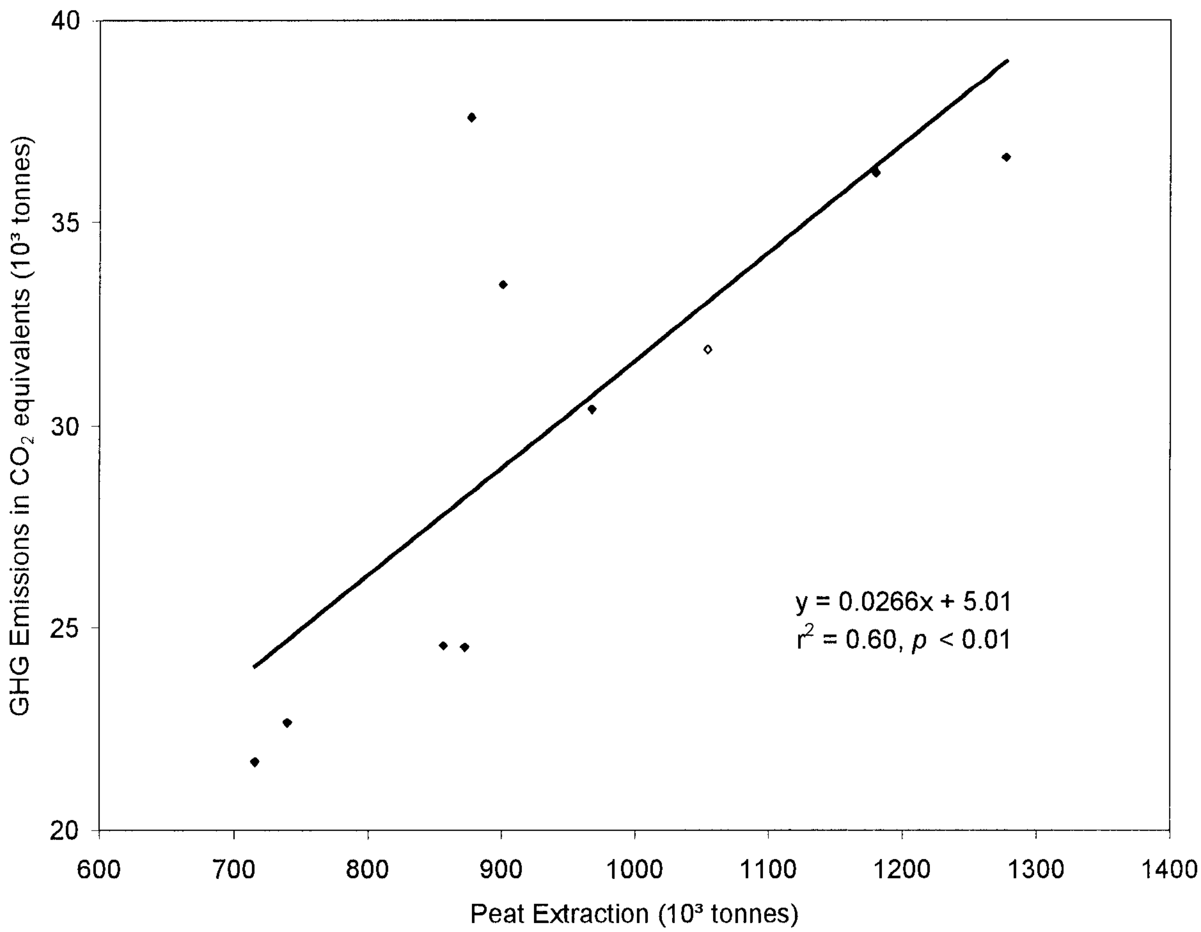

Figure 4-6 Greenhouse Gas Emissions from Peat Extraction and Processing Versus Peat Extraction, 1990-2000

The "business as usual" GHG emissions from peat extraction and processing were based on an extrapolation of the linear relationship defined in Figure 4-6, assuming that peat extraction increases by 5% annually, using the year 2000 as the base year (Table 4-5).

Table 4-5. "Business as Usual" Greenhouse Gas Emissions during Peat Extraction and Processing, 2001-2012

Year	Extraction	"Business as Usual" Emissions	Percent Change from 1990
	tonnes of peat	tonnes of GHG in CO_2 equivalents	%
2001	1 340 850	40 700	87
2002	1 407 893	42 500	96
2003	1 478 287	44 300	104
2004	1 552 201	46 300	113
2005	1 629 812	48 400	123
2006	1 711 302	50 500	133
2007	1 796 867	52 800	143
2008	1 886 711	55 200	154
2009	1 981 046	57 700	166
2010	2 080 098	60 300	178
2011	2 184 103	63 100	191
2012	2 293 309	66 000	204

4.9 Greenhouse Gas Reduction Scenarios

The greenhouse gas emissions from extraction and processing can be reduced by adopting more fuel-efficient equipment and peat extraction techniques. The rate of adoption of some GHG-reducing measures would depend on the turnover time of the capital and equipment currently in use. Higher economic costs would likely inhibit the replacement of capital and fuel-intensive extraction and processing techniques with labour-intensive ones that produce lower levels of GHG emissions.

Table 4-6 displays the greenhouse gas emissions from peat extraction and processing if the GHG intensity was equivalent to its lowest level during the period from 1990 to 2000, which is 0.0281 tonnes of GHG (in CO_2 equivalents – 100 year time horizon) per tonne of peat extracted. [8]

[8] The GHG intensity of peat extraction and processing in the year 1993 was 0.0281 tonnes of GHG per tonne of peat extracted.

Table 4-6. Greenhouse Gas Reduction Scenario for the Extraction and Processing of Peat, 2001-2012

Year	"Business as Usual" Extraction	GHG Emissions from Peat Extraction and Processing†	Percent Change from 1990
	tonnes of peat	tonnes of GHG in CO_2 equivalents	%
2001	1 340 850	37 700	74
2002	1 407 893	39 600	82
2003	1 478 287	41 500	91
2004	1 552 201	43 600	101
2005	1 629 812	45 800	111
2006	1 711 302	48 100	122
2007	1 796 867	50 500	133
2008	1 886 711	53 000	144
2009	1 981 046	55 700	157
2010	2 080 098	58 400	169
2011	2 184 103	61 400	183
2012	2 293 309	64 400	197

† Assuming GHG Intensity is 0.0281 t GHG/t peat.

The results shown in Table 4-6 indicate that the GHG emissions of the peat industry during extraction and processing will increase significantly over the next decade, assuming that peat extraction grows at an annual rate of 5%, using year 2000 extraction as the baseline. This would be the case even if the peat industry ensured that its future GHG intensity remained at a low level relative to the 1990 to 2000 period.

To seriously address its GHG emissions during peat extraction and processing, the peat industry may need to reduce extraction and substitute its current fossil fuels with ethanol, e-diesel,[9] electricity, and hydrogen fuel cells, where and when technologies permit. A reduction in the time spent idling the machines used to extract and process peat is also both environmentally and economically desirable.

[9] A combination of ethanol and diesel fuel.

CHAPTER FIVE

TRANSPORT OF PEAT TO MARKET

After extraction and processing, peat is shipped to market[1] via truck, train or ship. Each of these modes of transport requires fossil fuels for their operation, and thus release greenhouse gases to the atmosphere. In the year 2000, the main areas of peat extraction in Canada were New Brunswick, with 36.4% of domestic production, followed by Quebec, with 28.2% (Statistics Canada 2002). The most important markets for Canadian peat, as a percentage of total production for the year 2000, were the United States, at 65.4%, Canada, at 20.8% and Japan, consuming 12.4% (Statistics Canada 2001).

5.1 Greenhouse Gas Accounting Methodology

The following information was used to calculate GHG emissions resulting from the transportation of peat:

- the size, origin and destination of peat shipments, based upon peat export and domestic shipment data from Statistics Canada;
- the proportion of peat shipments using each mode of transport (truck, train and ship), based upon estimates by the Canadian Sphagnum Peat Moss Association; and
- the fuel efficiency of each mode of transport for the shipment of peat, based upon the published literature.

The methods used to estimate the GHG emissions from the transportation of peat destined for the domestic, American and overseas markets differ and are depicted in separate sections within this chapter.

5.2 Modes of Transport

As noted above, the transportation of peat to market takes place by truck, train and ship. Of these modes of transport, the truck is the most GHG intensive (i.e., least fuel-efficient) by far. Shipments by train are more fuel-efficient than by truck, with ships

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[1] For this study, the market refers to the retailer or customer. It is assumed that the distance between this market and the location where the peat is finally used is insignificant.

surpassing rail in fuel efficiency. According to the *Foundation Paper on Climate Change – Transportation Sector*, trucks, trains and ships transport goods an average of 24, 135, and 311 tonne-km/litre([2]) in Canada, respectively (Transportation Table: National Climate Change Process 1998). These figures were used in equations 5-2 and 5-3 to calculate the greenhouse gases produced when transporting peat by rail and ship. Another method was used to calculate the GHGs produced when transporting peat by truck (Equation 5-1). This method has greater accuracy than that used for rail and ship deliveries because it takes into account the average mass of peat on each truck, not the average mass of a good.

The following equations were used to calculate the greenhouse gases emitted when transporting peat to market by truck, train and ship:

Equation 5-1

$$GHG_{Truck} = S * D / Truckload * F_{efficiency} * GHG_{converter}$$

Equation 5-2

$$GHG_{Rail} = S * D / (Tkm / l_{Rail}) * GHG_{converter}$$

Equation 5-3

$$GHG_{Ship} = S * D / (Tkm / l_{Ship}) * GHG_{converter}$$

where S represents the size of the peat shipments between two particular locations (tonnes)[3]; D represents an estimate of the distance travelled by the peat (km)[4]; *Truckload* represents the mass of peat transported by the average truck (17.36 tonnes)[5]; $F_{efficiency}$ is the fuel consumed by one truck, per unit of distance travelled (0.39 litres/km)[6]; Tkm/l_{Rail}

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[2] A tonne-km/litre represents the number of tonnes of goods that can be transported a distance of one kilometre per litre of fuel consumed.

[3] Based upon peat export and domestic shipment data from Statistics Canada. It is not guaranteed that the destination reported is the location of consumption. It could be the location of a wholesaler that distributes the good to another location, or where value is added (Brown and Anderson 1999).

[4] The origin of the figures used for D is explained in *Appendix D: Transportation Distances.*

[5] Equivalent to 450 bales of peat. Source: Three-D Geoconsultants (1992) and G. Hood, pers. comm., (2001 10 18)

[6] Source: Transportation Table: National Climate Change Process (1998)

and Tkm/l_{Ship} represent the average tonne-km that a good travels, per litre of fuel used, by rail (135 tonne-km) and ship (311 tonne-km), respectively[7]; and $GHG_{converter}$ converts fuel use data into tonnes of carbon dioxide, methane and nitrous oxide emissions (tonnes of CO_2, CH_4, and N_2O per litre of fuel). Table 5-1 displays the figures used for $GHG_{converter}$.

Table 5-1. Greenhouse Gases Emitted Per Litre of Fuel for Trucks, Trains and Ships

Type of Transport	CO_2	CH_4	N_2O
		tonnes / litre of fuel	
Heavy duty road vehicle moderate pollution control (diesel)	$2.73*10^{-3}$	$1.3*10^{-7}$	$1.0*10^{-7}$
Rail (diesel)	$2.73*10^{-3}$	$1.5*10^{-7}$	$1.1*10^{-6}$
Marine (diesel)	$2.73*10^{-3}$	$1.5*10^{-7}$	$1.0*10^{-6}$

Source: Neitzert, F., Olsen, K. and P. Collas, 1999, *Canada's Greenhouse Gas Inventory: 1997 Emissions and Removals with Trends*, (Ottawa: Greenhouse Gas Division, Pollution Data Branch, Air Pollution Prevention Directorate, Environment Canada).

5.3 Proportion of Peat Shipments by Truck, Rail and Ship

Trucks are used more commonly than rail for the land-based movement of peat because of their greater flexibility and lower shipping costs (Physical Distribution Advisory Service 1984). Trucks tend to be less expensive for short haul trips while trains and ships are economically superior for longer distance transport (Webber 1984).

Based on a survey of the peat industry, G. Hood of the Canadian Sphagnum Peat Moss Association (CSPMA) estimated that approximately 78% of Canadian peat (by weight) was transported primarily[8] by truck, 12% by rail and 10 % by ship in 1990 (pers. comm., 2001 10 18). Between 1990 and 2000, the transport of peat by truck had declined substantially, with transport by rail compensating for this decline. In the year 2000, 70% was shipped primarily by truck, with rail and ship accounting for 20% and 10%, respectively (G. Hood, pers. comm., 2001 10 18).

[7] Source: Transportation Table: National Climate Change Process (1998)

[8] Some shipments of peat to market rely on more than one mode of transportation. It is assumed that the mode that transports the peat over the majority of its distance is the mode of transport used.

It is assumed that truck and rail were the only methods used to transport peat within Canada and between Canada and the United States.[9] It is also assumed that trucks and trains were responsible for the same percentage of the peat shipments in both countries, and that all of the markets outside of the domestic and American markets were served by ship. By applying these assumptions to the data from the CSPMA, it follows that, in 1990, 87% of North American shipments of Canadian peat (measured in tonne-km)[10] were sent via truck. In the year 2000, this percentage had declined to 78%. In both cases, the remainder of the peat was shipped by rail. Estimates of the proportions of peat shipments that travelled by truck and train from 1990 to 2000 are shown in Table 5-2.

Table 5-2. Proportion of the Land-Based Peat Shipments Served by Trucks and Trains, 1990-2000

Year	Proportion by Truck (P_{Truck})	Proportion by Rail (P_{Rail})
1990	0.870	0.130
1991	0.861	0.139
1992	0.852	0.148
1993	0.843	0.157
1994	0.834	0.166
1995	0.825	0.175
1996	0.816	0.184
1997	0.807	0.193
1998	0.798	0.202
1999	0.789	0.211
2000	0.780	0.220

The proportions shown in Table 5-2 were used in the following equation to calculate the GHG emissions from transporting peat to markets by land ($LBGHG_{Emissions}$):

Equation 5-4

$$LBGHG_{Emissions} = P_{Truck} * (GHG_{Truck}) + P_{Rail} * (GHG_{Rail})$$

where P_{Truck} represents the proportion of land-based peat shipments by truck, P_{Rail} signifies the proportion of land-based peat shipments by rail, GHG_{Truck} represents the GHG emissions from the transport of peat to market if all land-based shipments were by

[9] In the late 1990s, ships were used to transport peat from New Brunswick to Florida, but this was a very small percentage of total exports to the United States (less than 1%) (Statistics Canada 2000).
[10] A tonne-kilometre is defined as the number of tonnes of peat in a shipment, multiplied by the distance it travels (in km) to get to market.

truck, and GHG_{Rail} represents the GHG emissions if all land-based shipments were by rail.

5.4 Size of Domestic, American and Overseas Markets for Peat

During the period from 1990 to 2000, Canadian peat had been shipped to over fifty countries around the world, with the majority of peat shipped to the United States. Table 5-3 depicts the amount of Canadian peat that was consumed domestically, in the United States and overseas[11] over this eleven-year period.

Table 5-3. Amount of Canadian Peat Consumed in Domestic, American and Overseas Markets, 1990-2000

Year	Domestic Market	American Market	Overseas Market
		tonnes of peat	
1990	99 618	542 431	73 727
1991	190 731	592 157	73 529
1992	22 136†	637 051	80 733
1993	139 001	644 724	88 878
1994	208 105	665 283	94 004
1995	103 776	667 311	105 913
1996	133 996	665 550	101 454
1997	230 526	751 839	71 635
1998	275 850	759 428	89 722
1999	334 062	750 086	95 852
2000	330 876	781 097	165 027

† Although the size of the domestic market in 1992 seems abnormally small in comparison with other years, this figure is based upon the published peat extraction and export figures from Energy, Mines and Resources Canada (1994) and Statistics Canada (1996).

Sources: Statistics Canada, 2000-2002, *Non-metallic Mineral Mining and Quarrying*, Catalogue no. 26-226. Statistics Canada, 1996-1999, *Non-metal mines*, Catalogue no. 26-224. Statistics Canada, 1996, *Trade information and retrieval system*, (CD-ROM). Energy, Mines and Resources Canada / Natural Resources Canada, 1992-1996, *Canadian Minerals Yearbook: Review and Outlook*. Natural Resources Canada, Minerals and Mining Statistics Division, J. Toro, personal communication, 2001 08 29.

Figure 5-1 illustrates the percentage of total Canadian peat production exported and consumed domestically over the 1960 to 2000 period. As the figure indicates, there does not appear to be any long-term trend for the exported proportion of Canadian peat production to increase or decrease.

[11] In this study, exports of Canadian peat to non-American markets are considered exports to overseas markets.

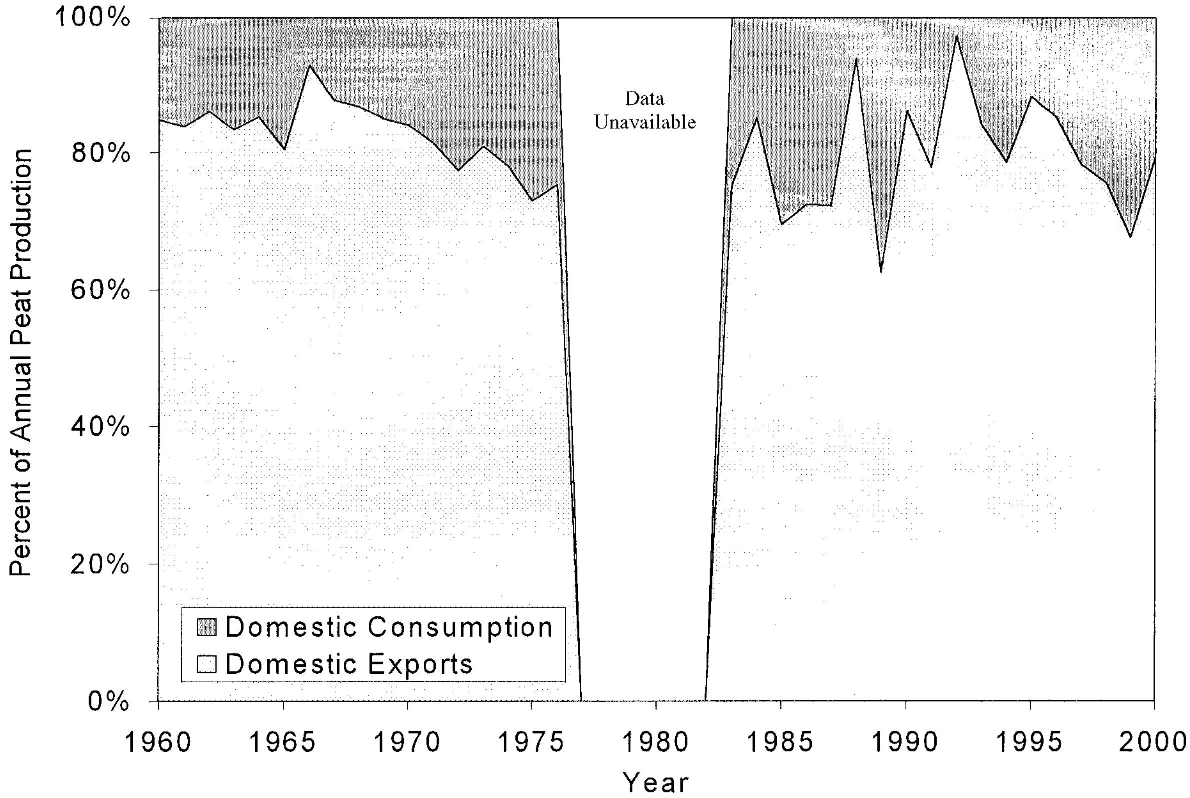

Figure 5-1. Percentage of Canadian Peat Production Exported and Consumed Domestically, 1960-2000. [Note: Peat export statistics are unavailable for the years 1977 to 1982.]

5.5 Domestic Transport

From 1990 to 2000, the size of the peat market in Canada varied widely from a low of 3.0% to a high of 32.5% of annual peat production (Statistics Canada 1991-2001; J. Toro, pers. comm., 2001 08 29). Data on the primary destinations[12] for Canadian peat deliveries from major producing regions in 1987 and 1988 (Energy, Mines and Resources 1991; 1990) was extrapolated in order to estimate the GHG emissions resulting from the transportation of peat to domestic markets.[13] These studies identified the shipments of peat within and between Western Canada (British Columbia, Alberta, Saskatchewan, Manitoba), Central Canada (Ontario, Quebec) and Atlantic Canada (New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland).

[12] A primary destination is the first destination of a shipped good. The good may be transferred to another location before it is used (Statistics Canada, Trucking Section, Transportation Division, John Nicoletta, pers. comm., 2002 06 11).

[13] The years 1987 and 1988 were the only years in which such data was available. In other years, tonnage of peat was aggregated with other materials (Statistics Canada, Trucking Section, Transportation Division, John Nicoletta, pers. comm., 2002 06 11).

By taking averages of the data from the 1987 and 1988 studies, it was estimated that Western, Central and Atlantic Canada accounted for 11.7%, 54.8% and 33.5% of peat extraction destined for the domestic market, respectively (signified by $Pext_{wc}$, $Pext_{cc}$, and $Pext_{ac}$ as proportions in Equation 5-5). The proportions of peat shipped between and within Western, Central and Atlantic Canada were estimated from the Energy, Mines and Resources Canada data. This data reveals that there is relatively little peat shipped between these three regions. It would also seem to confirm the observation of the peat company, Normiska, that supply lines from Canadian peat establishments generally run north to south ("Peat Products" http://www.normiska.com/ourproducts/peatproducts/ppmoss.html). To estimate the GHG emissions resulting from the transport of peat to domestic markets, it was assumed that there had been no change in the relative amounts of peat extracted and consumed in Western, Central and Atlantic Canada since the late 1980s.

Equation 5-5 was used to estimate the number of tonne-km that peat destined for domestic markets was shipped (Tkm_{DOMyr}) during the 1990 to 2000 period:

Equation 5-5

$$Tkm_{DOMyr} = Cdom_{yr}*\{Pext_{wc}*[(Pc_{wc}*D_{wc})+(Pc_{wccc}*D_{wccc})+(Pc_{wcac}*D_{wcac})] +Pext_{cc}*[(Pc_{ccwc}*D_{wccc})+(Pc_{cc}*D_{cc})+(Pc_{ccac}*D_{ccac})] +Pext_{ac}*[(Pc_{acwc}*D_{wcac})+(Pc_{accc}*D_{ccac})+(Pc_{ac}*D_{ac})]\}$$

where $Cdom_{yr}$ represents the domestic consumption of peat in year $_{yr}$ (tonnes); $Pext_{wc}$ (=0.117), $Pext_{cc}$ (=0.548) and $Pext_{ac}$ (=0.335) signify the proportions of domestic peat extraction derived from Western Canada (wc), Central Canada (cc) and Atlantic Canada (ac), respectively; Pc_{wc} (=1), Pc_{ccwc} (=0) and Pc_{acwc} (=0.003) represent the proportions of peat extracted in Western Canada, Central Canada, and Atlantic Canada that were consumed in Western Canada; Pc_{wccc} (=0), Pc_{cc} (=1) and Pc_{accc} (=0.696) represent the proportions of peat extracted in Western Canada, Central Canada, and Atlantic Canada that were consumed in Central Canada; Pc_{wcac} (=0) Pc_{ccac} (=0) and Pc_{ac} (=0.301) represent the proportions of peat extracted in Western Canada, Central Canada, and Atlantic Canada that were consumed in Atlantic Canada; D_{wc} (=917.5 km), D_{wccc} (=2693 km), D_{wcac} (=3484.5 km), D_{cc} (=545 km), D_{ccac} (=1052.5 km) and D_{ac} (=419 km) represent the distances that peat travels within and between Western Canada, Central Canada and Atlantic Canada (km). Tkm_{DOMyr} replaces the "$S*D$" portion of equations 5-1 and 5-2 in order to calculate the GHG emissions from the transportation of peat to domestic markets.

The distances travelled by the peat within the major producing regions were adapted from the methodology used in a paper by Brown and Anderson (2002). This adaptation is depicted in *Appendix D: Transportation Distances*.

As described in *Appendix C: Overview of Questionnaire Design and Results*, an extrapolation of the questionnaire data on provincial peat consumption would likely not be representative of the distribution of peat consumption across the country. However, the data proved valuable in elucidating the peat distribution patterns between certain regions of the country.

Table 5-4 displays the carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions for the transportation of Canadian peat to domestic markets.

Table 5-4. Greenhouse Gas Emissions from the Transport of Peat to Markets in Canada, 1990-2000

Year	Total GHG Emissions		
	CO_2	CH_4	N_2O
	tonnes		
1990	3 900	0.2	0.2
1991	7 400	0.4	0.4
1992	900	0.0	0.1
1993	5 300	0.3	0.3
1994	7 900	0.4	0.5
1995	3 900	0.2	0.2
1996	5 000	0.2	0.3
1997	8 600	0.4	0.5
1998	10 200	0.5	0.7
1999	12 300	0.6	0.8
2000	12 100	0.6	0.8

5.6 Transport between Canada and the United States

The vast majority of Canada's peat exports were shipped to the United States from the year 1990 to 2000. Therefore, the use of domestic export data from Statistics Canada (2000; 1996) that specified the American state to which the peat was destined greatly reduced the uncertainty in estimating the distances travelled and the GHG emissions resulting from peat transport. Unfortunately, at the time of writing, Statistics

Canada did not possess the appropriate peat export data for the year 1990 and the year 2000.

The median distances travelled between each province and U.S. state were derived from a method developed in a paper by Brown and Anderson (2002) (*Appendix D: Transportation Distances*).

The tonne-kilometres of peat shipments to the United States in the years 1990 and 2000 were estimated by extrapolating from a linear relationship produced between the tonne-km of peat exports to the United States from 1991 to 1999 and the size of peat exports to the United States (Figure 5-2). The tonne-km are equivalent to "*S*D*" in equations 5-1 and 5-2).

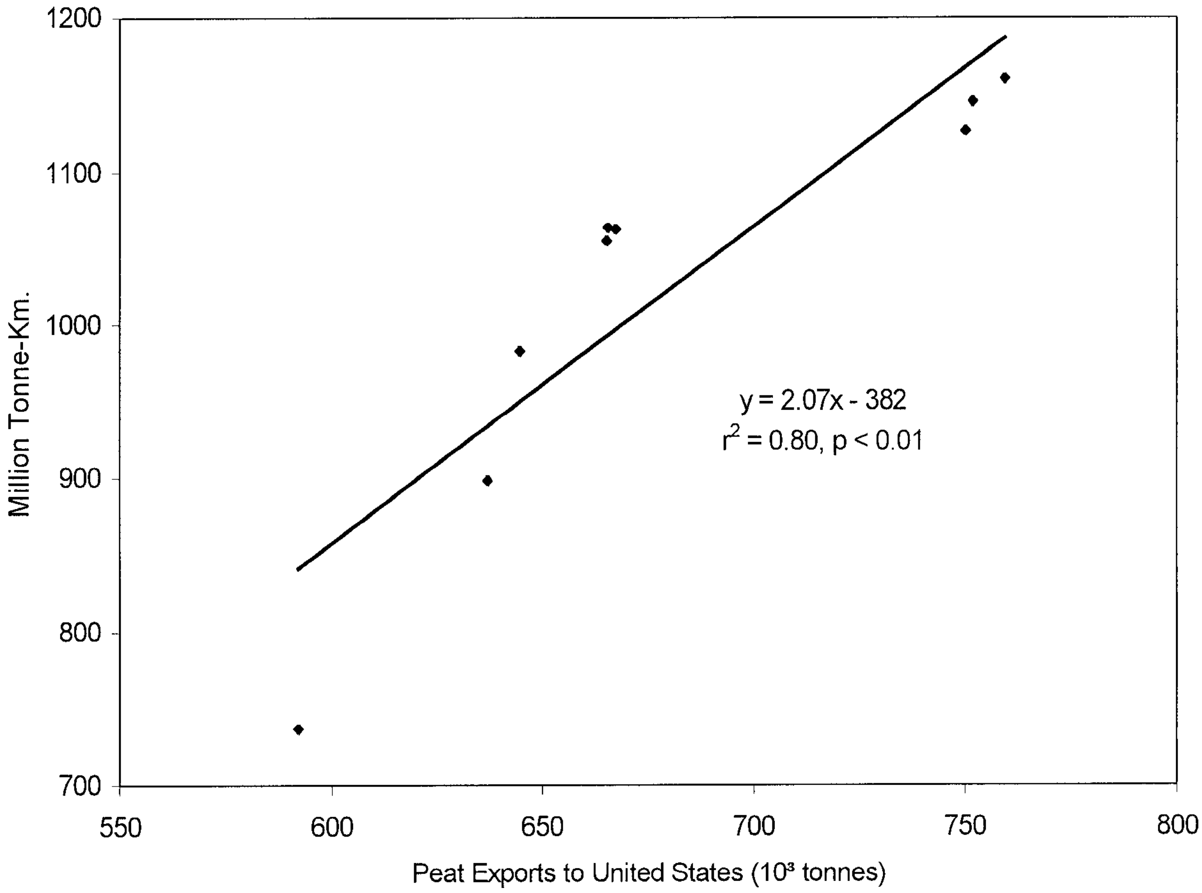

Figure 5-2. Tonne-Kilometres of Peat Shipments Versus Peat Exports to the United States, 1991-1999

The result of the GHG calculations for peat shipped to the American market is shown in Table 5-5.

Table 5-5. Greenhouse Gases Emitted from the Transport of Peat to Markets in the United States, 1990-2000

Year	Total GHG Emissions		
	CO_2	CH_4	N_2O
	tonnes		
1990	40 300	1.9	2.2
1991	40 900	2.0	2.3
1992	49 600	2.4	2.8
1993	53 900	2.6	3.1
1994	57 500	2.8	3.4
1995	57 500	2.8	3.5
1996	57 200	2.8	3.5
1997	61 200	2.9	3.9
1998	61 500	3.0	4.0
1999	59 300	2.9	3.9
2000	63 400	3.1	4.3

5.7 Overseas Transport

Markets for peat outside of Canada and the United States have ranged between 6.8% and 13.8% of Canada's annual peat production in the period 1990 to 2000 (J. Toro, pers. comm., 2001 08 29; Statistics Canada 1991-2001). It was assumed that all markets outside of the U.S. and Canada were served by ship.[14] Estimates of GHG emissions from the overseas transport of peat required the use of export statistics, estimates of the distances between major ports of the world, as well as the fuel efficiency of marine transport. It was assumed that the peat for overseas markets travelled an average of 250 km from the location of extraction to the shipping port, and another 250 km from the overseas port of arrival to its final market destination. The figures displayed in Table 5-2 were used to depict the proportions of the land-based shipments using truck and rail. The GHG emission figures for overseas transport include those from marine and land-based transport to markets.

[14] Trucks and trains are used to transfer peat to and from shipping ports. Some Canadian peat has been shipped to Mexico by truck, although it is a miniscule figure (less than 232 tonnes annually between 1990-2000) (J. Toro, pers. comm., 2001 08 29; Statistics Canada 1991-2001).

The distances to ship peat overseas were generated from World-Ports Distances software available at *http://www.distances.com*. *Appendix D: Transportation Distances*, contains further information on the method used to estimate the distances that Canadian peat would travel to overseas markets.

Table 5-6 displays the carbon dioxide, methane and nitrous oxide emissions for overseas peat transport. The GHG emissions resulting from peat shipments to countries that received less than a total of 100 tonnes of peat over the eleven-year time horizon from 1990 to 2000 were not accounted for. This omission should have a negligible effect on the GHG estimates, since it represents the transport of a total of 1 379 tonnes of peat to overseas markets, out of a total of 1 040 356 tonnes, or 0.13% of the total.

Table 5-6. Greenhouse Gases Emitted from the Transport of Peat to Markets other than Canada and the United States, 1990-2000

Year	Total GHG Emissions		
	CO_2	CH_4	N_2O
	tonnes		
1990	8 000	0.4	0.3
1991	8 100	0.4	0.3
1992	8 900	0.4	0.4
1993	9 700	0.5	0.4
1994	10 200	0.5	0.4
1995	11 400	0.5	0.5
1996	10 900	0.5	0.5
1997	7 800	0.4	0.3
1998	8 800	0.4	0.4
1999	9 000	0.4	0.4
2000	17 700	0.8	0.8

5.8 Total Greenhouse Gas Emissions from Transportation

The greenhouse gas emissions from the transport of peat to domestic, American and overseas markets were added together to produce the total emissions from the transport of Canadian peat to all markets between 1990 and 2000 (Table 5-7).

Table 5-7. Greenhouse Gases Emitted from Peat Transportation, 1990-2000

Year	Total GHG Emissions		
	CO_2	CH_4	N_2O
	tonnes		
1990	52 200	2.5	2.7
1991	56 400	2.7	3.0
1992	59 400	2.8	3.2
1993	68 900	3.3	3.8
1994	75 600	3.6	4.3
1995	72 900	3.5	4.2
1996	73 100	3.5	4.3
1997	77 500	3.7	4.8
1998	80 500	3.9	5.0
1999	80 600	3.9	5.2
2000	93 100	4.5	5.9

5.9 Greenhouse Gas Intensity

A greenhouse gas intensity indicator may be used to quantify and compare the GHG emissions from transportation, per tonne of peat shipped, to the domestic, American and overseas markets. Although the distance travelled by truck, train or ship, is an important factor in GHG production, this factor may be counterbalanced by the superior fuel efficiencies of trains and ships over trucks. The results displayed in Table 5-8 indicate that a unit of peat destined for the domestic market is less GHG intensive than one destined for the American and overseas markets. Distance would, therefore, seem to be the most important factor influencing GHG production from peat transport.

Table 5-8. Greenhouse Gas Intensity of Peat Shipments to the Domestic, American and Overseas Markets, 1990-2000

Year	GHG Intensity		
	Domestic Market	U.S. Market	Overseas Market
	tonnes of GHG (CO_2 equivalents) / tonne of peat		
1990	0.0397	0.0756	0.1098
1991	0.0394	0.0703	0.1110
1992	0.0392	0.0793	0.1115
1993	0.0390	0.0851	0.1109
1994	0.0387	0.0880	0.1104
1995	0.0385	0.0878	0.1092
1996	0.0382	0.0876	0.1086
1997	0.0380	0.0830	0.1098
1998	0.0377	0.0826	0.0997
1999	0.0375	0.0807	0.0957
2000	0.0372	0.0829	0.1085

5.10 "Business As Usual" Greenhouse Gas Emissions

There appears to be a significant relationship between greenhouse gas emissions resulting from the transportation of peat to market and annual peat extraction. An x-y scatter diagram was produced to illustrate the quantitative relationship between the GHG emissions from peat transportation (in CO_2 equivalents) and peat extraction, for the period 1990 to 2000 (Figure 5-3). A linear relationship was defined between GHG emissions and peat extraction.

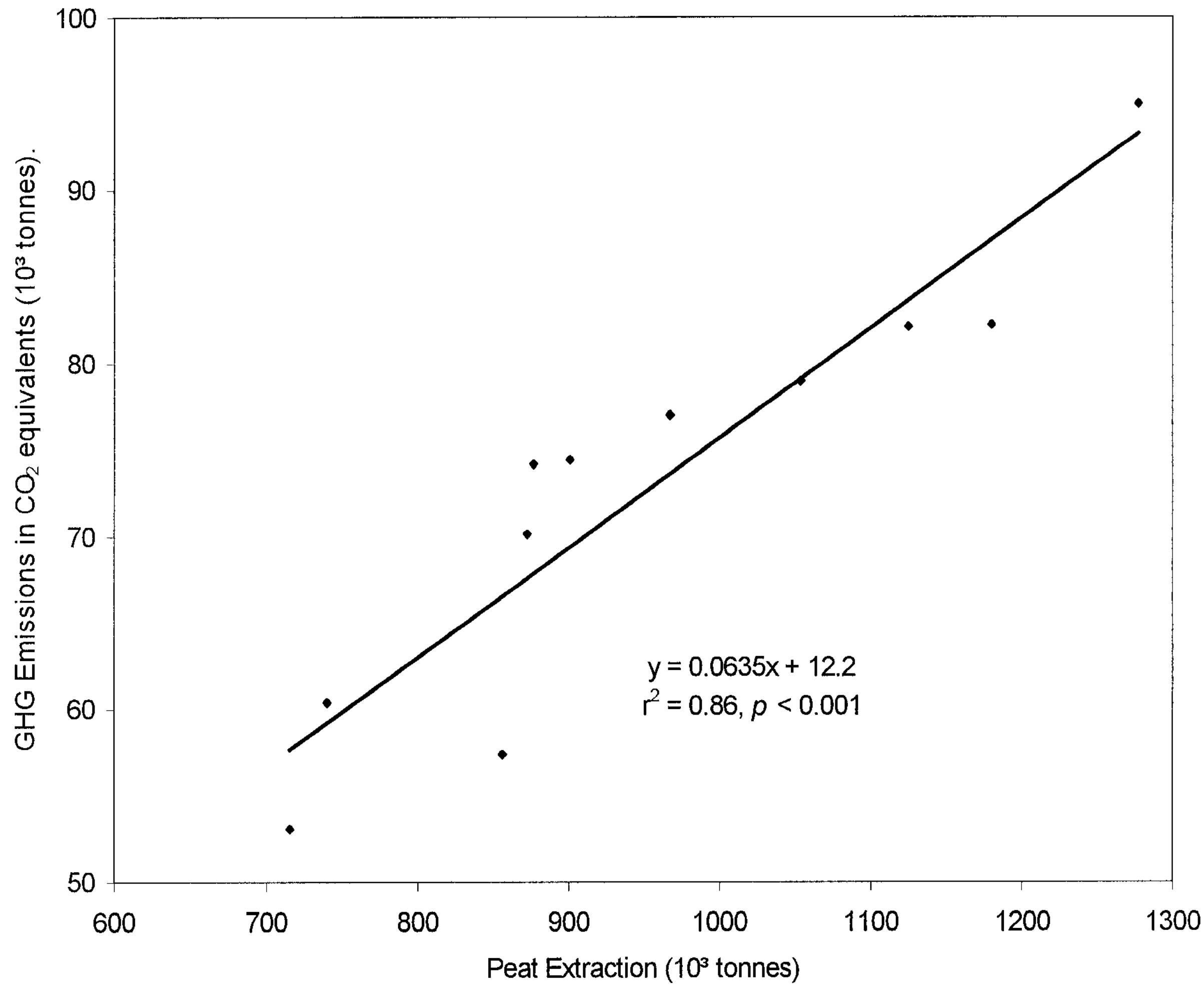

Figure 5-3. Greenhouse Gas Emissions from Peat Transportation Versus Peat Extraction, 1990-2000

The "business as usual" greenhouse gas emissions from the transportation of peat were based upon an extrapolation of the linear relationship defined in Figure 5-3, assuming that peat extraction would increase by 5% annually,[15] and using the year 2000 as the base year. The "business as usual" GHG emissions from 2001 to 2012, as well as the percent change of these emissions from 1990, are shown in Table 5-9.

Table 5-9. "Business as Usual" Greenhouse Gas Emissions from the Transportation of Peat, 2001-2012

Year	Extraction	"Business as Usual" GHG Emissions	Percent Change from 1990
	tonnes of peat	tonnes of GHG in CO_2 equivalents	%
2001	1 340 850	97 300	83
2002	1 407 893	101 600	91
2003	1 478 287	106 100	100
2004	1 552 201	110 800	109
2005	1 629 812	115 700	118
2006	1 711 302	120 900	128
2007	1 796 867	126 300	138
2008	1 886 711	132 000	149
2009	1 981 046	138 000	160
2010	2 080 098	144 300	172
2011	2 184 103	150 900	184
2012	2 293 309	157 800	197

5.11 Greenhouse Gas Reduction Scenarios

A reduction of greenhouse gas emissions from peat transportation may be achieved in several ways: one could reduce the mass of peat transported, the distance required to transport the material, or adopt a more fuel-efficient mode of transport. There are already substantial economic incentives to reduce the distance to ship peat to market, since peat is very price sensitive (Physical Distribution Advisory Service 1984). GHG reductions may be achieved by locating production sites closer to the location of peat consumption. For example, peat extraction sites in Manitoba were expressly developed due to their proximity to central and mid-western United States markets (Physical Distribution Advisory Service 1984).

[15] An explanation for the use of a 5% annual rate of growth is provided in section 7.6 of the "Summary and Discussion" chapter.

One feasible method to decrease GHG emissions would be to use trains instead of trucks whenever possible. To provide an indication of the impact on GHG emissions of substituting trains for trucks, the GHG emissions from peat transport to market have been estimated for a scenario whereby 80% of land-based peat transport takes place by rail. Although it is unlikely that this scenario will take place in the short term, the increasing availability of inter-modal services could make trains more attractive for peat shipments in the future.

A linear relationship was defined between the GHGs resulting from peat transportation (with 80% of land-based travel by rail) calculated for the period from 1990 to 2000, and peat extraction, (Figure 5-4). By substituting the predicted "business as usual" levels of peat extraction into the linear regression equation, the GHG emissions resulting from a scenario whereby 80% of land-based travel takes place by rail are predicted.

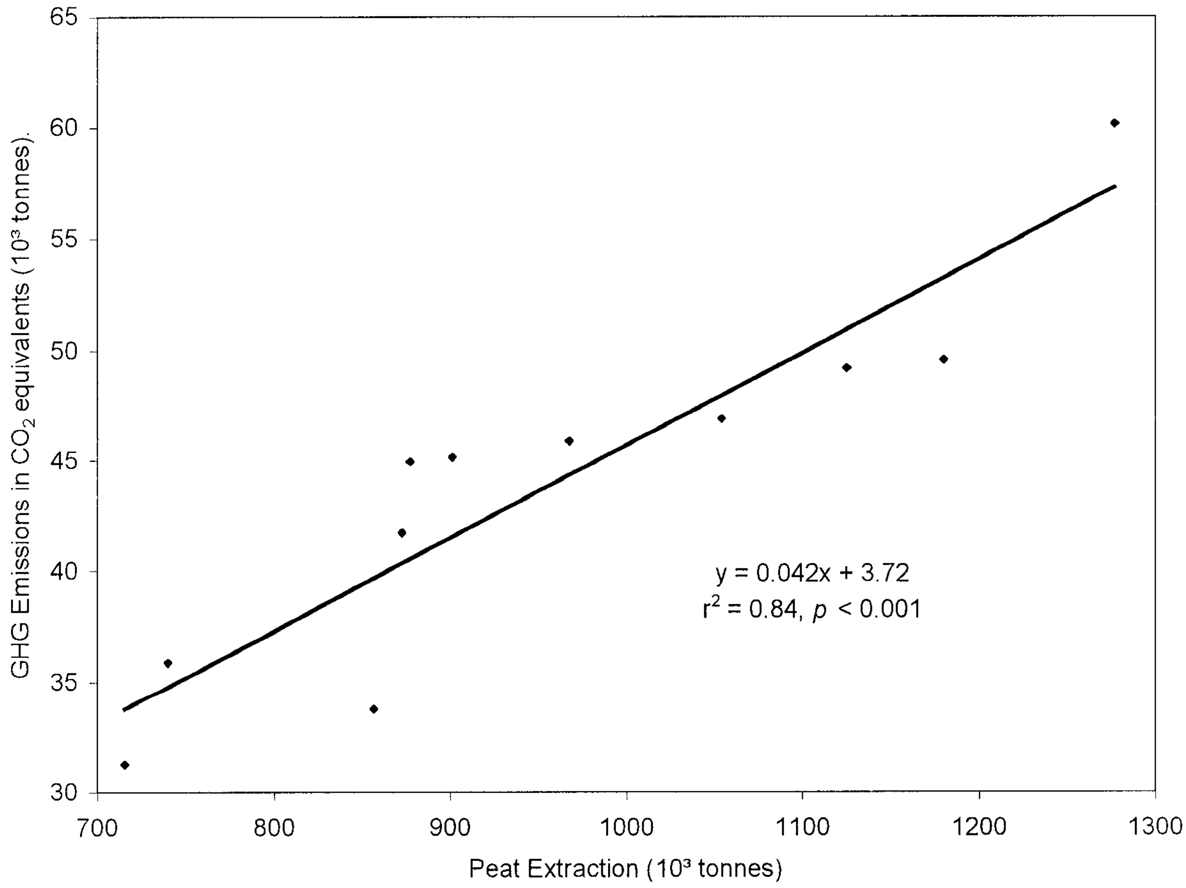

Figure 5-4. Greenhouse Gas Emissions from Peat Transportation (with 80% of Land-Based Travel by Rail) Versus Peat Extraction

Table 5-10 displays the estimates of the GHG emissions from the transportation of peat from 2001 to 2012, assuming that 80% of the land-based transport is by rail. These estimates show a substantial reduction in GHG emissions over the "business as usual" scenario depicted in Table 5-9. Nevertheless, this scenario does not achieve GHG emission levels below that of 1990, which is mandated under the Kyoto Protocol. In fact, the GHG emissions in 2010 are at almost twice the level of 1990.

Table 5-10. Greenhouse Gas Emissions from the Transportation of Peat, Assuming That 80% of Land-Based Shipments Travel by Rail, 2001-2012

Year	Extraction	GHG Emissions 80% Rail	Percent Change from 1990
	tonnes of peat	tonnes of GHG in CO_2 equivalents	%
2001	1 340 850	60 000	13
2002	1 407 893	62 900	18
2003	1 478 287	65 800	24
2004	1 552 201	68 900	30
2005	1 629 812	72 200	36
2006	1 711 302	75 600	42
2007	1 796 867	79 200	49
2008	1 886 711	83 000	56
2009	1 981 046	86 900	64
2010	2 080 098	91 100	72
2011	2 184 103	95 500	80
2012	2 293 309	100 000	89

Technological advances in the design of trucks, trains and ships should decrease GHG emissions per unit of peat shipped. In addition, GHG emissions may be reduced if additional peat could be carried in truck, rail and ocean containers due to an increase in peat compression ratios (Physical Distribution Advisory Service 1984). This solution would be constrained by highway weight restrictions and a questionable demand for highly compressed peat.

CHAPTER SIX

DECOMPOSITION OF EXTRACTED PEAT

The identification and quantification of the long-term environmental impacts of product use and disposal are inherent components of life cycle assessments (Todd and Curran 1999). This chapter provides a synthesis of knowledge on the rate of decomposition of extracted peat and attempts to quantify the greenhouse gases that emerge from the decomposition of this product.

Extracted peat decomposes through bacterial and fungal activity, which tends to vary with temperature, the carbon:nitrogen ratio, pH, and water availability (Belyea 1996; Mathur and Lévesque 1980). The decomposition process generates carbon dioxide under aerobic conditions, and both methane and carbon dioxide under anaerobic conditions.

6.1 Stockpiling

Once extracted from a drained peat bog, the peat is formed into stockpiles until it is deemed ready to be moved into the peat processing facility for screening and bagging (Three-D Geoconsultants 1992). Results from the questionnaire indicate that Canadian peat remains stockpiled for an average of 5.6 months, with 98.5% of total production stored in outdoor stockpiles at some point (*Appendix C: Overview of Questionnaire Design and Results*).

The drying of extracted peat in outdoor stockpiles fosters aerobic conditions that increase the decomposition rate of the peat, thus generating heat. Since the thermal conductivity of peat is relatively low, it cannot dissipate all of the heat produced in the peat stockpile as fast as it is generated (Silvola and Ahlholm 1989). The rise in temperature within the stockpile further accelerates its decomposition. Relatively large emissions of greenhouse gases may occur from extracted peat when stockpiled, mostly due to this self-heating phenomenon (Ahlholm and Silvola 1990).

The process of self-heating may be reduced by preventing oxygen from diffusing into the stockpiles (Silvola and Ahlholm 1989; Mikola and Komppula 1981). Covering a stockpile with plastic sheeting may decrease the occurrence of self-heating, the loss of peat through wind action, as well as the possibility of spontaneous combustion (Z. Gautrealt, pers. comm., 2001 06 11). The responses to the questionnaire suggest that 68.3% of peat companies cover their stockpiles with plastic sheeting as soon as the stockpiles are constructed (*Appendix C: Overview of Questionnaire Design and Results* - Table A4). Without such mitigation measures, GHG emissions from stockpiles may reach a level of 3 g CO_2 m^2/h, depending on the mass of peat stockpiled per unit area (Ahlholm and Silvola 1990).

6.2 Uses of Peat

Some common properties of extracted peat include a high water-retention capacity, low density, relatively high resistance to decomposition, low heat conductivity, and high porosity (Prud'homme 1991). These properties make *Sphagnum* peat moss ideal for use in horticulture, nurseries, landscaping, gardening, and mushroom farming (Daigle and Gautreau-Daigle 2001; Prud'homme 1991). A study by Fred Kennedy & Associates (1997) noted that 32.4% of peat products from New Brunswick were used for greenhouse and horticultural uses, 23.1% for retail trade, and 16.9% for mushroom farming, with the rest (27.6%) used for other value-added purposes. The last year that Canada produced peat for use as a fuel was in 1954 because the product was deemed more profitable for other purposes.[1]

Used in agriculture and horticulture as a soil conditioner, peat improves clay soils, retains moisture in sandy soils, and adds organic matter to depleted soils (Bergeron 1996). It is utilized in the manufacture of artificial mixtures such as potting soil, seedling flats, peat-perlite and peat-vermiculite blends, fertilizers and compost (Schmilewski 1996). Peat can be used as bedding in stables, barns and henhouses in order to absorb liquids and odours (Bergeron 1996). It is also made into pots for the germination of seeds (Daigle and Gautreau-Daigle 2001; Schmilewski 1996). Industrial uses include the purification of industrial and domestic effluents, the absorption of oil spills, and the production of paper serviettes, chemicals, metallurgical coke and activated charcoal (Rubec 1996).

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[1] The Dominion Bureau of Statistics / Statistics Canada (1944-2001) did not record any peat extracted for fuel after 1954.

6.3 Decay Functions

In the scientific literature, three main types of equations have been used to depict the rate of decomposition of organic matter, including single and double exponential decay functions and non-zero asymptotic functions (Latter *et al.* 1998, Updegraff *et al.* 1995). As there is ample evidence that peat becomes increasingly recalcitrant with time, linear decay constants do not seem appropriate for the depiction of peat decomposition (Cannell *et al.* 1993; Hogg *et al.* 1992; Clymo 1984; Janssen 1984; Weider and Lang 1982). Single exponential decay functions, which presuppose that the decomposition rate of peat remains constant relative to the amount of substrate remaining, do not account for a number of characteristics of peat that may affect its decomposition patterns (Latter *et al.* 1998; Weider and Lang 1982). For instance, one component of peat may show a different rate of decomposition than another, or may prove resistant to decomposition. Under such circumstances, double exponential functions or non-zero asymptotic decay functions may prove superior (Latter *et al.* 1998). These functions partition organic matter into two pools, one labile, the other recalcitrant, that decay at different rates, but do not consider any transfer of material between the pools (Updegraff *et al.* 1995; Weider and Lang 1982). The non-zero asymptotic function may closely depict decomposition data, but incorrectly assumes that one portion of the peat sample is entirely resistant to decomposition (Wieder and Lang 1982). All of the aforementioned functions possess substantial uncertainty in depicting decomposition.

With the dearth of long-term studies depicting peat decomposition, an attempt to predict the size of the labile and recalcitrant fractions of peat carbon and their respective rates of decomposition would accomplish little in reducing the uncertainty of the annual GHG estimates. Therefore, after consulting the body of literature that contains empirical data on the decomposition of peat and assessing this data, it seems reasonable to use a single exponential decay function with an annual decay rate for peat carbon of 5% (see Section 6.4), relative to the amount of peat remaining.

6.4 Rates of Peat Decomposition

There are few empirical studies of peat decomposition that last more than one year, and I have been unable to locate any studies of ten years or more. Much research has shown the aerobic decomposition of peat carbon in the first year to range from 0% to 6% for moderately to well-humified peat (Scanlon and Moore 2000, Updegraff *et al.* 1995; Hogg 1993; Hogg *et al.* 1992; Murayama *et al.* 1990; Farrell and McDonnell 1986). Fewer studies have shown rates reaching levels above 10% in the first year, and these have generally depicted the decomposition of peat mixed with other substances such as fertilizer and soil. The variations shown in these empirical studies provide an indication of the scale of uncertainty associated with GHG estimates for peat decomposition.

In his study of the decay potential of peat at different depths in a Swedish raised bog, Hogg (1993) estimated that *Sphagnum* peat derived from a depth of 10 to 12.5 cm show an average mass loss of 2.6% annually under aerobic field conditions. Another field study has shown carbon losses between 0% and approximately 6% over one year for *Sphagnum* and *Carex* peat derived from depths of 6 to 22 cm (Murayama *et al.* 1990).

Peat incubation studies have shown similar results. For peat derived from a depth of one metre, Updegraff *et al.* (1995) observed a mass loss of 7.2% over 80 weeks at 15 °C, and of 8.4% at 30 °C. This correlates to 4.7% and 5.4% over one year, respectively, assuming that the rate of decomposition remained constant over the period of measurement.

Studies by Hogg *et al.* (1992), Farrell and McDonnell (1986), and Scanlon and Moore (2000) show peat decomposition rates that are slightly lower than Updegraff *et al.* (1995). Hogg *et al.* (1992) measured the loss of peat mass derived from different depth intervals of a peat bog. They found that, at 16 °C, the dry mass loss of peat derived from a depth interval of 30 to 40 cm below the surface was less than 1% over a 125-day period. If this rate of decomposition remained constant over an entire year,[2] the peat would have shown a mass loss of approximately 2%. In a 14-week incubation experiment, Farrell and McDonnell (1986) measured the carbon dioxide evolution from primarily *Sphagnum* peat derived from an ombrotrophic bog. The peat would lose 1.4% of its dry mass if the rate of CO_2 evolution remained constant over the year (Farrell and McDonnell 1986). A decomposition study by Scanlon and Moore (2000), with

[2] It is unlikely that peat decomposition rates observed over periods of less than one year would remain constant over the entire year because decomposition rates tend to decrease with time.

incubations of *Sphagnum* peat (Von Post of 5.5) derived from a depth of 40 cm in an ombrotrophic bog in eastern Ontario, showed a loss of 1.6%, at 14 °C.

One factor that further complicates the depiction of peat decomposition is that the vast majority of extracted peat is mixed with other substances when used in horticulture, gardening, composting and mushroom farming. It is, therefore, difficult to isolate the decomposition of peat from the decomposition of the substances that are added to peat. Most studies indicate that the mixing of peat with soil increases the rate at which peat decomposes, since soil supplies microbial nutrients, such as nitrogen, that facilitate decomposition (Murayama *et al.* 1990).

In general, empirical studies by Murayama *et al.* (1990), Farrell and McDonnell (1986) and Aendekerk (1997) have shown that peat mixed with fertilizer or soil decomposes at a faster rate than peat in isolation. Murayama *et al.* (1990) found a mass loss varying from 3.7% to 10.9% per year when peat was mixed with soil (peat:soil ratios varied from 1:4 to 1:7). Farrell and McDonnell (1986) observed decomposition rates equivalent to 2.6% and 3.1% per year for peat mixed with soil at ratios of 1:1 and 1:2, respectively, assuming that the rate of CO_2 evolution over the 14-week period of measurement remained constant for an entire year.[3] Aendekerk (1997) studied the decomposition of fertilized, moderately humified peat (Von Post of 5) when raising nursery stock (*Chamaecyparis lawsoniana*) in containers at different levels of pH over 42 days. A carbon decomposition rate that varied from 0.72% to 3.04% was observed, with the fastest rate associated with a high pH level and the addition of fertilizer. If the decomposition rates remained constant over an entire year, a mass loss of between 6.3% and 26.4% could be extrapolated from these results.[4]

In order to estimate the rate of decomposition of extracted peat, the following assumptions have been made:

- Horticulture and gardening are the typical end uses of Canadian peat. This implies that extracted peat undergoes decomposition within an aerobic environment, thus generating carbon dioxide emissions;
- The rate of peat decomposition is not limited by lack of water;

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[3] See footnote 2.
[4] See footnote 2.

- The typical unit of extracted peat has a Von Post humification number of 7.[5]

It is assumed that the average rate of decomposition of extracted peat tends to be higher than the rates measured for peat in isolation, and lower than the rates measured for peat mixed with other substances. An annual rate of decomposition of 5% satisfies these criteria.

6.5 Quantity of Peat Extracted, 1941-2000

The GHG estimates for the decomposition of extracted peat were based upon non-fuel peat extraction statistics for the years 1941 to 2000. These statistics were derived from reports on the peat and non-metal mining industries by the Dominion Bureau of Statistics / Statistics Canada (2000-2002; 1996-1999; 1980-1991; 1942-1979) and Energy, Mines and Resources Canada / Natural Resources Canada (1992-1996) (See Figure 3.1). Over this 60-year period, a total of 24 323 555 tonnes of non-fuel peat was extracted, representing approximately 6 688 978 tonnes of carbon.[6] Very little peat was extracted before the 1940s, amounting to little more than a few thousand tonnes per year (Daigle and Gautreau-Daigle 2001; Swinnerton 1950).

6.6 Greenhouse Gas Accounting Results

The following single exponential decay equation was used to calculate the peat remaining from peat extracted in a particular year (P_t):

Equation 6-1

$$P_t = P_0 e^{-kt}$$

where P_t is the peat carbon remaining at time t, P_0 is the initial amount of peat carbon extracted, k is the annual rate of decomposition (0.05) and t is the number of years that the peat has been extracted.

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[5] Studies conducted by researchers from McGill University have shown that the average Von Post humification coefficient of peat from peatlands under extraction in Rivière-du-Loup, Québec and Shippagan, New Brunswick was approximately 6.7 (Nathan Basiliko, pers. comm., 2002).
[6] The total amount of peat extracted from 1941 to 2000 (including fuel peat) was 24 325 912, representing 6 689 626 tonnes of carbon.

The following equation was used in order to calculate the total amount of peat carbon extracted from 1941 onward that remained undecomposed in a particular year (Cr_{yr}):

Equation 6-2

$$Cr_{yr} = Cr_{yr-1} * 0.95 + Ext_{yr}$$

where Cr_{yr-1} represents the peat carbon remaining undecomposed in the previous year and Ext_{yr} represents the peat carbon extracted in the year of interest. Figure 6-1 depicts the total (non-fuel) peat extracted and the total non-decomposed extracted peat from the years 1941 to 2000. At a 5% annual rate of decomposition, 53.2% of the total peat extracted from 1941 to 2000 remained non-decomposed in the year 2000.

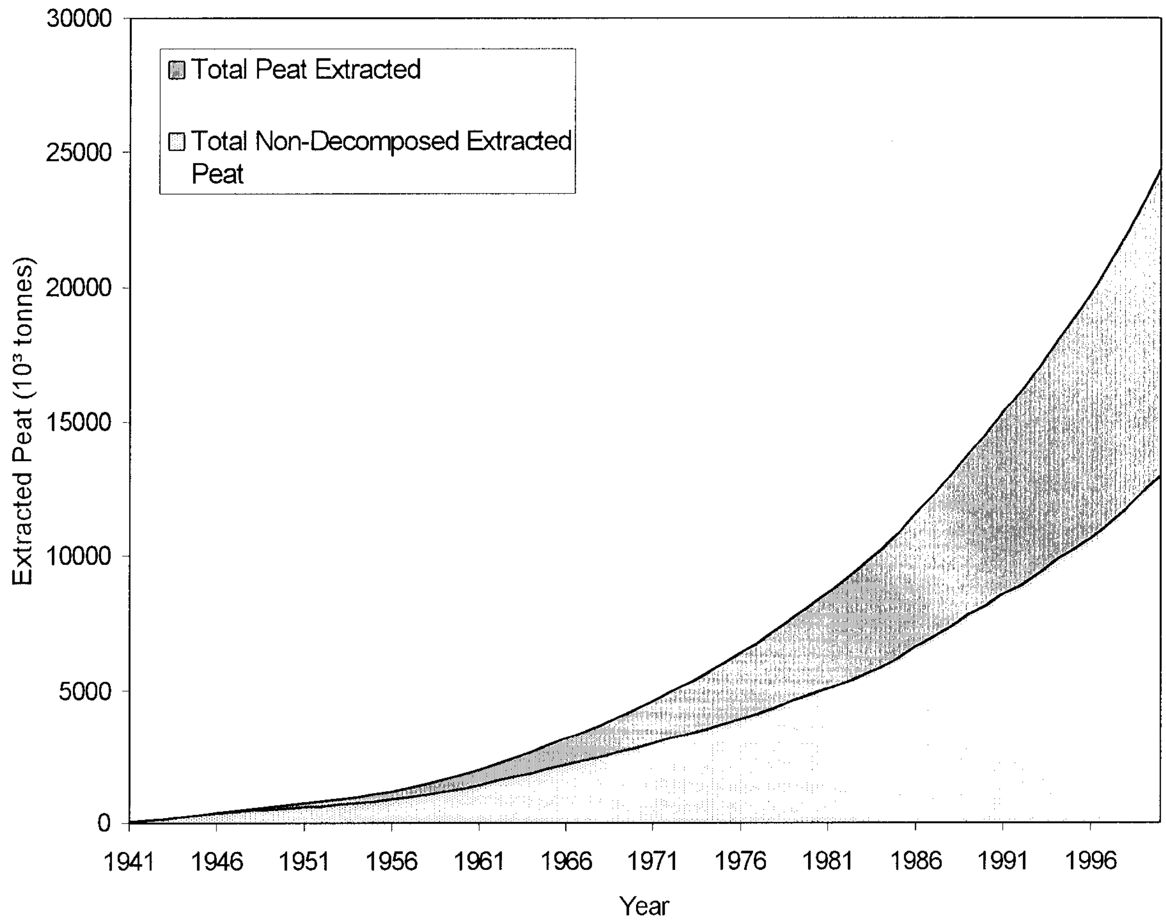

Figure 6-1. Total (Non-Fuel) Peat Extracted and Total Non-Decomposed Extracted Peat, 1941-2000

The greenhouse gases emitted in a particular year encompass the emissions from peat extracted from the year 1941 up to the year for which the GHG estimate is produced. For example, GHG emissions in the year 1990 include those from extracted peat that has been decomposing for some 50 years (1941-1990). The following equation was used to calculate the amount of carbon dioxide emitted into the atmosphere from the decomposition of extracted peat in a particular year (GHG_{yr}):

Equation 6-3

$$GHG_{yr} = (Cr_{yr-1} - Cr_{yr})*3.67$$

where Cr_{yr} represents the total amount of extracted peat carbon remaining undecomposed in a given year (tonnes), Cr_{yr-1} represents the total amount of peat carbon remaining undecomposed in the previous year (tonnes), and the constant (3.67) is used to convert tonnes of carbon to tonnes of CO_2.

Table 6-1 displays the CO_2 resulting from the decomposition of extracted peat for the years 1990 to 2000.

Table 6-1. Greenhouse Gas Emissions from the Decomposition of Extracted Peat, 1990-2000

Year	Carbon Dioxide Emissions Tonnes
1990	392 100
1991	408 600
1992	431 400
1993	447 100
1994	468 700
1995	494 100
1996	513 600
1997	533 300
1998	559 800
1999	588 500
2000	618 600

The uncertainty associated with the CO_2 estimates for peat decomposition can have a substantial impact on the final estimate of greenhouse gas emissions from the life cycle of peat extraction. Figure 6-2 illustrates the magnitude of GHG emissions if the annual rates of decomposition are 1%, 2.5%, 5%, 10%, 25% and 100%, assuming that peat decomposition shows a behaviour that could be depicted using a single exponential function.

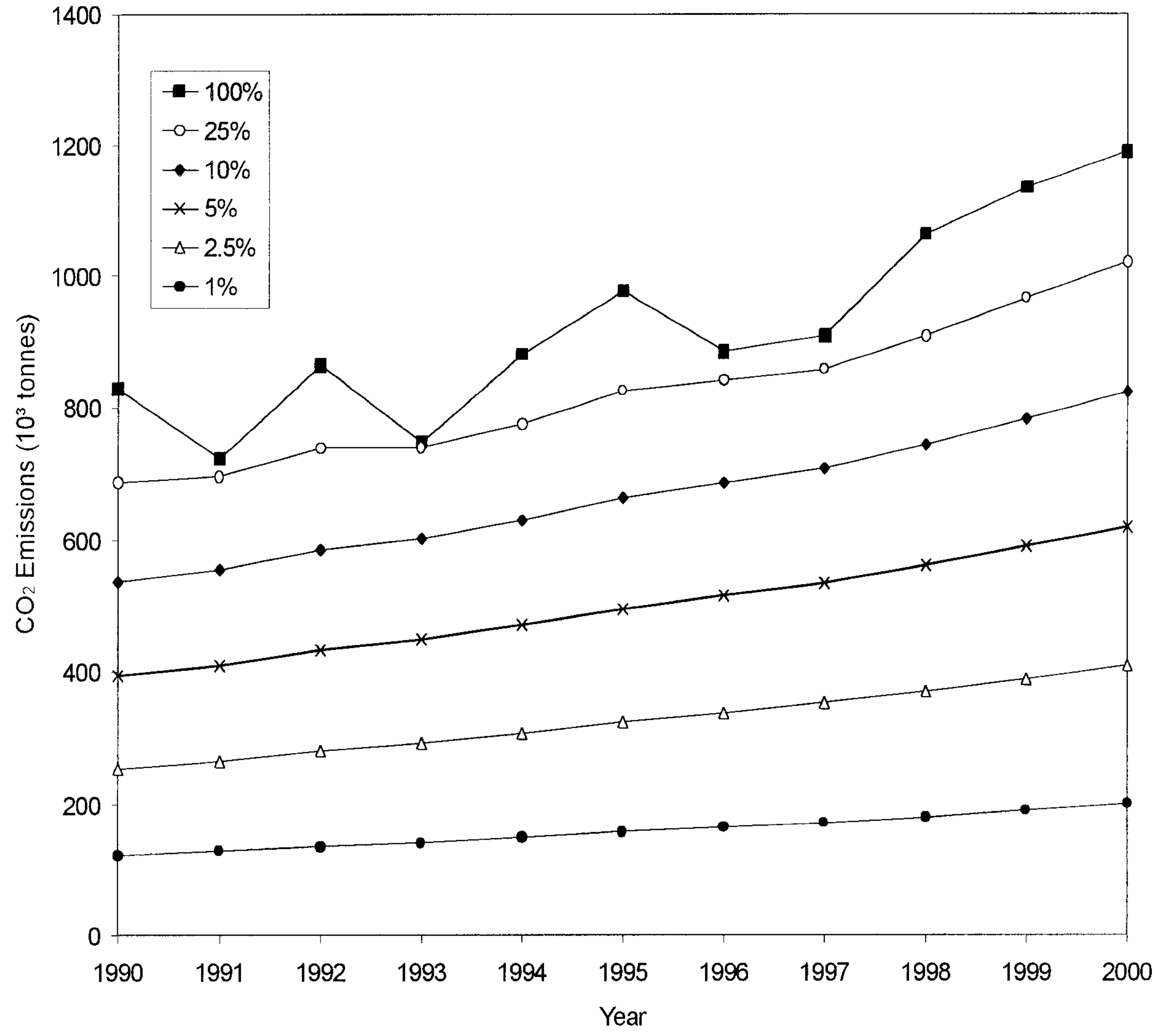

Figure 6-2. Annual Carbon Dioxide Emissions from Peat Decomposition at Different Rates of Decay, 1990-2000

Most of the variation in the levels of greenhouse gas emissions from peat decomposition is explained by decomposition rates of 10% or lower. For example, in the year 2000, carbon dioxide emissions resulting from a 5% annual rate of decay (619 000 tonnes) was almost equivalent to the difference in emissions from a 5% to a 100% annual decomposition rate (571 000 tonnes).

6.7 Greenhouse Gas Reduction Scenarios

The rate of decomposition of extracted peat may be decreased by storing the peat at low temperatures, by keeping it relatively dry, or by restricting its access to oxygen and nutrients. Unfortunately, many of the end uses of peat such as horticulture, landscaping, gardening, and mushroom farming necessarily create conditions that promote peat decomposition.

Strategies to reduce the GHGs emitted from peat decomposition are not easily implemented since companies and governments currently have little ability to measure and control the end uses of the product. Moreover, it is also difficult to quantify the effect of a specific end use of peat on GHG emissions due to the dearth of scientific research in this area.

Under certain circumstances, peat may contribute to processes that produce less greenhouse gas emissions than alternative processes that do not require peat. Therefore, it is possible for peat producers to enter into agreements with peat consumers for the purpose of reducing greenhouse gas emissions. Such agreements would be especially desirable in instances where peat would be used to stabilize a methane-emitting substance, such as sludge or liquid manure (Mutka 1996).

Though not decreasing greenhouse gas emissions from peat decomposition itself, the export of peat could reduce GHG emissions in Canada and increase those of peat-importing countries. The export of decomposable carbon-based products, such as peat or wood, is not yet recognized under the GHG accounting framework of the Intergovernmental Panel on Climate Change as a method of reducing domestic emissions (Olsen *et al.* 2002). Once this issue is resolved, it may be possible for one country to financially compensate another for importing peat because this transfer of decomposable carbon would help to reduce domestic GHG emissions.

CHAPTER SEVEN

SUMMARY AND DISCUSSION

This chapter provides an overview of the greenhouse gas emissions from each component of the life cycle of peat extraction during the period 1990 to 2000. The impact of time horizon on the climatic consequences of peat extraction in Canada is explored. A discussion follows on those greenhouse gas accounting issues relating to the Kyoto Protocol that could significantly affect the amount of emissions attributed to the peat industry. Finally, the GHG effects of a "business as usual" growth pattern for the peat industry are examined.

7.1 Overview of Each Component of the Life Cycle of Peat Extraction

In addition to GHG estimates for land use change from 1990 to 2000, Chapter Three produces land use figures for the peat industry based on extraction data from 1941 to 2000. It provides an estimate of the size of Canada's peat reserves and the number of years it would take to exhaust these reserves. The chapter indicates that peat extraction would seem to be sustainable over a period of a few thousand years. It also reveals that the restoration of cutover peatlands may be a very important means of reducing CO_2 emissions over the long term, although methane emissions remain a concern.

Diesel, liquefied petroleum gases and gasoline are the fossil fuels used most commonly during peat extraction and processing. Though significant, the GHGs emitted during extraction and processing are less than the amounts emitted during all the other stages of the peat industry life cycle. Chapter Four also reveals that fuel efficiency did not improve over the 1990s. There is no evidence that fuel prices affected the GHG intensity of peat extraction and processing. The questionnaire results do not reveal a relationship between the size of the peat extraction establishment and its GHG intensity. The responses to the questionnaire also demonstrate that there was a great deal of variability in GHG intensity among peat extraction establishments in Canada.

Chapter Five addresses the GHG emissions from the transportation of peat to market by truck, train and ship. The magnitude of these emissions was influenced by the distance between extraction sites and markets, the inherent bulk of the product, and the relative fuel inefficiency of the truck,[1] the preferred mode of peat transport. The United States and Japan have been the largest markets for Canadian peat while the transport of peat between Western, Central and Atlantic Canada for domestic consumption has been of relatively little significance. This chapter demonstrates that an increase in rail use could significantly reduce GHG emissions during the transport of peat to market.

Unlike many European nations, Canada's peat industry does not extract any peat for use as fuel. Chapter Six uses peat extraction data from 1941 to the year 2000 to estimate the amount of CO_2 emitted from the decomposition of extracted peat. The greenhouse gas emissions from this final stage of the life cycle of peat extraction surpasses the GHG emissions during all of the other stages.

7.2 Greenhouse Gas Emissions, 1990-2000

The GHG emissions from the life cycle of peat extraction increased by 65.8% from 1990 to the year 2000. Peat decomposition was by far the largest source of GHG emissions, ranging from 392 100 to 618 600 tonnes of carbon dioxide annually during this period, with land use change, the transport of peat to market and peat extraction and processing, being, respectively, the next largest sources (Table 7-1).

Table 7-1. Greenhouse Gas Accounts for Each Component of the Life Cycle of Peat Extraction, 1990-2000

Year	Components of Life Cycle				
	Land Use Change	Peat Extraction and Processing	Transport of Peat to Market	Decomposition of Extracted Peat	Total GHG Emissions
	tonnes of carbon dioxide equivalents, 100-year time horizon				
1990	73 686	21 700	53 100	392 100	540 600
1991	88 471	24 600	57 300	408 600	579 000
1992	77 896	22 700	60 400	431 400	592 300
1993	92 078	24 500	70 200	447 100	633 800
1994	102 634	30 400	77 000	468 700	678 800
1995	94 780	37 600	74 200	494 100	700 600
1996	98 475	33 500	74 400	513 600	720 000
1997	115 151	31 900	79 000	533 300	759 300
1998	123 837	36 500	82 100	559 800	802 200
1999	131 266	36 200	82 200	588 500	838 200
2000	143 108	36 600	95 000	618 600	893 300

[1] The truck is fuel inefficient relative to the train and the ship.

Over the period from 1990 to 2000, decomposition, land use change, transportation, and extraction and processing averaged approximately 70.6%, 14.7%, 10.4% and 4.3% of annual GHG emissions from the peat industry, respectively. There was little variation in these percentages over the eleven-year period (Figure 7-1).

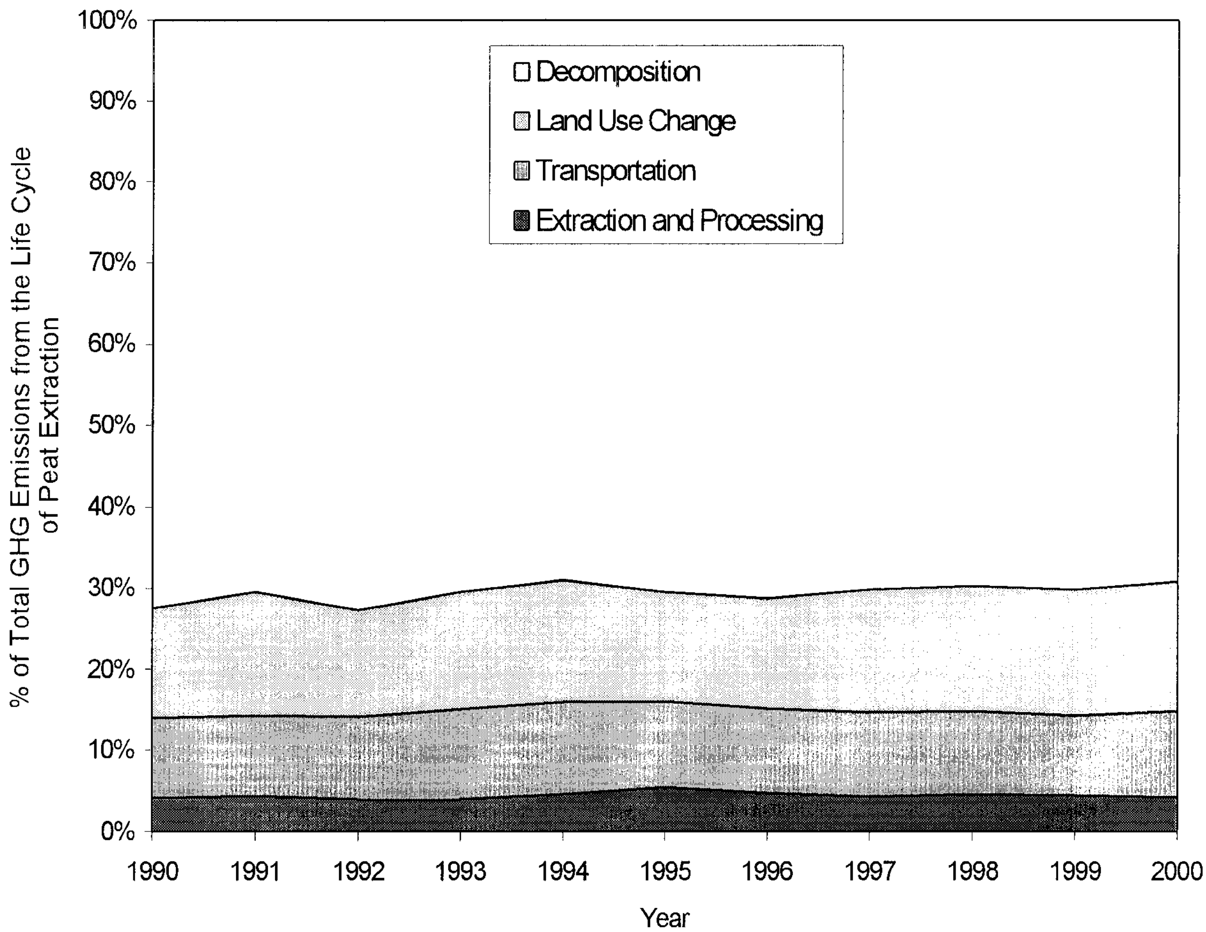

Figure 7-1. Percentage of Total Greenhouse Gas Emissions from the Life Cycle of Peat Extraction (in CO_2 Equivalents) Attributable to Each Component of Peat Production, 1990-2000

7.3 Greenhouse Gas Intensity, 1990-2000

Greenhouse gas intensity is an indicator of the amount of GHGs emitted per tonne of extracted peat during the life cycle of peat extraction. There is a direct economic incentive (i.e., the price of fuel) to reduce GHG emissions from fuel use, but not from land use change or from the decomposition of extracted peat. Nevertheless, there is no evidence that the GHG intensity of peat extraction and processing and peat transportation has decreased from 1990 to 2000. The GHG intensity of decomposition has varied with the changes in peat extraction of previous years. The GHG intensity of land use change has risen steadily because the total amount of peatlands that is or has been affected by the peat industry is increasing faster than the rate of peat extraction. If and when the peatlands harvested in the past begin to sequester carbon, the annual increase in GHG intensity could be reduced. Figure 7-2 illustrates the change in the GHG intensity of each stage of the life cycle of peat extraction from 1990 to the year 2000.

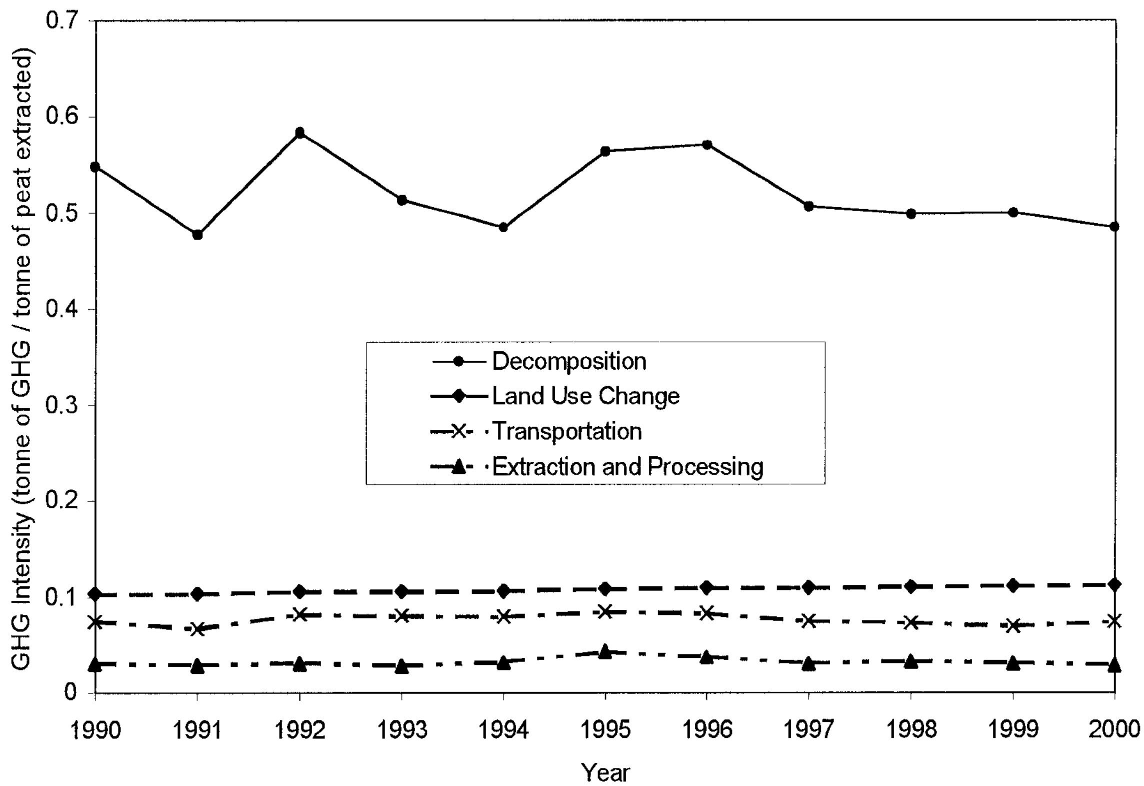

Figure 7-2. Change in the Greenhouse Gas Intensity of Land Use Change, Peat Extraction and Processing, Transport of Peat to Market and Decomposition of Extracted Peat, 1990-2000

7.4 Global Warming Potentials (GWPs)

The three greenhouse gases emitted during the life cycle of peat extraction, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), differ in their radiative effects upon the global climate system (IPCC 2001; Whiting and Chanton 2001; Lashof and Ahuja 1990). Their combined climate impact depends on the time horizon chosen, since these gases differ in their atmospheric residence times (IPCC 2001). Global warming potentials are used to measure the relative radiative effect of one greenhouse gas in comparison to another (carbon dioxide is generally used as the standard), integrated over a selected time horizon (IPCC 2001). Table 7-2 lists the global warming potentials of methane and nitrous oxide in comparison to carbon dioxide over 20, 100 and 500-year time horizons. A time horizon of one hundred years is used for GHG accounting under the Kyoto Protocol.

Table 7-2. Global Warming Potentials of Methane and Nitrous Oxide over 20, 100 and 500-year Time Horizons (CO_2 Standard Measure)

Gas	Time Horizon		
	20 years	100 years	500 years
	global warming potential		
Methane	62	23	7
Nitrous Oxide	275	296	156

Source: Intergovernmental Panel on Climate Change (IPCC), 2001, *Climate Change 2001: The Scientific Basis*, Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change, (New York: Cambridge University Press).

Since the emission of methane and nitrous oxide is small relative to that of carbon dioxide, the time horizon does not alter significantly the measurement of the impact of the total GHG emissions from the life cycle of peat extraction on the global climate. This impact varies by no more than 3.3% between the 20, 100 and 500-year time horizons.

7.5 Greenhouse Gas Accounting under the Kyoto Protocol

Canada has made a commitment under the Kyoto Protocol to reduce its annual greenhouse gas emissions by an average of 6% below the 1990 level over the five-year period from 2008 to 2012 (Olsen *et al.* 2002). The Canadian peat industry has not yet been identified specifically for reductions in its GHG emissions. The year 1990 had an abnormally low level of peat extraction, at 745 842 tonnes, a 6% decline from the previous year, partly due to unfavourable weather conditions (Prud'homme 1991). This low level of peat extraction resulted in a relatively low output of greenhouse gases, an output which would place an extra burden on the peat industry, should it be asked to reduce its GHG emissions to 6% below its 1990 emissions during the 2008 to 2012 period.

There is yet to be an agreement between the Parties to Kyoto on the precise design of the framework to be used to account for GHG emissions under the Prototcol (Olsen *et al.* 2002). The net GHG emissions from land use, land use change and forestry are certain to be included within this framework. However, the Intergovernmental Panel on Climate Change (IPCC), which designs the methodology to account for greenhouse gas emissions under the Kyoto Protocol, has not included the emissions from peat decomposition and land use change due to peat extraction in its preliminary GHG accounting framework. The only emissions from the peat industry that are presently included in Canada's greenhouse gas inventory are those from fossil fuel combustion.

Fuels used in peat extraction machinery and peat transportation within Canada accounted for approximately 60 000 tonnes of carbon dioxide equivalents in the year 2000, or about 0.008% of total GHG emissions.[2] The following equation (7-1) was used to calculate the domestic greenhouse gas emissions from peat extraction as is currently recognized by Canada's GHG inventory ($GHG_{IPCC\ Domestic}$):

Equation 7-1

$$GHG_{IPCC\ Domestic} = GHG_{E+P} + GHG_{Tdomestic} + GHG_{Toverseas} + 0.2*GHG_{Tusa}$$

where GHG_{E+P} represents the GHG emissions from the extraction and processing component of this life cycle assessment study, $GHG_{Tdomestic}$ depicts the GHG emissions from the transport of peat to domestic markets, $GHG_{Toverseas}$ symbolizes the GHG emissions from the transportation within Canada of peat destined for overseas markets, and GHG_{Tusa} represents the GHGs emissions from the transportation within Canada of peat destined for American markets. I have assumed that 20% of the GHG emissions from transporting peat to the United States result during travel within Canada.

Although GHG emissions from the decomposition of carbon-based materials are not yet included under Article 3.4 of the Kyoto Protocol, a default IPCC methodology

[2] Greenhouse gas emissions from the transportation of peat beyond Canada's borders are not recognized as domestic emissions under the GHG accounting framework of the Kyoto Protocol to the UNFCCC, as defined by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 1997). Moreover, the IPCC excludes GHG emissions from international marine transport from domestic emissions totals (IPCC 1997).

assumes that harvested wood fully decomposes in the year of harvest (Olsen *et al.* 2002). If this assumption is also applied to the decomposition of extracted peat, the GHG emissions of the peat industry will be substantially greater than those calculated via the life cycle assessment methodology used in this study. The following equation (7-2) was used to calculate the domestic GHG emissions from peat extraction, assuming that land use change is included[3] and that extracted peat decomposes fully in the year of extraction:

Equation 7-2

$$GHG_{IPCC\ Domestic\ (LUC+Decomposition)} = GHG_{IPCC\ Domestic} + GHG_{LUC} + GHG_{100\%\ Decomp.}$$

where GHG_{LUC} represents the GHG emissions from the land use component of this LCA study and $GHG_{100\%\ Decomp.}$ depicts the GHG emissions from peat decomposition, assuming that all of the peat decomposes in the same year in which it was extracted.

Table 7-3 compares the greenhouse gas emissions from the peat industry under the life cycle assessment and IPCC GHG accounting frameworks, with and without land use change activities and peat decomposition. Clearly, the IPCC method based on fuel use alone produces a substantially lower GHG estimate than the estimate from this life cycle assessment (LCA) - averaging 14.6 times less. Conversely, an IPCC method which includes GHG emissions from land use change and the decomposition of carbon-based products in the year of extraction, produces GHG emission estimates greater than under the LCA method by an average factor of 1.5 times. These immense factor differences illustrate the importance of the GHG accounting method used to estimate the greenhouse gas emissions from the peat industry.

[3] The methodology used in this study to calculate the GHG emissions from land use change may not be the same as the one that could be adopted by the IPCC in the future.

Table 7.3 Greenhouse Gas Emissions of the Peat Industry under the Life Cycle Assessment and IPCC GHG Accounting Frameworks, 1990-2000

Year	GHG Accounting Method				
	Life Cycle Assessment Method	IPCC Method (not including Land Use Change and Peat Decomposition)		IPCC Method (including Land Use Change and Peat Decomposition)	
	GHGs	GHGs	Factor difference	GHGs	Factor difference
	tonnes†			tonnes†	
1990	540 600	33 900	-16.0	935 400	+1.7
1991	579 000	40 400	-14.3	850 600	+1.5
1992	592 300	33 600	-17.6	975 100	+1.6
1993	633 800	40 900	-15.5	879 100	+1.4
1994	678 800	50 200	-13.5	1 032 700	+1.5
1995	700 600	53 300	-13.2	1 123 500	+1.6
1996	720 000	50 200	-14.3	1 033 000	+1.4
1997	759 300	53 100	-14.3	1 076 800	+1.4
1998	802 200	59 400	-13.5	1 246 100	+1.6
1999	838 200	60 800	-13.8	1 326 500	+1.6
2000	893 300	61 900	-14.5	1 394 800	+1.6

† CO_2 equivalents – 100 year time horizon

7.6 Future Scenarios and the Kyoto Target

This section of the summary will discuss future GHG emission scenarios that are based upon "business as usual" peat extraction in Canada, which assumes an annual increase of 5% per year, using the year 2000 as the base year. There is little reason to believe that the average annual growth rate of peat extraction over the next decade will differ substantially from the assumption of 5%. This rate of growth could be influenced negatively by pressure from environmental groups to reduce the use of peat moss and by an increase in the use of peat alternatives in home gardening (G. Hood, pers. comm., 2002 12 04). Conversely, the demand for *Sphagnum* peat could increase in the future. Although the average annual growth rate of the peat industry from 1941 to 2000 was approximately 7.9%, between 1990 and 2000 it was somewhat lower, at 6.5%. Therefore, an annual growth rate of 5% seems to be a conservative estimate.

7.6.1 Greenhouse Gas Emissions

The "business as usual" scenario used to predict GHG emissions from the peat industry has assumed that environmental, technological and economic conditions will remain essentially unchanged. The results shown in Table 7-4 were calculated by extrapolating from a linear relationship produced between the GHG emissions estimates for the life cycle of peat extraction, and peat extraction (Figure 7-3).

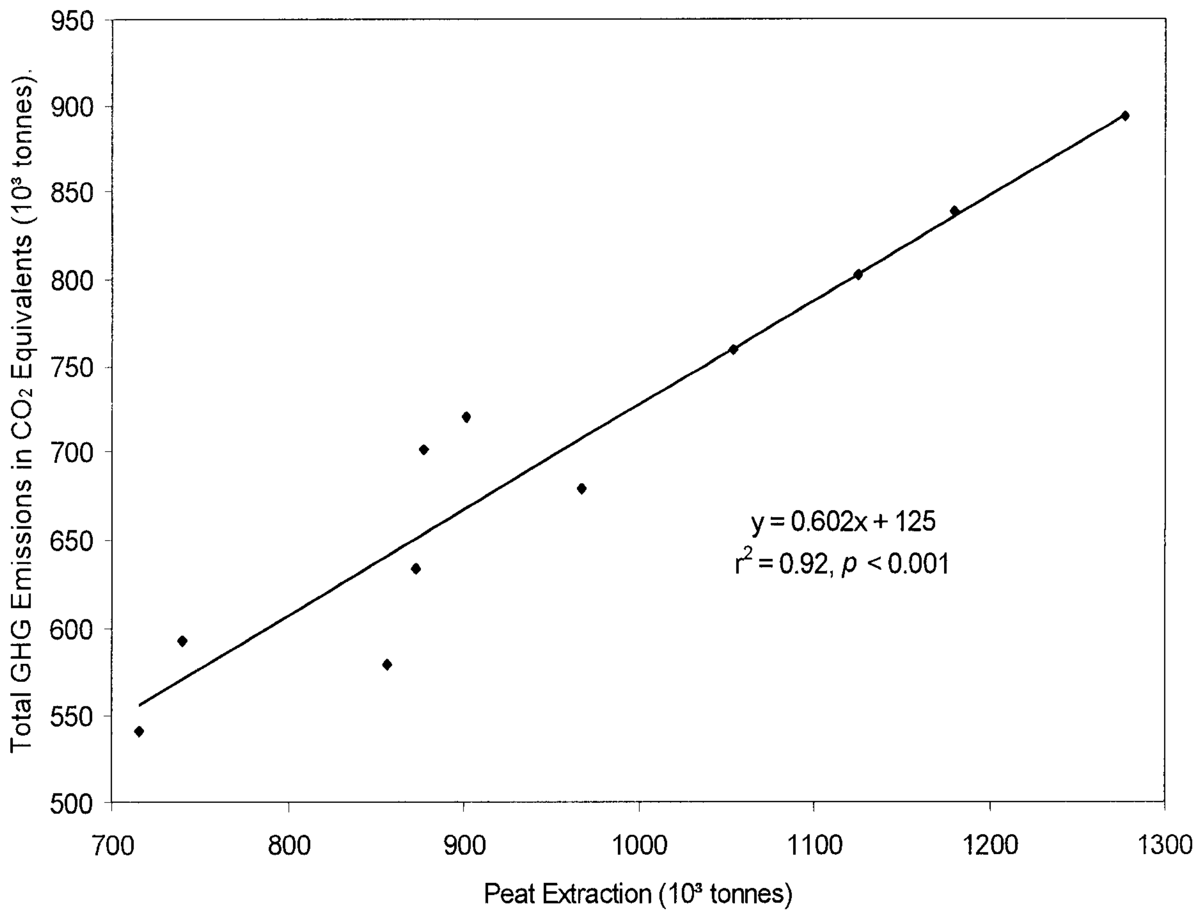

Figure 7-3. Greenhouse Gas Emissions from the Life Cycle of Peat Extraction Versus Peat Extraction, 1990-2000

Although there are currently no government demands on the peat industry to reduce GHG emissions, the estimates shown in Table 7-4 demonstrate that it will be extremely difficult for the industry to help meet Canada's Kyoto target if it intends to increase the rate of peat extraction by 5% annually.

Table 7-4. "Business as Usual" Greenhouse Gas Emissions, 2001-2012

Year	"Business as Usual" Peat Extraction	GHG Emissions	Percent Change from 1990 Emissions
	tonnes of peat	tonnes of CO_2 equivalents	%
2001	1 340 850	932 300	72
2002	1 407 893	978 400	81
2003	1 478 287	1 021 100	89
2004	1 552 201	1 065 800	97
2005	1 629 812	1 112 900	106
2006	1 711 302	1 162 200	115
2007	1 796 867	1 214 100	125
2008	1 886 711	1 268 500	135
2009	1 981 046	1 325 700	145
2010	2 080 098	1 385 700	156
2011	2 184 103	1 448 700	168
2012	2 293 309	1 514 900	180

7.6.2 Greenhouse Gas Intensity

Figure 7-4 displays the GHG intensity of the peat industry that would be necessary in order to reduce the industry's total emissions by 6% below the 1990 level, while growing at the "business as usual" (BAU) rate. The "actual" and BAU greenhouse intensities of peat extraction were calculated by dividing the total greenhouse gas emissions of the peat industry in a given year by the peat extraction in the same year. The trend illustrated in Figure 7-4 indicates that, by 2012, the GHG intensity of peat extraction would need to be reduced by 3.1 times in order to meet the Kyoto target of 507 600 tonnes of GHG emissions (in CO_2 equivalents) per year.

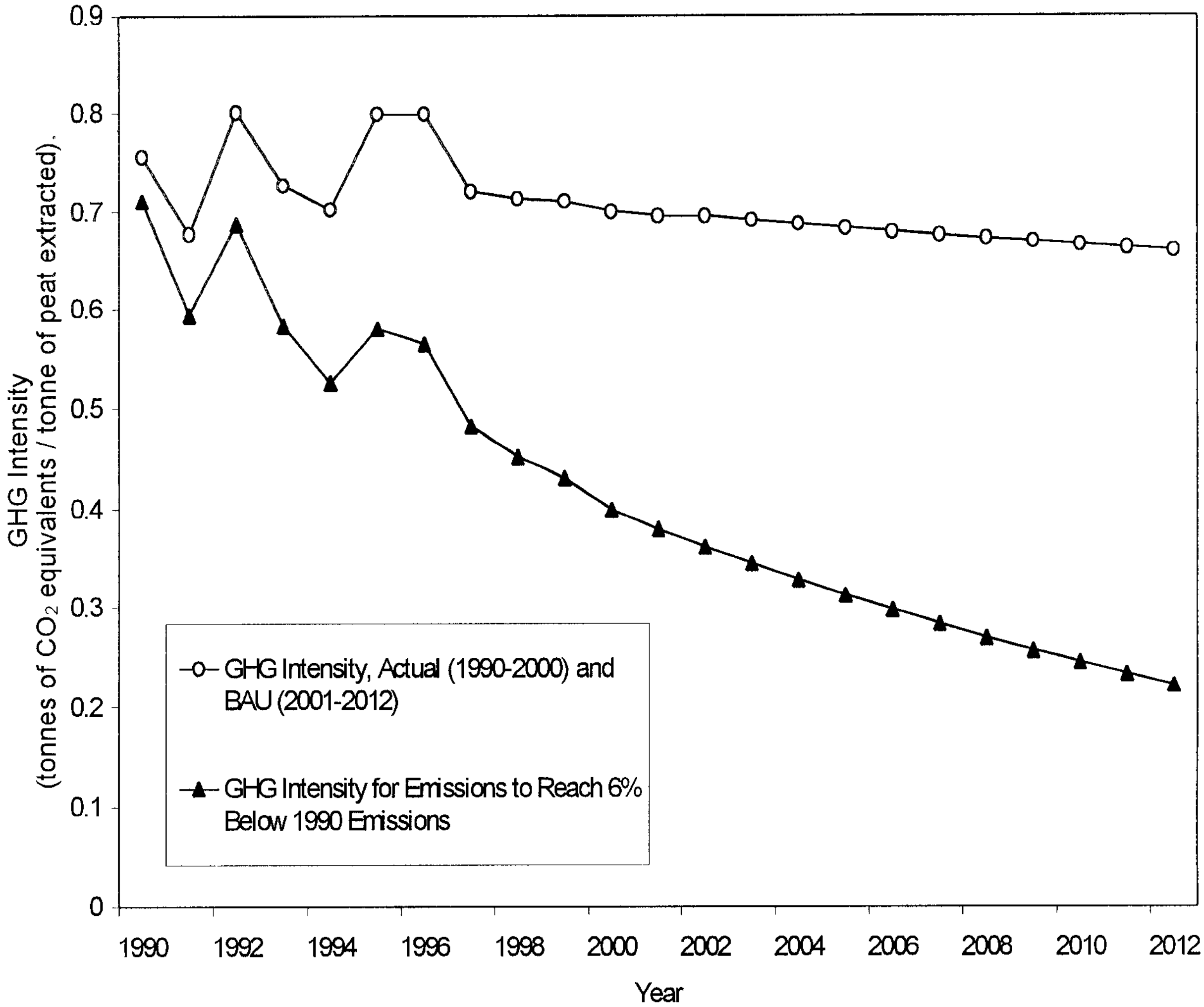

Figure 7-4. The Actual and Projected Greenhouse Gas Intensity Necessary to Meet Canada's Kyoto Target, 1990-2012

7.7 Greenhouse Gas Emissions and Peat Substitutes

A number of products may be used as substitutes for peat, such as compost, barks, mulches, and coir dust (Knight 1991; Physical Distribution Advisory Service 1984). These materials are not perfect substitutes, as they may differ from peat in quality, use and price. When evaluating the impact of greenhouse gases from Canada's peat industry, it will therefore be necessary to consider whether the present peat industry generates less GHG emissions than might another industry producing peat substitutes.

CHAPTER EIGHT

CONCLUSION

Global climate change and the pivotal role played by greenhouse gas emissions have become widely discussed issues of public policy. Consequently, greenhouse gas accounting has emerged as a method of scientific investigation that carries increasing political and economic significance, particularly since the ratification of the Kyoto Protocol by many countries throughout the world. This study has applied a life cycle perspective to examine the greenhouse gas emissions from one industry in one country – peat extraction in Canada. Through this perspective, the four components of the peat extraction life cycle were identified and greenhouse gas emissions estimated for (1) land use change; (2) extraction and processing; (3) transportation; and (4) decomposition.

The accounting models and final numbers for the four components of this life cycle of peat extraction were based upon scientific literature, government and industry statistics, and a questionnaire designed by the writer and sent to Canada's peat extraction establishments. Some of the information derived from these sources was incorporated into the GHG accounting models themselves, with the remainder used to corroborate the GHG estimates produced from these models.

Of these sources, the questionnaire proved an especially useful primary source of information. An exceptionally high response rate showed the interest of the peat industry in this study. The response rate also made it an extremely valuable source of current information on the peat industry itself - a snapshot of the industry in the year 2000.

The importance of climate change as a public policy issue and the relative dearth of research on GHG emissions from Canada's peat industry clearly indicated a need for this greenhouse gas accounting study. It stands alone as the first life cycle analysis of the greenhouse gas emissions of any non-fuel peat extraction industry. It could, therefore, serve as a template upon which to conduct further studies on the GHG emissions of the peat industry, and on the wise management of Canada's peat resource.

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APPENDIX A

QUESTIONNAIRE

Section A: Peat Extraction and Land Use

(1) Please indicate the current size of your peatland holdings (in hectares)?

Peatland holdings: _________ hectares

(2) a) What percentage of your peatland holdings is currently undergoing harvesting, has undergone harvesting in the past or has never been harvested?

Undergoing harvesting ____ %

Harvested in the past ____ %

Never been harvested ____ %

100%

b) Of the peatlands harvested in the past, what percentage is undergoing natural revegetation or active restoration?

Natural Revegetation ____ %

Active Restoration ____ %

100%

(3) Which method does your establishment use to extract peat? Please indicate % of peat extracted (by weight) by each method.

Vacuum Harvesting ____ %

Block Cut ____ %

100%

(4) a) Do you have outdoor stockpiles of peat?

Yes ☐
No ☐ If no, skip to #5

Questionnaire (continued)
Page 2

b) Do you cover your stockpiles with plastic sheeting?

Yes ☐
No ☐

c) On average, for what total length of time do you leave peat in outdoor stockpiles?

________ months

(5) a) In general, what proportion of the material extracted (by weight) from the peat harvesting sites is sifted out during peat processing?

Proportion = _____ %

b) What happens to this portion?

____

____

Section B: Peat Production and Fuel Use

(1) Please indicate your annual peat production for the year 2000.

Annual Peat Production: ____________ tonnes

(2) If available, please indicate what was your annual peat production for the year 1990.

Annual Peat Production: ____________ tonnes

Questionnaire (continued)
Page 3

(3) What quantity of each of the following fossil fuels did your establishment consume in the year 2000?

Fuel	*Quantity Used (litres)*	
Natural gas	____________	m^3
Gasoline	____________	litres
Diesel	____________	litres
Liquefied petroleum gases	____________	litres
Light Fuel Oil	____________	litres
Heavy Fuel Oil	____________	litres
Other (specify)	____________	____ (units)

(4) For what purposes do you use fossil fuels, and what types of fuel do you use for each stage of peat production? If certain stages are not listed, please state them in the sections under "Other."

Stage of Peat Production	*Applicable to your establishment*	*Type(s) of Fuel Used (list in descending order of importance)*
1) Digging of drainage ditches	Yes ☐ No ☐	1. ____________ 2. ____________ 3. ____________
2) Extraction	Yes ☐ No ☐	1. ____________ 2. ____________ 3. ____________
3) Stockpiling	Yes ☐ No ☐	1. ____________ 2. ____________ 3. ____________
4) Moving the peat to the factory	Yes ☐ No ☐	1. ____________ 2. ____________ 3. ____________
5) Sifting the peat	Yes ☐ No ☐	1. ____________ 2. ____________ 3. ____________

Questionnaire (continued)
Page 4

Stage of Peat Production	*Applicable to your establishment*	*Type(s) of Fuel Used (list in descending order of importance)*
6) Bagging	Yes ☐ No ☐	1. ______________ 2. ______________ 3. ______________
7) Other		
a)__________________	Yes ☐ No ☐	1. ______________ 2. ______________ 3. ______________
b)__________________	Yes ☐ No ☐	1. ______________ 2. ______________ 3. ______________

Section C: Peat Transportation and Distribution

(1) What percentage of your peat production (by weight) was shipped <u>to the end user</u> in bulk and packaged in the year 2000?

Bulk: _____ %

Packaged: _____ %

Other (please specify): ______________ _____ %

100%

(2) Does your establishment <u>own</u> the trucking fleet that it uses to ship peat to market?

Yes ☐ Number of trucks in this fleet: __________
No ☐

If yes, what is the average distance travelled by these trucks? _________ km

Questionnaire (continued)
Page 5

(3) How much of your peat production in the year 2000 was destined for the Canadian market?

Peat production destined for the Canadian Market: _____________ tonnes

(4) What percentage of this was *consumed* in each province?

Province	*Percentage of peat destined for Canadian Market*
Alberta	____ %
British Columbia	____ %
Manitoba	____ %
New Brunswick	____ %
Newfoundland	____ %
Nova Scotia	____ %
Ontario	____ %
Prince Edward Island	____ %
Quebec	____ %
Saskatchewan	____ %

(5) Please indicate the three largest foreign export markets for your peat (by weight)?

1. ___________________________________
2. ___________________________________
3. ___________________________________

Comments on Questionnaire:

____

____

____

THANK YOU FOR YOUR TIME

QUESTIONNAIRE

Section A : Extraction de la tourbe et affectation des terres

(1) Veuillez préciser les dimensions actuelles de vos tourbières (en hectares).

Tourbières : _________ hectares

(2) a) Quel pourcentage de vos tourbières fait actuellement l'objet d'une récolte, a subi une récolte par le passé ou n'a jamais été récolté?

en cours de récolte ____ %

récolté par le passé ____ %

jamais récolté ____ %

100 %

b) Sur les tourbières récoltées par le passé, quel pourcentage subit une régénération naturelle ou une reconstitution active?

régénération naturelle ____ %

reconstitution active ____ %

(3) Quelle méthode votre entreprise utilise-t-elle pour extraire la tourbe? Veuillez préciser le pourcentage de tourbe extraite (selon le poids) par chaque méthode.

récolte sous vide ____ %

coupe par blocs ____ %

100 %

(4) a) Avez-vous des tas de tourbe à l'extérieur?

oui ☐

non ☐ dans la négative, passez à la question numéro 5

questionnaire (suite)
page 2

b) Recouvrez–vous vos tas de baches de protection en plastique?

oui ☐
non ☐

c) En moyenne, pendant combien de temps laissez-vous la tourbe à l'extérieur?

________ mois

(5) a) En général, quelle proportion des matériaux extraits (selon le poids) des sites de récolte de la tourbe est tamisée durant la transformation de la tourbe?

proportion = _____ %

b) Qu'advient-il de cette proportion?

____

____

Section B : Production de tourbe et consommation de carburant

(1) Veuillez préciser votre production annuelle de tourbe en 2000.

Production annuelle de tourbe : ____________ tonnes

(2) Si vous le savez, veuillez préciser votre production annuelle de tourbe en 1990.

Production annuelle de tourbe : ____________ tonnes

questionnaire (suite)
page 3

(3) Quel volume de chacun des carburants suivants votre établissement a-t-il consommé en 2000?

Carburant	*Volume consommé (litres)*	
Gaz naturel	____________	m^3
Essence	____________	litres
Carburant diesel	____________	litres
Gaz de pétrole liquéfié	____________	litres
Mazout léger	____________	litres
Mazout lourd	____________	litres
Autre (préciser)	____________	____ (unités)

(4) À quelles fins consommez-vous du carburant, et quels types de carburant consommez-vous pour chaque étape de la production de tourbe? Si certaines étapes ne sont pas mentionnées, veuillez les préciser dans la section «Autre».

Étape de production de tourbe	*Concerne votre établissement*	*Type(s) de carburant consommé(s) (énuméré(s) par ordre d'importance décroissant)*
1) Excavation de fossés de drainage	oui ☐ non ☐	1. ____________ 2. ____________ 3. ____________
2) Extraction	oui ☐ non ☐	1. ____________ 2. ____________ 3. ____________
3) Mise en tas	oui ☐ non ☐	1. ____________ 2. ____________ 3. ____________
4) Transport de la tourbe jusqu'à l'usine	oui ☐ non ☐	1. ____________ 2. ____________ 3. ____________

questionnaire (suite)
page 4

5) Tamisage de la tourbe oui ☐ non ☐
1. ______________
2. ______________
3. ______________

6) Mise en sacs oui ☐ non ☐
1. ______________
2. ______________
3. ______________

7) Autre

a)________________ oui ☐ non ☐
1. ______________
2. ______________
3. ______________

b)________________ oui ☐ non ☐
1. ______________
2. ______________
3. ______________

Section C : Transport et distribution de la tourbe

(1) Quel pourcentage de votre production de tourbe (selon le poids) a été expédié <u>jusqu'au consommateur</u> en vrac et emballé en 2000?

En vrac _____ %

Emballé _____ %

Autre (veuillez préciser) ______________ _____ %

100 %

(2) Votre établissement est-il propriétaire du parc de camions qu'il utilise pour transporter la tourbe jusqu'au marché d'écoulement?

oui ☐ nombre de camions faisant partie du parc : __________

non ☐

Dans l'affirmative, quelle est la distance moyenne parcourue par ces camions?

_________ km

questionnaire (suite)
page 5

(3) Quel volume de votre production de tourbe en 2000 était destiné au marché canadien?

Production de tourbe destinée au marché canadien : ______________ tonnes

(4) Quel pourcentage de ce volume a été consommé dans chaque province?

Province	*Pourcentage de tourbe destiné au marché canadien*
Alberta	____ %
Colombie-Britannique	____ %
Manitoba	____ %
Nouveau-Brunswick	____ %
Terre-Neuve	____ %
Nouvelle-Écosse	____ %
Ontario	____ %
Île-du-Prince-Édouard	____ %
Québec	____ %
Saskatchewan	____ %

(5) Veuillez indiquez les trois principaux marchés d'exportation de votre tourbe (selon le poids).

1. ____________________________________
2. ____________________________________
3. ____________________________________

Remarques sur le questionnaire:

____

____

____

MERCI DE VOTRE COLLABORATION

RESEARCH CONSENT FORM

Title of Research: Modelling Greenhouse Gas Emissions from Peat Extraction in Canada: A Life Cycle Perspective

Principal Investigator: Julian Cleary
Department of Geography
McGill University
Burnside Hall
805 Sherbrooke St. West,
Montreal (Québec)
H3A 2K6
Tel: (514) 398-4111; Fax: (514) 398-7437
Tel: (450) 653-4563; e-mail: jcstbrno@dsuper.net

Project Supervisors: Nigel Roulet, Tim Moore and Mark Brown (Department of Geography, McGill University)

Project Sponsors: This project is funded by *Fonds pour la Formation de Chercheurs et l'Aide à la Recherche* (Master's Fellowship), the Natural Sciences and Engineering Research Council of Canada and the Canadian Sphagnum Peat Moss Association.

Purpose of the Research:
The Kyoto Protocol on Climate Change, if ratified, commits Canada to reducing its greenhouse gas (GHG) emissions by 6% below 1990 levels between 2008 and 2012. To meet this target, the GHG emitting industries of Canada require additional data on the contribution of their activities to Canada's total emissions. I am designing a model to track, on an annual basis, the net GHG emissions that result both directly and indirectly from the activities of the Canadian peat industry. The model will calculate this industry's contribution to global climate change from the base year of 1990.

Description of the Research:
The design of the model will be based upon the emission of GHGs from land use changes, the combustion of fossil fuels used for peat extraction, processing and transportation, and the long term decomposition of extracted peat. Subsequent sequestration of carbon due to peat regrowth and restoration will also be included. The model will indicate the relative importance of each stage of peat production to the emission of GHGs. Sources of information include government documents, scientific literature on the environmental controls of carbon fluxes in restored peatlands; statistics from the Canadian peat industry relating to the extraction, transportation, processing and end uses of peat; and the information gained from your answers to this questionnaire.

Laboratory and field experiments will provide data on the turnover time of carbon in peat.

Confidentiality:
Only this consent form bears your name as a participant. It will be kept in a secure location separate from the research data. In any oral or written presentation of the results of this study, the anonymity of the participant will be protected. Personal identity will not be traceable to a particular participant or recognizable through any oral presentation or written material produced from this research.

Disposition of Research Results:
A summary of the study will be sent to each participant who leaves a forwarding address. It should be noted that given that this is a MSc research project, a copy of the thesis is held by McGill University and will be accessible through the library.

Right of Exclusion or Withdrawal:
Participants have the right to refuse inclusion in the research, not to answer any specific question, or to withdraw from the project at any time.

Consent to Participate:
I have read and understood the above consent form. I agree to take part in the above described study.

DATE

NAME OF ESTABLISHMENT

LOCATION

SIGNATURE

FORMULAIRE DE CONSENTEMENT DE RECHERCHE

Titre du projet de recherche: Modélisation des émissions de gaz à effet de serre de l'extraction de tourbe au Canada : point de vue sur le cycle de vie

Chercheur principal: Julian Cleary
Département de géographie
Université McGill
Pavillon Burnside
805, rue Sherbrooke ouest
Montréal (Québec)
H3A 2K6
Tél. : (514) 398-4111; téléc. : (514) 398-7437
Tél. : (450) 653-4563;
courriel : jcstbrno@dsuper.net

Directeurs du projet: Nigel Roulet, Tim Moore et Mark Brown (département de géographie, Université McGill)

Commanditaires du projet: Ce projet est financé par le Fonds pour la formation de chercheurs et l'aide à la recherche (bourse de maîtrise), le Conseil de recherches en sciences naturelles et en génie du Canada et l'Association Canadienne Tourbe de Sphaigne.

But de la recherche:
S'il est ratifié, le Protocole de Kyoto sur le changement climatique obligera le Canada à réduire ses émissions de gaz à effet de serre (GES) de 6 % par rapport aux niveaux de 1990 entre 2008 et 2012. Pour atteindre cette cible, les industries canadiennes qui émettent des GES ont besoin de données complémentaires sur la contribution de leurs activités aux émissions totales du Canada. Je m'occupe donc de concevoir un modèle pour suivre chaque année les émissions nettes de GES qui résultent directement et indirectement des activités de l'industrie canadienne de la tourbe. Ce modèle calculera la part de responsabilité de l'industrie aux changements climatiques planétaires par rapport à l'année de référence 1990.

Description du projet:
La conception du modèle reposera sur les émissions de GES résultant des modifications de l'affectation des terres, de la combustion de combustibles fossiles utilisés pour l'extraction, la transformation et le transport de la tourbe et de la décomposition à long terme de la tourbe extraite. Le piégeage du carbone attribuable à la régénération et à la reconstitution de la tourbe sera également inclus. Le modèle précisera l'importance relative de chaque étape de la production de tourbe jusqu'aux émissions de GES. Parmi les sources d'information, mentionnons les documents gouvernementaux, la

documentation scientifique sur les contrôles environnementaux des flux du carbone dans les tourbières régénérées; les statistiques de l'industrie canadienne de la tourbe sur l'extraction, le transport, la transformation et les utilisations de la tourbe; et les renseignements qui se dégageront de vos réponses à ce questionnaire. Des expériences en laboratoire et sur le terrain fourniront des données sur le taux de renouvellement du carbone dans la tourbe.

Confidentialité:
Seul ce formulaire de consentement porte votre nom en tant que participant. Celui-ci sera mis sous clé loin des données du projet de recherche. Dans toute communication orale ou écrite des résultats de ce projet, l'anonymat des participants sera rigoureusement respecté. Il sera impossible de connaître l'identité personnelle d'un participant donné ou de la reconnaître dans le cadre d'une communication orale ou d'un rapport écrit résultant de ce projet.

Disposition des résultats de la recherche:
Un résumé de l'étude sera envoyé à chaque participant qui indique une adresse postale. Je tiens à signaler qu'étant donné qu'il s'agit d'un projet de recherche de maîtrise, une copie du mémoire est conservée par l'Université McGill et est accessible dans ses bibliothèques.

Droit d'exclusion ou de retrait:
Les participants ont le droit de refuser de participer à ce projet de recherche, de ne pas répondre à certaines questions ou de se retirer du projet à tout moment.

Consentement à participer:
J'ai pris connaissance du formulaire de consentement et en ai compris tous les éléments. J'accepte de participer au projet décrit ci-dessus.

DATE

NOM DE L'ÉTABLISSEMENT

LIEU

SIGNATURE

4 February 2002

Dear Sir/Madam:

My name is Julian Cleary, and I am a graduate student in the Department of Geography at McGill University in Montreal. I am writing to ask for your help with my study, which is part of an effort by McGill University researchers to quantify the effect of the activities of Canada's peat industry on atmospheric greenhouse gases. This research program has received financial support from the Canadian Sphagnum Peat Moss Association, *Fonds pour la Formation de Chercheurs et l'Aide à la Recherche* (Quebec), and the Natural Sciences and Engineering Research Council of Canada.

The attached questionnaire was put together to obtain information on your methods of peat production and distribution. The data you provide will be used to increase the reliability of a scientific model I am designing to estimate the net greenhouse gases resulting from peat extraction. I would very much appreciate if you would complete the questionnaire, sign the Research Consent Form, and return both of them to me in the enclosed self-addressed stamped envelope by the end of February 2002.

The information you provide will be aggregated with the information received from other companies. No reference will be made to individual answers and in no way will anyone be able to identify the information provided by your company. Should you so desire, you will have the right to withdraw the information you have provided at any time, without consequence.

I will send to all those who reply to the questionnaire a brief report summarizing all the data that I receive. This report will hopefully be of some use to you.

Please do not hesitate to contact me if you have any questions or comments about the questionnaire.

Thank you.

Julian Cleary
MSc Candidate, Department of Geography, McGill University

*****I hereby confirm that Julian Cleary is a Master's student under my supervision. Your responses to this questionnaire will be used only in relation to his thesis.**

______________________________ **T.R. Moore, Chair, Department of Geography** le 4 février 2002

Monsieur,

Je m'appelle Julian Cleary et je suis étudiant de maîtrise au département de géographie de l'Université McGill à Montréal. Je viens solliciter votre concours dans le cadre de mes études, qui s'inscrivent dans un projet de recherche de l'Université McGill visant à quantifier l'effet des activités de l'industrie canadienne de la tourbe sur les gaz à effet de serre dans l'atmosphère. Ce programme de recherche bénéficie de l'aide financière de l'Association Canadienne Tourbe de Sphaigne, du Fonds pour la formation de chercheurs et l'aide à la recherche (Québec) et du Conseil de recherches en sciences naturelles et en génie du Canada.

Le questionnaire ci-joint a été préparé en vue de recueillir des renseignements sur vos méthodes de production et de distribution de tourbe. Les renseignements que vous fournirez contribueront à accroître la fiabilité d'un modèle scientifique que je m'occupe de mettre au point pour estimer les émissions nettes de gaz à effet de serre résultant de l'extraction de la tourbe. Je vous serais infiniment reconnaissant de bien vouloir remplir ce questionnaire, de signer le formulaire de consentement de recherche et de retourner les deux documents dans l'enveloppe-réponse pré-affranchie avant la fin de février 2002.

Les renseignements que vous fournirez seront regroupés avec ceux que nous recevrons d'autres entreprises. Aucune mention ne sera faite des réponses individuelles et il ne sera pas possible d'identifier les renseignements fournis par votre entreprise. Si vous le souhaitez, vous avez le droit de retirer les renseignements fournis à tout moment, sans conséquences.

J'adresserai à tous ceux et celles qui répondent à ce questionnaire un bref rapport résumant toutes les données reçues. J'espère que ce rapport vous sera utile.

N'hésitez pas à me contacter si vous avez des questions ou des remarques au sujet de ce questionnaire.

Je vous remercie de votre précieuse collaboration.

Julian Cleary
Étudiant de M.Sc., département de géographie, Université McGill

***** Je confirme par la présente que Julian Cleary est étudiant de maîtrise dont j'assure la direction. Vos réponses à ce questionnaire ne seront utilisées que dans le cadre de son mémoire.**

______________________________ **T.R. Moore, directeur, département de géographie**

APPENDIX B

LIST OF PEAT EXTRACTION ESTABLISHMENTS CONTACTED (BY PROVINCE)

Alberta:

Alaska Peat Inc.
13810 170th Street
Edmonton, Alberta
T5V 1T2

Al's Peat Moss Farm
11819 49th Street NW
Edmonton, Alberta
T5W 2Z9

Lakeland Peat Moss Ltd.
RR 8, Lcd. 2
Edmonton, Alberta
T5L 4H8

Mr. Kent Heggurad, Plant Manager
Sun Gro Horticulture Canada Ltd.
P.O. Box 189,
Seba Beach, Alberta
T0E 2B0

Manitoba:

M. Richard Pellettiere, Plant Manager
Premier Horticulture Ltd.
P.O. Box 1142, Stn. Main,
Ste Anne, Manitoba
R5H 1C1

Mr. Walter Amerongen,
General Manager
Sun Gro Horticulture Canada Ltd.
P.O. Box 100,
Elma, Manitoba
R0E 0Z0

New Brunswick:

Mr. Helmut Aurenz, President
ASB Greenworld Ltd.
200 ch. Daigle,
Pointe-Sapin, NB
E9A 1T6

M. Gilles Haché
Acadian Peat Moss (1979) Ltd.
Usine Lamèque
P.O. Box 2002,
Lamèque, NB
E8T 3N3

M. Gilles Haché
Acadian Peat Moss (1979) Ltd.
Usine St-Margarets
P.O. Box 2002,
Lamèque, NB
E8T 3N3

M. Gilles Haché, président
Acadian Peat Moss (1979) Ltd.
Usine Pigeon Hill
P.O. Box 2002,
Lamèque, NB
E8T 3N3

M. Paul-Emile Léger, président
Beauséjour Peat Moss Inc.
P.O. Box 2006,
Grand-Barachois, NB
E4P 8V1

M. Paul Leroux, président
Fafard Peat Moss Co. Ltd.
Usine St-Paul-de-Kent
422 Pallot Rd.,
Inkerman, NB
E8P 1B5

New Brunswick (continued):

M. Paul Leroux, président
Fafard Peat Moss Co. Ltd.
Usine Inkerman
422 Pallot Rd.,
Inkerman, NB
E8P 1B5

M. Paul Leroux, président
Fafard Peat Moss Co. Ltd.
Usine Burnt Church
422 Pallot Rd.,
Inkerman, NB
E8P 1B5

Mr. Guenter M. Burkhardt, President
Good Earth Canada Ltd.
P.O. Box 321,
Baie-Sainte-Anne, NB
E9A 1V9

Mr. Paul Tocci, President
Grande-Anse Peat Moss Co. Ltd.
P.O. Box 90, Stn. Main
Grande-Anse, NB
E8N 2T9

M. Roch Poitras, directeur
Group Berger Peat Moss Ltd.
P.O. Box 351,
Stn. Baie-Sainte-Anne,
Baie-Sainte-Anne, NB
E9A 1W1

Mr. Rolf Mecking, General Manager
Heveco Ltd.
4534 Route 11,
Tabusintac, NB
E9H 1J4

M. Florent Chiasson, président
Groupe Qualité Lamèque Ltée.
86 rue de la Tourbe,
Lamèque, NB
E8T 1A3

Mr. Solomon Curry, President
Malpec Peat Moss Ltd.
P.O. Box 2051,
Rexton, NB
E4W 5N6

M. Zoël Gautreau
New Product & Special Project
Manager, Eastern Region
Sun Gro Horticulture Canada Ltd.
4492 Route 113,
Haut-Lamèque, NB
E8T 3L3

M. Ronald Boudreau, vice-président
Sun Gro Horticulture Canada Ltd.
124 ch. de la Tourbe,
Maisonnette, NB
E8N 1P8

M. Gélas Thériault, président
Thériault & Hachey Peat Moss
201 ch. Thériault-Haché,
Baie-Sainte-Anne, NB
E9A 1N7

M. Edmond Chiasson, directeur-général
La Tourbe de Pigeon Hill Ltée.
P.O. Box 2067,
Lamèque, NB
E8T 3N5

Miramichi Peat Moss Ltd.
St. Margarets,
Nelson-Miramichi, NB
E1N 3A8

La Tourbière de Petit (Shippagan)
C.P. 2130
Lameque, NB
E8T 3N7

New Brunswick (continued):

La Tourbière du Centre de l'Ile
C.P. 553
Lameque, NB
E0B 1V0

Clare Organic Peat Moss Products
Maxwellton,
Meteghan, Nova Scotia
B0W 2J0

Newfoundland:

Emerald Sod Producers Inc.
P.O.
St. Shotts, NF
A0A 3R0

Hi Point Industries Ltd.
P.O. Box 779
Bishop Falls, NF
A0H 1C0

Ross Traverse
P.O. Box 133
Torbay, NF
A0A 3Z0

Walter Tulk
P.O. Box 66
Gander, NF
A1V 1W5

Nova Scotia:

Mr. Henry Endres, Chairman
Annapolis Valley Peat Moss Co.
RR 1,
Berwick, NS
B0P 1E0

MacDonald Peat Moss Ltd.
Bishop Road,
Kennetcook, Nova Scotia
B0N 1P0

Prince Edward Island:

M. Louis Arsenault, General Manager
Gulf Island Peat Moss Co. Inc.
RR1, Foxley River
Coleman, PEI
C0B 1H0

Mr. Charles Sark, President
Mahemigew Inc.
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APPENDIX C

OVERVIEW OF QUESTIONNAIRE DESIGN AND RESULTS

After conducting preliminary research, it was found that insufficient data was currently available to undertake a substantive GHG accounting study of peat extraction in Canada. A questionnaire was sent to all of Canada's peat establishments to address this shortfall of available data. The questionnaire was designed to obtain information on the methods of peat extraction, land and fuel use, as well as the transport of peat, in order to be able to quantify greenhouse gas emissions from the peat industry in Canada.

A cover letter and a research consent form were included with the questionnaire in order to inform the respondents of the nature of the research and the limits on the use of the data. Most importantly, they stipulated that the data would not be disseminated in a manner by which a particular source could be identified. All participants were asked to sign the research consent form, thereby giving their consent to the use the information they supplied by answering the questionnaire, within the parameters set out in the form.

Some peat companies own more than one peat operation. Sending one questionnaire to each peat operation (establishment), rather than each company, therefore seemed more appropriate for a number of reasons.

- There could be substantial variation between methods of peat extraction and processing within one company - a variation that is less likely to be present in a single peat establishment that extracts peat from a specific site. Therefore, much detail could be lost if one collects data at the corporate level.
- It could be more complex for companies with peat establishments all over Canada to provide inter-provincial peat transport data than for a particular peat establishment to do so.
- Plant managers would likely have better access to much of the requested information than would those in the company bureaucracy.

Results

The questionnaire was sent to a total of 74 peat establishments (*Appendix B: List of Peat Extraction Establishments Contacted [by Province]).* The addresses and contact names were located in Scott's Industrial Directory, the Yellow Pages and from Natural Resources Canada. Some of the peat establishments to which questionnaires were sent no longer exist, in which case, the questionnaires were returned by Canada Post.

Table A1. Geographical Breakdown of Responses to the Questionnaire

Province	Number of Questionnaires Sent	Number of Questionnaires Returned	Number of refusals, closed establishments and blank returns
Alberta	4	0	-
Manitoba	2	1	-
New Brunswick	21	7	2 refusals 2 returned by post office
Newfoundland	4	2	-
Nova Scotia†	3	3	-
Ontario	5	1	2 returned by post office
Prince Edward Island	3	1	-
Québec‡	31	15	1 refusal 1 closed 2 sold 1 returned by post office
Saskatchewan	1	1	-
Total§	74	31	-

† One establishment did not provide its amount of peat production for the year 2000. See Footnote 1.
‡ Although one establishment refused to participate, it nevertheless answered the questionnaire. This data remains unused.
§ Only 23 responses were received, but they provided data for 31 peat establishments. The difference results from the fact that some companies decided to answer one questionnaire for all of their peat establishments throughout Canada.

The response rate for the questionnaire was very high, representing approximately 69.0% of Canada's peat production (Table A1). Out of 23 responses, 19 were from establishments and four were from companies with more than one establishment. Although questionnaires were sent to each establishment, some companies preferred to answer one questionnaire for all of their operations. There were some instances in which certain questions remained unanswered, either due to confidentiality concerns, or because the information was not readily available to the respondent. One establishment did not provide production data for the year 2000. This set of responses was omitted from the sample, as the production data was necessary to ascertain the weight to give to it.[1] Occasionally, some questions were misunderstood, especially those pertaining to the outdoor stockpiling of peat.

Data Requested and Justification

The following sections provide a justification for the choice of questions and an overview of the quality of the responses. For some questions, the data itself was of little utility without cross-referencing it with other data. Responses to the questions have been amalgamated and are displayed in tables.

Section A: Peat Extraction and Land Use

There were five questions in Section A. The purpose of this section of the questionnaire was to acquire information on: (1) the size of peatland holdings; (2) the use of peatland holdings (3); the method of peat extraction used; (4) the process of stockpiling; and (5) the amount of extracted material that remained unused.

Data on the size and use of peatland holdings were needed to estimate GHG emissions resulting from land use. By comparing the method of extraction used with the data on the fuel use of the establishment, the fuel efficiency of each method could be determined. Questions related to the stockpiling of peat were also necessary in order to develop an industry-wide estimate of GHGs released during this stage of peat extraction.

A question on the proportion of extracted material sifted out of production was included in the questionnaire in order to estimate the amount of material extracted from peatlands beyond the quantity of peat shipped to market. This question, 5A, caused some confusion among questionnaire recipients.[2] While the percent of extracted material sifted

[1] This set of responses was not included when extrapolating the questionnaire responses to produce estimates for the entire Canadian peat industry.
[2] The text of the question reads as follows: In general, what proportion of the material extracted (by weight) from the peat harvesting sites is sifted out during peat processing?

out should be low, a number of respondents stated that they sifted out 85% or more of the material. In retrospect, it seems that the question should have been phrased with greater clarity.

The peat producers indicated by their answers a wide variety of uses for the portion of the extracted material sifted out of production. This material was: "marketed;" "reused in the form of mulch;" "transferred to a disposal site (landfill);" "made into stockpiles (may be reintroduced to bog);" "composted;" "sold in bulk;" "packed and shipped;" "dumped into holes on bog;" "mixed and bagged."

Table A2. Land Use Data

Land Use	Results from questionnaire	Extrapolated to entire industry
	hectares	
Total peatland holdings	54 925	79 577
Total holdings vacuum harvested	8 832	12 655 (15.9% of holdings)
Total holdings harvested using non-vacuum methods	207	441 (0.6% of holdings)
Peatlands under extraction	9 039	13 096 (16.5% of holdings)
Peatland holdings harvested in the past	878	1 272 (1.6% of holdings)
Peatland holdings never harvested	45 009	65 210 (81.9% of holdings)
Peatlands under natural restoration	673	975 (1.2% of holdings)
Peatlands under active restoration	204	296 (0.4% of holdings)

Table A3 Peat Extraction Data

Method of Extraction	Results from questionnaire	Extrapolated to entire industry
	tonnes of peat	
Total production vacuum harvested	855 896	1 240 055 (97.1% of production)
Total production harvested using non-vacuum methods	25 500	36 945 (2.9% of production)

Table A4 Stockpiling Data

Proportion of production in outdoor stockpiles	98.50%
Proportion of production in outdoor stockpiles with plastic sheeting	68.31%
Average length of time the peat is left in outdoor stockpiles	5.6 months

Section B: Peat Production and Fuel Use

The purpose of Section B of the questionnaire, which consisted of four questions, was to acquire information on: (1) the peat production of the establishment in the year 2000; (2) the peat production of the establishment in the year 1990; (3) the fuel use of the establishment in the year 2000; and (4) the stages of peat extraction and processing that take place at each establishment, and the types of fuels used during each stage.

As the most important piece of information collected in the questionnaire, the peat production data from the year 2000 was used to ascertain the extent to which each set of responses reflected the activities of the entire Canadian peat industry. The fuel use data was intended to be cross-referenced with production values in order to generate a greenhouse gas to peat production ratio.

Table A5. Response Rate to Questionnaire (% of Year 2000 Production)

	Sum of Data from Questionnaire	Entire industry (Statistics Canada)	Percent Response
	tonnes of peat		%
Total peat production (year 2000)	881 396	1 277 000	69.0

By calculating the greenhouse gas emissions from the fuel use data received from respondents, it was found that 9 027 tonnes of GHGs (in CO_2 equivalents) were produced from those peat operations that answered Section B of the questionnaire, representing 45% of peat production in Canada. Extrapolating this information to the entire industry showed that extraction and processing produced 20 104 tonnes of greenhouse gases (in CO_2 equivalents), which differed significantly from the figure for the year 2000 estimated from the Statistics Canada fuel consumption data, which showed an emission of 36 603 tonnes. Chapter Four addresses this discrepancy (Section 4.1).

Section C: Peat Transportation and Distribution

Section C of the questionnaire, which consisted of five questions, was used to obtain data on: (1) the amount of peat shipped in bulk and packaged; (2) the ownership of the means of transport used to ship the product to market; (3) the consumption of peat in Canada in the year 2000; (4) the consumption of peat in each province in the year 2000; and (5) the three largest export markets.

The form of shipped peat (packaged or in bulk) has implications on the method of transportation used and the compression of the peat. It was found that 2.4% of respondents (percentage based upon peat production by mass) shipped the peat to the end user in bulk form in the year 2000, with the remainder packaged.

The ownership of a trucking fleet may be of importance in relation to the amount of fuel purchased by each peat establishment. Establishments representing 12.7% of the total peat production of the questionnaire respondents owned their own trucking fleet, although most hired trucks to ship their product as well.

Recent data on the consumption, by province, of domestically produced peat may be used to help estimate GHG emissions from transport. This data was required because Statistics Canada has not collected inter-provincial peat transport information since 1988. The answers to this question are tabulated in the following table:

Table A6 Consumption of Domestically Produced Peat by Province (Year 2000)

Province	Consumption (Data from questionnaire)	Consumption (Extrapolated to entire industry)
	tonnes	
Alberta	4 448.5	6 447.1
British Columbia	0.0	0.0
Manitoba	2.5	3.6
New Brunswick	8 743.5	12 671.7
Newfoundland	520.0	753.6
Nova Scotia	2 481.5	3 596.4
Ontario	68 194.0	98 831.9
Prince Edward Island	1 214.0	1 759.4
Quebec	62 414.5	90 455.8
Saskatchewan	2.5	3.6
Canada	148 021.0	214 523.2

Note: Applicable to 69.0% of Canadian peat production.

Space was left at the end of the questionnaire for comments. Although the majority of respondents had no comments, one establishment indicated that its consumption of fuel for peat extraction, per unit of peat, had decreased a great deal over the past decade. While this claim could be the consequence of specific remedial measures taken within this one establishment, it cannot be substantiated by the fuel consumption data supplied by Statistics Canada for the peat industry as a whole.

APPENDIX D

TRANSPORTATION DISTANCES

Distances between Provinces and American States

The median distances that goods travel between Canadian provinces and American states are assumed to be the straight-line distance between the centroid of each region (state or province). This centroid is determined by using the median point (minimum aggregate travel point). The method used to determine the median distances between Canadian provinces and U.S. states was described in detail by Brown and Anderson (2002).[1]

Domestic Distances

The median distances that goods travel within and between Canada's provinces were also produced via the method used in a paper by Brown and Anderson (2002). Atlantic Canada, including New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland, was the exception, in that it was treated as a region.

Domestic peat transportation data was not available at the provincial level. Thus, the distance figures needed to be adapted in order to represent the median distances that goods travel within and between Western Canada (British Columbia, Alberta, Saskatchewan, Manitoba), Central Canada (Ontario, Quebec) and Atlantic Canada (New Brunswick, Nova Scotia, Prince Edward Island, Newfoundland) (Table A7).

[1] Mark Brown supplied me with the list of distances that he used for the research described in the paper by Brown and Anderson (2002).

Table A7. Methods of Estimating the Distance that Peat Travels Between Western, Central and Atlantic Canada

Regions	Western Canada	Central Canada	Atlantic Canada
Western Canada	Equivalent to half of the distance between Manitoba and British Columbia	(Half the distance between Manitoba and British Columbia) + (Distance between Manitoba and Ontario) + (Half the distance between Ontario and Quebec)	(Half the distance between Manitoba and British Columbia) + (Distance between Manitoba and Atlantic Canada)
Central Canada	-	Equivalent to the distance between Ontario and Quebec	(Distance between Atlantic Canada and Quebec) + (Half the distance between Ontario and Quebec)
Atlantic Canada	-	-	Already defined. [2]

Overseas Distances

The distances between international ports were derived from software entitled "World-Ports Distances –Trial Version" available at *http://www.distances.com/* (Table A8).

[2] Brown and Anderson (2002) had already defined Atlantic Canada as one region from which to calculate inter and intra-regional distances.

Table A8 List of Export Markets, Assumed Port-of-Entry and Distance from Halifax, Nova Scotia to Each Assumed Port-of-Entry

Export markets	Assumed Port-of-Entry	Distance (km)
Algeria	Algiers	4 037
Argentina	Buenos Aires	5 730
Australia	Sydney	9 907
Austria	Venice	5 467
Bahrain	Sharjah	9 047
Barbados	Bridgetown	1 908
Belgium	Antwerp	2 766
Bermuda	Hamilton	745
Brazil	Santos/Rio de Janeiro	4 625
Chile	Valparaiso	4 984
China, Peoples Republic of	Shanghai	10 530
Colombia	Cartagena	2 175
Costa Rica	Limon	2 716
Denmark	Copenhagen	4 682
Dominican Republic	Santo Domingo	1 616
Ecuador	Guayaquil	3 033
Egypt	Alexandria	5 664
France	Le Havre	2 668
Germany	Hamburg	3 003
Guatemala	Puerto Barrios	2 296
Haiti	Port-au-Prince	1 652
Hong Kong	Hong Kong	11 018
Indonesia	Djakarta	10 641
Israel	Tel Aviv	5 947
Italy	Bari	5 093
Jamaica	Kingston	2 611
Japan	Tokyo	9 418
Jordan	Beirut	5 985
Korea, North	Inchon	11 242
Korea, South	Pusan	10 061
Kuwait	Kuwait City	9 522
Lebanon	Beirut	5 985
Malaysia	Singapore	10 348
Mexico	Veracruz	2 566
Netherlands	Antwerp	2 766
Netherlands Antilles	Willemstad	1 977
Nigeria	Lagos	3 392
Philippines	Manila	10 682
Portugal	Lisbon	2 484
Saudi Arabia	Bahrain	9 321
Singapore	Singapore	10 348
South Africa	Cape Town	6 484
Spain	La Corunna	2 789
Switzerland	Genoa	4 518
Taiwan	Keelung	10 548
Trinidad and Tobago	Port of Spain	2 044
United Arab Emirates	Dubai	9 056
United Kingdom	London	2 795
Uruguay	Montevideo	5 656
Venezuela	Maracaibo	2 094

APPENDIX E

LIST OF PERSONAL COMMUNICATIONS

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