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CANADIAN PARKS COUNCIL

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Carbon Sequestration In Protected Areas Of Canada: An Economic Valuation

by

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December 2000

Economic Framework Project

Report 549

The Canadian Parks Council is an organization consisting of senior managers representing Canada's national, provincial and territorial parks agencies. It provides a Canada-wide forum for inter-governmental information sharing and action on parks and protected areas that:

promotes excellence in parks and protected areas planning and management;
advocates parks and protected areas values and interests;
encourages cooperation and provides support to member agencies on parks and protected areas issues and initiatives.

The Canadian Parks Council (CPC), known until 2002 as the Federal Provincial Parks Council (FPPC), was established in 1961, as a result of the *Resources for Tomorrow* conference. Current strategic directions of the Council include:

1. ADVANCING THE PROTECTION EFFORTS OF MEMBER AGENCIES;
2. PROMOTING HERITAGE APPRECIATION AND COMMUNICATIONS ABOUT PARKS AND PROTECTED AREAS;
3. SUPPORTING AGENCIES' EFFORTS TO ADDRESS ABORIGINAL PEOPLES' INTERESTS IN PARKS AND PROTECTED AREAS;
4. SUPPORTING ECOLOGICALLY SUSTAINABLE TOURISM RELATED TO PARKS AND PROTECTED AREAS;
5. FACILITATING EFFECTIVE MANAGEMENT OF PARKS AND PROTECTED AREAS.

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Economic Framework Project

In 1998 the Federal Provincial Parks Council called for the development of a common framework for measuring the economic value of protected areas. The purpose of the framework was to help FPPC members speak with one voice when talking about the economic benefits of protected areas within their jurisdictions. It was proposed that the framework should include not only traditional economic impact measurement (e.g., tourism spending, spending on capital development), but also direct user benefits (e.g., consumer surplus, existence benefits) and societal benefits (e.g., benefits from biodiversity, water production, scientific and educational benefits).

Because knowledge and measurement techniques are not equally developed in each of these areas, it was proposed that the work of developing a framework be done in three separate phases, which could be pursued concurrently or sequentially as resources allowed. The three phases are:

I. A user-friendly computerized model for estimating economic impact at the provincial level.
II. A handbook of user benefits showing how the FPPC members could undertake such studies in their own jurisdictions.
III. A series of up to 10 exploratory pilot studies undertaken with the help of academics, to establish a body of case studies on societal benefits

The work was carried out by a project task force, made up of representatives from Ontario Parks, BC Parks, Quebec Parks, NWT Parks and Parks Saskatchewan, and chaired by Dick Stanley, Director, Strategic Research and Analysis, Department of Canadian Heritage (as representative of Parks Canada. The publications in this series are the results of the work of this task force.

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Economic Framework Project, Report 549

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EXECUTIVE SUMMARY

Protected areas provide many important benefits to the society. Besides the obvious commercial activities that are associated with them, they also provide many ecosystem services. Understanding of such ecosystem services is important in policy making particularly with respect to resource conservation, and allocation of financial resources. Such services are not very commonly understood, and quite often taken for granted.

Carbon sequestration is an important ecosystem service provided by protected areas. Vegetation (trees, shrubs, and grasslands) through the process of photosynthesis, absorb carbon dioxide from the atmosphere, and store it in the form of organic carbon in various plant and root biomass over a period of time (generally their respective life period). As these organic materials decay, an even higher body of carbon pool is created in the soils. Some special soils, such as the peatlands, have an even higher level of carbon storage.

Canada and various provinces and territories have set aside lands where typical anthropogenic activities are not undertaken. These areas include: national parks, national park reserves, and provincial parks. In addition, there are other protected areas in Canada. These include: ecological reserves, wildlife improvement areas, representative area network reserves, and community pastures. All these areas provide various ecosystem services, including carbon sequestration.

In the context of global warming, the carbon sequestration function has an economic value. Ever since the world community has been aware of global climate change, carbon sequestration has taken another meaning. In order to curb the detrimental effect of global climate change, some 167 countries signed the Framework Convention on Climate Change in 1992. However, the actions to reduce greenhouse gas emissions were non-binding. These countries met again in Kyoto, and signed on a binding agreement, called the Kyoto Protocol, to reduce the level of emissions of greenhouse gases from various anthropogenic activities to the atmosphere. Canada has agreed to reduce its emissions in the 2008 – 2012 period by 6% below the 1990 level of emissions.

The Federal-Provincial Parks Council of Canada is engaged in a documentation of the total value of protected areas in Canada. Since carbon sequestration is an important function, and since economic valuation of ecosystem services is replete with problems, a study of this subject was sponsored.

The protected areas selected for further investigation in this study were all the national parks (including national park Reserves) and all Saskatchewan Provincial Parks.

The primary objective of this study was to place an economic value on one of the several functions (service) provided by a natural ecosystem within a protected area. The focus of this study was on the carbon sequestration. One of the major considerations involved in the development of methodology for this study was the use of secondary data.

The study was divided into two distinct phases: One, estimation of the physical quantity of carbon being stored in the study parks; and Two, economic valuation of the stored carbon.

The total amount of carbon sequestered in a protected area is affected by three things:

1. Physical area of the entity;
2. Nature of the land cover; and
3. Location of the entity in terms of ecoregion.

The last two factors affect the level or density of carbon stored.

Carbon is stored in two major pools: the plant biomass pool, and the soil pool. The former includes aboveground and root biomass, and the latter one includes peatlands, and other soils. All three carbon pools were estimated in the report. Since land cover for various national and provincial parks was not available, a survey of these areas was undertaken using a mail-in questionnaire. Response rate of 38% was considered poor. For the parks missing in the survey, alternative ways to estimate the amount of carbon pools were devised.

The economic value of protected areas' carbon sequestration function can be conceptualized within the context of climate change. Several methods of valuation are available. These include: avoided damage method; contingent valuation method; alternative cost method; marginal social opportunity cost method; market method; replacement cost method; and substitute cost method.

No studies were found for the first two methods. For the rest, studies have been conducted for North America. Results from various studies were converted into Canadian dollars per tonne in 2000 dollars. Average value of carbon in this study was based on the replacement and substitute cost method. Forests were taken as the most logical replacement for carbon sequestration. Reforestation was assumed to the vehicle chosen. A cost of $16.25 per tonne was estimated for this option. The next best option was that of converting the marginal agricultural lands into forests through afforestation. This option was costed at $17.50 per tonne. In addition to the median values, carbon sequestered was evaluated at a low price scenario -- $2.30 to $3.00 per tonne and under a high price scenario -- $500 per tonne.

One of the inescapable conclusions of this study is that the protected areas in Canada play a significant role in terms of carbon sequestration and its value to Canadians. The 39 National Parks in Canada have sequestered a total of 4.43 gigatonnes of carbon in various pools. The soils and peatlands are the most important pool of carbon, storing little over 90% of the total carbon sorted in the national parks. Average density of carbon in national parks is very high at 170 tonnes per ha. Northernmost national parks are particularly rich in this resource. Total economic value of stored carbon in the national parks is estimated to be $72 - 78 billion. However, this value could range between $12 to $2,216 billion, depending upon society's valuation of carbon sequestration function of the protected areas.

Provincial parks do store carbon but in smaller quantities. Here, the total amount is 487 Mt, valued between $1.5 to $214 billion.

Much of this analysis is based on secondary information, and much of this is incomplete. In the future, attempts should be made to improve the physical database for national and provincial parks. These improvements would require first hand measurement of carbon stored in the soil, and development of an improved inventory of the forestland and grassland ecosystems. More attention needs to be placed on the parks located in the northern ecozones.

ACKNOWLEDGEMENTS

This study benefited from several individuals and agencies, all of which are gratefully acknowledged. In particular we acknowledge the help and assistance from:

- Mr. Luc Perron, Senior Economist, Strategic Research and Analysis Directorate, Department of Canadian Heritage, Hull, for timely advice on various matters pertaining to the study;
- Gene Murphy, National Manager, Federal Provincial Parks Council, Thunder Bay, for assistance in administrative matters related to this study;
- The Federal Provincial Parks Council for financial assistance provided to the research team;
- Stephen Gray, Research Officer, Landscape Management Network, Pacific Forestry Center, Canadian Forestry Service, Victoria, for providing us with data on various carbon pools for National and Provincial Parks;
- Stephen McCanny and Jean Pointevin of Parks Canada for providing data on parks in the northern Canada;
- To various national and Saskatchewan provincial park managers who participated in the survey;
- Natasha Slobodian, Department of Soil Science, University of Saskatchewan, for providing information on grassland ecosystems;
- Professor Mohammed Dore, Brock University, for providing selected references on the economics of carbon sequestration;
- Jeff Keith, Saskatchewan Environment and Resource Management, Regina, for providing us with data on Saskatchewan Provincial Parks from the Canadian Conservation Area Database;
- Dr. David Gauthier, Executive Director, and Lorena Patino, of the Canadian Plains Research Center, for assisting in identifying data availability in the Canadian Conservation Area Database;

Any remaining errors, either of commission or omission, are entirely the responsibility of the authors.

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INTRODUCTION

1.1 Background

Canada has a policy of setting aside some lands in its natural habitat. These lands are free from all human intervention, in contrast to those in other parts, where human activity, including economic development has changed the landscape and its related flora and fauna. However, certain types of uses of these areas are made and this leads to many benefits realized by the society at large.

Natural resources provide numerous benefits to society. Some of these are obvious to people, since they either directly or indirectly affect them economically, while others are either not very well understood or just taken for granted. The latter tend to be those that are not a part of the commercial system. Some of these benefits accrue through provision of environmental amenities, some of which are intimately linked to economic system. These interrelationships between economic development and the environment have been brought to focus since the Bruntland Report (See WCED, 1987). According to the Commission (p. 37),

> “Environment and development are not separate challenges; they are inexorable linked. Development cannot subsist upon a deteriorating environmental resource base; the environment cannot be protected when growth leaves out of account the costs of environmental destruction….They are linked in a complex system of cause and effect.”

Examples of environmental stresses brought about by economic development activities are a common sight world over. For example, deforestation, by increasing water run-off, leads to an accelerated level of soil erosion, further leading to siltation of rivers, lakes, irrigation reservoirs, and other water bodies. Thus, forest protection is intertwined with soil conservation in many parts of the world.

Forests and other bodies that can store carbon over a period of time are also important in another respect – global climate change. The Intergovernmental Panel on Climate Change (IPCC), in 1995, concluded that human activities, particularly the burning of fossil fuels and, to a lesser extent, change in land use patterns, are increasing the atmospheric concentration of greenhouse gases, mainly carbon dioxide, nitrous oxide and methane, which tend to warm the atmosphere. This is counteracted in some regions, by the use of aerosols, which tend to cool the atmosphere. Scientists predict that these increases in greenhouse gases and aerosols will lead to regional and global changes in climate and climate-related parameters such as temperature, precipitation, soils moisture, and sea level (IPPC, 1995). Among the three major greenhouse gases, carbon dioxide is the main gas. Its concentration in the atmosphere has risen significantly since the industrial development, and at an even higher rate of increase since the early 1900s. This has become a major concern of various governments world-over. Lowering the concentration of carbon dioxide may have significant implications for economic development and on lifestyles of people in various parts of the world. This goal could be achieved by lowering the emissions of this gas in the atmosphere, by holding back the industry, or managing the forests to uptake this gas from the atmosphere.

1.2 Need for the Study

1.2.1 Benefits from Protected Areas

Protected areas and their role in the socio-economic milieu have been recognized worldwide. According to the IUCN (World Conservation Council)[1] "protected areas provide options for humanity in a rapidly changing world. They ensure the continuing flow of ecosystem services, including maintaining water and air quality and the availability of soil nutrients and act as carbon sinks." Canada and its various provinces and territories have recognized such roles. Various ecosystem services that have some social significance for Canadians have been identified by the Federal Provincial Parks Council (FPPC)[2.] This list includes the following types of services[3]:

1. **Natural Services:** Lands located in the vicinity of the protected areas benefits in terms of physical productivity through various natural services provided by them. Included here are pollination by insects from the protected areas, cross-fertilization, microclimate stabilization, and mitigation of pest infestations. Such productivity gains have economic values to land holders located in the vicinity of protected areas.

2. **Value of Biodiversity and Genetic Resources:** Under a certain conjunction of climate, topography, and natural resources, some protected areas harbor exceptionally large number of plant species. Some of these contain plant material that can be used or developed for newer and better yielding varieties of various plants and trees. Protected areas may contain some valuable species whose commercial values have not yet been recognized.

3. **Commercial Services:** Some protected areas may have some natural resource endowments that have a potential for commercial operations. Development of such opportunities would lead to future economic development of the surrounding region.

4. **Value and Habitat:** Plant level biodiversity is also accompanied by protected areas housing a more diverse animal and bird population than other parts of the landscape. This may result in various types of recreation (mostly non-consumptive type, such as nature walks, nature appreciation, bird watching, among others). Thus, biodiversity has an economic (and social) value to the Canadian society.

5. **Water Production:** Protected areas retain and filter groundwater. Some of the groundwater resources lead to supplementing surface water or in conjoint use of surface and groundwater. In many arid and semi-arid climates, availability of such water resources can be a significant societal resource.

6. **Carbon Sequestration:** Many of the protected areas are either forested lands or grasslands. Both of these ecosystems sequester carbon in the plant biomass and in the soil. If left undisturbed, this would serve as a carbon sink. In the context of global climate change, carbon sequestration has a high economic value.

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[1] For details see IUCN Web site

[2] The Federal-Provincial Parks Council is a committee made up of the Directors of the Parks Services of each of the Provincial and Territorial Governments as well as the Federal Government. Among other responsibilities, the Committee discusses the issues of protected areas in Canada.

[3] The following discussion is based on a discussion paper developed by the FPPC.

7. **Fish Spawning:** Protected areas may include fish spawning areas, which would help in the future production of fish population in adjoining streams and lakes (and even oceans). The society would therefore benefit from this increased fish population.

8. **Amenities and Aesthetics:** Pristine areas, particularly those near the urban areas, offer green spaces to local residents. This adds to the aesthetics enjoyed by these residents, and thus has an economic and social value.

9. **Scientific Benefits:** Scientific benefits from protected areas are important for two reasons: One, some of them get commercialized, and thus related to the economic / commercial benefits; and Two, this information becomes a source of future education materials.

10. **Educational Benefits:** These benefits are derived from outdoor experience as a part of the curriculum. Some of these benefits are economic in nature, derived from the difference in costs of alternative learning -- cost of classroom learning.

11. **Cultural Benefits:** Protected areas can perform a significant role in the culture of people, particularly those that reside in urban areas. Some people may attach special emotional importance to isolated areas, away from the urban places, either due to sense of place or the role played by them in history or traditions.

12. **Mitigation of Natural Disasters:** Protected areas, since they are left in a natural state, can prevent or mitigate natural disasters such as the dust bowls, and floods. Forests and grasslands retain water and therefore, do not dry out as quickly as open lands.

13. **Landscape Values:** Natural landscapes provide unique aesthetically pleasing scenery. Many of these are unique, and may become a major attraction for tourism. These landscapes therefore have an economic value.

14. **Health and Productivity Benefits:** In the busy and hectic lifestyles of the present-day business world, rest and relaxation is being recognized as a measure to reduce stress and stress-related diseases. Natural areas provide such places and therefore, create benefits to the society.

Each of these benefits should ideally be measured for a protected area to come up with a total Socio-Economic Value for the society.

Carbon sequestration is an important aspect of protected areas, since many such areas are either forestlands or grasslands. Such lands have been recognized by the Intergovernmental Panel on Climate Change (IPCC) as a measure to reduce the emissions of carbon dioxide into the atmosphere. According to Brown et al. (1996), for forestry, there are three practices that promote sustainable forest management and at the same time sequester carbon:

1. Management of conservation of existing carbon pools in forests by slowing deforestation, changing harvest regimes, and protecting forest from other anthropogenic disturbances;

2. Management for expanding carbon storage by increasing the area and / or carbon density in native forests, plantations and agroforestry and / or in wood products; and,

3. Management for substitution by increasing the transfer of forest biomass carbon into products such as biofuel and long-lived wood products that can be used instead of fossil-fuel based products.

The first method of carbon sequestration as a measure to mitigate the effect of climate change applies to the protected areas. In the protected areas, carbon pools are enhanced through stopping deforestation, and through protecting the forests from other anthropogenic disturbances.

1.2.2 Protected Areas in Canada

In a perfect world, people would protect instinctively undisturbed wild lands. According to McNamee (1998), it's not a perfect world, and commercial and industrial activities have been implicated in a continuing loss of species and ecosystems.[4] With the concept of a sustainable society, where human economic development must be compatible with the long-term maintenance of ecosystems and biodiversity, the concept of protecting some landscapes was produced.

There are various types of protected areas in Canada. The following is a list of types of protected areas in Canada:

1. National Parks
2. Provincial Parks
3. National Park Reserves or Parkland Reserves
4. Ecological Reserves
5. Wildlife Improvement Reserves
6. Representative Area Network Reserves, and
7. Community Pastures.

National Parks are a country-wide system of representative natural areas of Canadian significance. According to the National Parks Act (1998), the National Parks are dedicated to the people of Canada, for their benefit, education and enjoyment, and should be maintained and made use of so, as to leave them unimpaired for the future generations. At present, the Canadian National Parks represent all the provinces, 60% of the Canadian natural regions, 93% of the Canadian ecozones and 91% of the ecoclimatic provinces. All National Parks are administered by the Federal Government of Canada, under the provisions of Canada Parks Act (1998).

The National Park reserves are areas set aside as a National Park pending settlement of any outstanding aboriginal land claim (Natural Resources Canada ,1997). During this interim period, unlike the other National Parks, aboriginal peoples are permitted to do hunting, fishing and trapping activities.

Like the federal government, various provinces, including Saskatchewan, have developed a system of Provincial parks. The administration, management, planning, development and maintenance of all parklands in the province of Saskatchewan are carried out through the jurisdiction of the Parks Act (1999). The same objective as for the National Parks prevails here as well -- Saskatchewan parks are dedicated to the people of Saskatchewan and visitors to Saskatchewan for their enjoyment; and the natural, prehistoric and historic resources of parklands are to be maintained for the future generations.
Other than National and Provincial Parks, Canada protects its natural heritage in regional and territorial parks, wildlife reserves, heritage reserves, ecological reserves, community pastures, and in lands under private stewardship (Natural Resources Canada, 1997).

[4] Based on a quote by Stephen Wooley, Parks Canada Ecologist.

1.2.3 Economic Valuation of Protected Areas

As noted above, protected forested, wooded areas and grasslands are a good source of carbon sinks, which are recognized by the IPCC as playing a very important role in reducing the harmful effects of global climate change by taking carbon dioxide (CO_2) out of the atmosphere and sequestering it in plant tissue. Three major questions in this regards are: One, What are the major benefits related to carbon sequestration that are imparted on the society through protected areas?; Two, How should the carbon so sequestered be valued in economic terms?; and Three, What is the potential for such carbon sequestration in Canada, and how valuable an asset is that to Canada?

The economic value of carbon sequestration is important to policy makers (as well as to public at large) for planning future protected areas as well as to take into account the worth of such resources in their policy deliberations. Faced with tightening budgets, governments often think of reducing conservation activity or have a difficult time in allocating public investment funds to conserve and preserve natural environment. This may be a result of lack of information on the worth of these and similar activities. Unfortunately, at present this information does not exist. This study was initiated to fill this void.

1.3 Objectives of the Study

Major objective of this project is to estimate the economic value of carbon sequestration in various forms in the protected areas in Canada. This objective is further divided into the following objectives:

1. To determine, using secondary data sources, level of carbon stock in selected protected areas in Canada;

2. To examine various approaches to valuation of carbon;

3. To estimate the total economic value of estimated carbon stock in protected areas; and,

4. To draw implications of estimated value for poly makers and for operation and management of selected protected areas.

1.4 Scope of the Study

Protected areas included in this study are limited to National Parks and National Park Reserves in Canada and to Provincial Parks in the province of Saskatchewan. Value of carbon is based on the stock of carbon in the selected areas. In other words, no attempt is made to estimate the flux of carbon from these regions.

1.5 Organization of the Report

This Report is divided in seven chapters, including the present Introduction chapter. Chapter 2 includes a conceptual framework, which became the basis for developing the study methodology, which is reported in Chapter 3. Estimation of physical relationships, leading to amount of carbon stored in various National and Provincial parks, is presented in Chapter 4. A review of the literature for studies documenting / estimating economic value of carbon was conducted next, which is reported in Chapter 5. Results of the physical estimation and economic valuation are combined in Chapter 6, followed by in Chapter 7, summary and conclusions of the study.

Chapter 2

CONCEPTUAL FRAMEWORK

2.1 Carbon Sequestration in Protected Areas

The global carbon cycle represents the most important set of processes linking forests and other vegetation with global warming. It is defined as the carbon exchange among the atmosphere, the oceans, and the terrestrial biosphere and, on geological time scales, with sediments and sedimentary rocks (Natural Resources Canada, 1997). The forest (and other vegetation) ecosystems play an important role in the dynamics of global carbon cycle, although they can either act as sinks of carbon dioxide or sources. Forests are particularly important in the global carbon cycle because they can sequester large amounts of carbon over long time periods (Brown et al., 1996). The global forest ecosystems account for approximately 50% of the annual exchange of carbon dioxide to the atmosphere (Apps and Kurz, 1991),

Through the actions of photosynthesis, forests (and other vegetation) remove carbon dioxide from the atmosphere and store some of this carbon in the plant above- and below-ground biomass. This storage can be effected for decades or even centuries. Such storages are known as carbon sinks. Decomposition of dead organic matter, respiration and disturbances such as wildfires, harvesting and pests, release carbon back to the atmosphere, in this way acting as a source of carbon dioxide (Natural Resources Canada, 1999). When the uptake of carbon dioxide is bigger than its release, the system is sequestering and storing carbon from the atmosphere. These areas also serve as important benchmarks against which to compare the effects of human disturbance on ecological functions, including carbon sequestration and loss.

2.1.1 Forest Ecosystems

According to Kurz et al. (1992), the forest ecosystems include two carbon pools: biomass and soils. The biomass carbon represents all living tree and plant biomass; the soil carbon pool includes detritus, forest floor, coarse woody debris, soil organic matters and peatland accumulation.

The carbon pools are created by interacting processes that can influence each other and are affected by the same factors, although maybe in different ways. Disturbances such as fires, harvesting or pests affect the carbon content of stand components both during the disturbance and sometime after. Fire, for example, transfers carbon from biomass to soil carbon pools and rapidly releases some carbon in the atmosphere as carbon dioxide; harvesting removes a portion of the biomass from the forest to the forest product sector and also transfers some carbon to the detritus components of soil carbon pools; and the impacts of pests, depending on the severity, can merely reduce the carbon accumulation (low or moderate pest damage) or can lead to a carbon release to the atmosphere through tree mortality and subsequent decomposition (more severe or repeated pest). Disturbances also may set the ecosystem back to an earlier succession stage (Kurz et al., 1992). As old forests have a lower rate of carbon sequestration (Kurz et al., 1992), the disturbances may be a positive factor, then, helping to manage the forest to sequester more carbon.

2.1.2 Grassland Ecosystems

Grassland ecosystems contain a mixture of grasses, shrubs, scattered trees and associated soils that store carbon. Grassland ecosystems are commonly associated with dry climatic regimes, and therefore store the majority of carbon below-ground (Coupland,1992). Root systems are large and complex and add large amounts of organic matter to the soil annually. Disturbance, especially fire and grazing, can reduce above-ground carbon storage but in most cases does not result in large losses of carbon as is found in forests (Allen-Diaz, 1996). Grasslands can sequester carbon more quickly than forests due to rapid rates of growth of grass and shrub species, but the total amount of carbon stored in grassland landscapes, especially in above-ground biomass, is generally less than that of mature forests (Goudriaan, 1995).

2.2 Economic Valuation

2.2.1 Concept of Economic Value

Concept of economic valuation is based on the premise that people have preferences and can decide what they want. Under this premise, people make choices. These lead to the notion of trade-offs that people are willing to make, given certain constraints, notabley income. In traditional economic theory, these choices are made in the market place, where buyers and seller interact with each other. Here these sellers of a product offer a good for sale at a given price, and the buyers make their choice of buying it or not. The interaction continues till market comes to an equilibrium – when the amount supplied equals amount demanded. The market price thus established reflect the equilibrium price.

Economic value of a good in the market place reflects what someone is willing to give up in terms of other goods (or services) in order to obtain the good. The demand function for a given market reflects peoples' "willingness to pay –WTP" for that good. Money is an universally accepted measure of valuation, becaue of its convinience in making trade-off decisions.

Frequently the price of a commodity is used as equivalent to its economic value to the society. However, this is not correct. Price only records the minimum amount of money that people are willing to spend. However, the value of a good to those who are buying may be more than that.

Economic value is best approximated by net economic benefits that the society could derive from a good or service. Since these benefits are received both by the buyers and sellers, net economic benefits can be broken down into two parts: (1) That received by the consumers called *Consumer Surplus*, and (2) That received by producers called *Producer Surplus*.

Net economic benefits (NEB) thus can be expressed as:

$$NEB = CS + PS \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

Where,

CS is the consumer surplus, and
PS is the producer surplus.

Consumer surplus is the difference between what people are willing to pay to acquire the good and what they actually pay. Thus, this is the unpaid benefits received by the consuymers – higher satisfaction from owning the good. In other words, the net economic benefit to a consumer is the benefit received from paying less for a good than the maximum amount that the person is willing to pay for it. This area is shown in Figure 2.1. as the area above the price line but under the demand function.

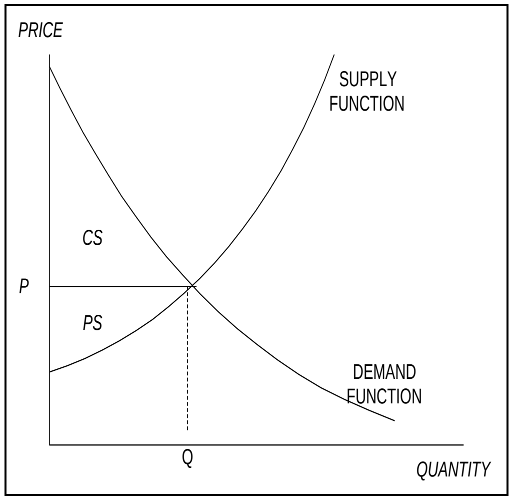


Figure 2.1: Concept of Consumer and Producer Surplus

The producers have an offer curve shown by the supply function. This is the price they would be willing to accept in exchange for that good. The consumers have their willingness to pay for the good shown by the demand function. Interaction between the buyers and sellers determines the equilibrium price.

The equilibruim price is shown in Figure 2.1 as the level P at which Q units of the good are sold. At this price, in addition to the consumers, producers also receive benefits from producing a certain good. These benefits are measured by producer surplus, which is the area under the price line and above the supply curve for the good.

The producers are better off if they could sell the good at a price higher than what it costs them to produce it. The higher the price, higher is the benefit to producers. However, at the higher price consumers are worse off, since some of the buyers may not be willing to pay for the good now at the price asked. This would result in a smaller net economic benefit from the good.

When the goods are bought and sold in a market place, and therefore, these are called market goods, estimation of economic value is rather simple. However, even here, market prices are accepteable only if the following conditions are met:

1. There are a large number of buyers and sellers in the market place. None of them act is such a manner as to exhibit collusion in setting prices or monopoly control.

2. The good must be capable of being ‘titled’ and transferreable. It must obey the exclusion principle – if one person uses it, no other one can.

3. There should not be a free rider problem. People who pay for the good must be able to prevent the non-payers from benefiting from the use of that good.

4. Production and consumption of a good must not create any uncompensated benefits aor costs to the people who are not directly engaged in either the

production or consumption of the good. In other words, there are no significant externalities resulting from the trading of the good.

5. Government intervention must be optimal, so that prices reflect society's valuation and do not differ from economic values.

6. The goods must not have the attributes of a merit or demerit good.

If all the above conditions are satisfied, market demand and supply information, along with prices, can be used to value the good or service.

2.2.2 Valuation of Protected Areas

Protected areas provide various types of benefits through the conservation of natural ecosystems. Ecosystem services are associated with various functions that are performed by them. These may be physical, chemical, or biological functions. Every ecosystem would perform an unique set of functions. For example, a wetland ecosystem provides wildlife, nutrient cycling, hydrological cycling, among others. Similarly, a forest ecosystem would provided carbon sycling, trapping of nutrient, holding soil erosion, and biodiversity. Dixon and Sherman (1990) have reviewed a variety of methods that are applicable to value various goods and services from the protected areas.

Application of market prices for ecosystem function valuation is replete with problems. At the very outset there are philosophical difficulties with such a valuation. Critics often ask the question how can one "price" nature. However, for the society and policy makers to make informed decisions regarding conservation and protection of such ecosystem services, arguments need to be made using unit commonly understood. Furthermore, since many of the ecosystem services have, in the long run, economic consequences, application of monetary valuation is necessary.

Here comes the second major problem. The ecosystem services are not traded in a market place, and therefore, their valuation requires an altogether different approach. The conceopt most commonly used is the "Total Economic Value – TEV" of an ecosystem[5]. This concept is shown in Figure 2.2.

The TEV consists of two major components: Use values and Non-Use values. These values may come from uses that the resources being put to now or from some future uses. Each of these types of uses could be further distinguished into direct uses and indirect uses. Direct use values included are based on those benefits that are generated by the use of various products produced by the natural ecosystem. Thus, for a forest, the direct use value would include timber harvest, in addition to wildcrafting, berries, and other food products. Indirect use values correspond to the concept of ecological function in ecology. Functions such as watershed protection, carbon storage in plants and soils, and biodiversity are some of the more known indirect uses of the forest, and are valued by the society for these functions.

The future use values are similar to the present use values, except these are based on some expectations of future uses and benefits. The future use values are often captured in the option values, where an inidividual is willing to pay a premium for conserving (preserving) the natural ecosystem for personal future use. Future benefits are more nebulous, and are often tied to scietific knowledge. For example, with newer technology development, scientists might be able to find a cure for some diseases using genetic materials that exist in the natural ecosystems.

[5] For more discussion on the TEV concept, see Pearce (1993).

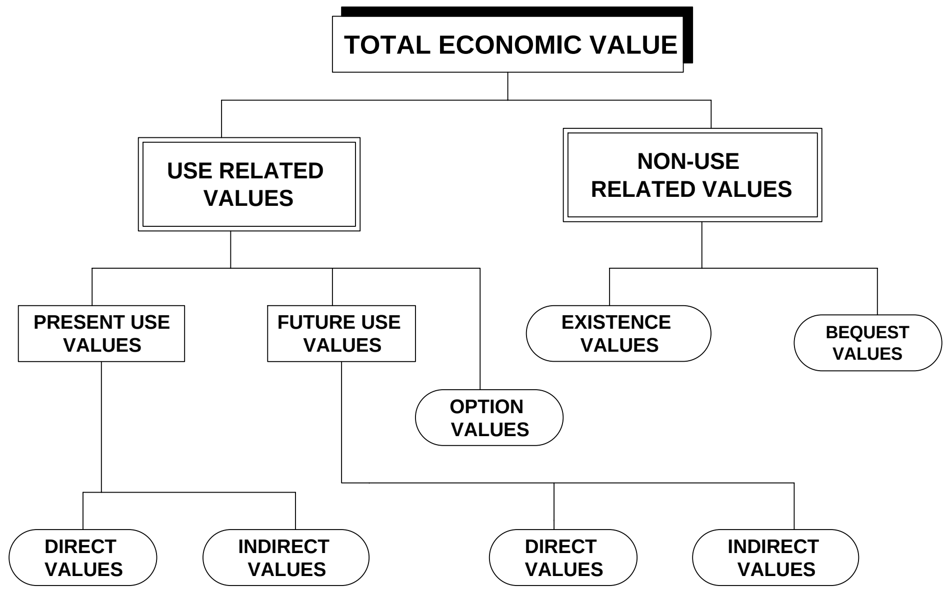


Figure 2.2: Concept of Total Economic Value

As noted above, option values[6] are not related to present use, but to ensuring that a future use is possible. When the resources being valued are diminishing in quantity, option values are expected to be positive.

There are two types of non-use values[7] associated with natural ecosystems. These are: Existence values, and Bequest Values. Existence values relate to valuation purely related to the existence of the natural ecosystem. These subjective valuation of their willinness to pay for the existence of certain natural assets such as pristine forests, wildlife, and other ecosystem fucntions. Use of these ecosystesm resources is not necessary.

Bequest values are associated with the wish of individuals to leave some resource for the use of future generations. Some economists regards bequest values as a part of the existence values. Empirical studies have also shown that it is hard to distinguish between these two types of values.

2.2.3 Valuation Methodologies

Since the TEV criterion of valuation is based on the willingness to pay, a variety of methods are available to estiamte the WTP. Besides the methodology, sources of data are equally important. As Kaplowitz (2000), based on an analysis of the focus group and individual interview data, concluded that the two provide different value of ecosystem values.

Various methods of valuation can be broadly divided into three tyeps[8]:

1. Revealed Willingness to Pay

[6] For an interpretation of option value, see Smith (1987).
[7] Non-use values tend to be non-market values. For a review of such valuation, see Smith (1993).
[8] This classification is based on material presented on the “Ecosystem Valuation” website: http://www.ecosystemvaluation.org/

2. Imputed Willingness to Pay, and

3. Expressed Willingness to Pay.

The first method is based on actual market mechnism, and can be applied to functions that have some commercial value. These are based on the concept of consumer and producer surplus. However, for some ecosystem functions that are not traded in the market (called non-market goods), such as aesthetic views or recreation, differences in the price paid with a certain attribute (affected by the natural ecosyste function) or expenditures incurred could be used as a close proxy for value. Typical example of methods included under this category are: Market Price Method, Production Function based Productivity Method, Hedonic Pricing Method, and Travel Cost Method.

An alternative way to value a natural function of an ecosystem is to measure what people are willing to pay (through adopting costly measures) to reduce the adverse effects resulting from losing the ecosystem function. Thus, if the ecosystem helps protecting watershed, and if that service is lost, people may be willing to invest in equipment for cleaning water. The value of the ecosystem function is then at least equal to the additonal cost that people willing to pay. Typical examples of methodologies falling in this type category are: Damage Cost Avoided Method, Replacement Cost Method, and Substitute Cost Method.

The third category of methods are based on the premise that if we wish to value something let us ask the peole themselves. These methods are useful in categories where the ecosystem services are neither traded in the market place, nor are there any other behaviour where they can reveal their preferences. Here surveys are used to elicit peoples' willingness to pay based on a hypothetical Category. Two methods commonly included here are the Contingent Valuation Method, and the Contingent Choice Method.

2.2.4 Valuation of Carbon Sequestration Function

Development of a conceptual method of valuation for the carbon sequestration function of the protected areas was based on the review of the concept of economic value and various valuation methods. However, two problems arose:

1. What is the context in which stored carbon can have an economic value?, and

2. Which of the above methods could be applicable to the valuation?

Answer to the first question was sought in terms of functions of stored carbon. If carbon was not stored, it would likely be released into the atmosphere. Here it is linked to emissions of greenhouse gases, and subsequently to global climate change[9]. Thus, the economic value of carbon sequestration can be cast in the context of global climate change and alternative methods of reducing emissions of greenhouse gases into the atmosphere.

If the value of stored carbon is to be estiamted in the context of global climate change, an obvious question to ask is what damages would be done if global climate change did not get

[9] According to Environment Canada, there are three major greenhouse gases: carbon dioxide, methane, and nitrous oxide. Carbon dioxide is the major gas, and accounts for over two-thirds of the total amount emitted in carbon dioxide equivalent. These equivalents are calculated using the 100-year global warming potential of each gas, and converted into weights relative to carbon dioxide. According to this method of calculation, methane is 21 times more, and the nitrous oxide is 310 time more potent in global warming than carbon dioxide.

stopped. Based on the work of IPCC (see Houghton et al., 1996), four major impacts of climae change are:

1. Increase in average temperature;

2. Change in precipitation (increase in some regions while a decrease in others) together with change in intrayear variability;

3. Increase in the frequency of extreme events, such as droughts and floods; and,

4. Rise in the sea level.

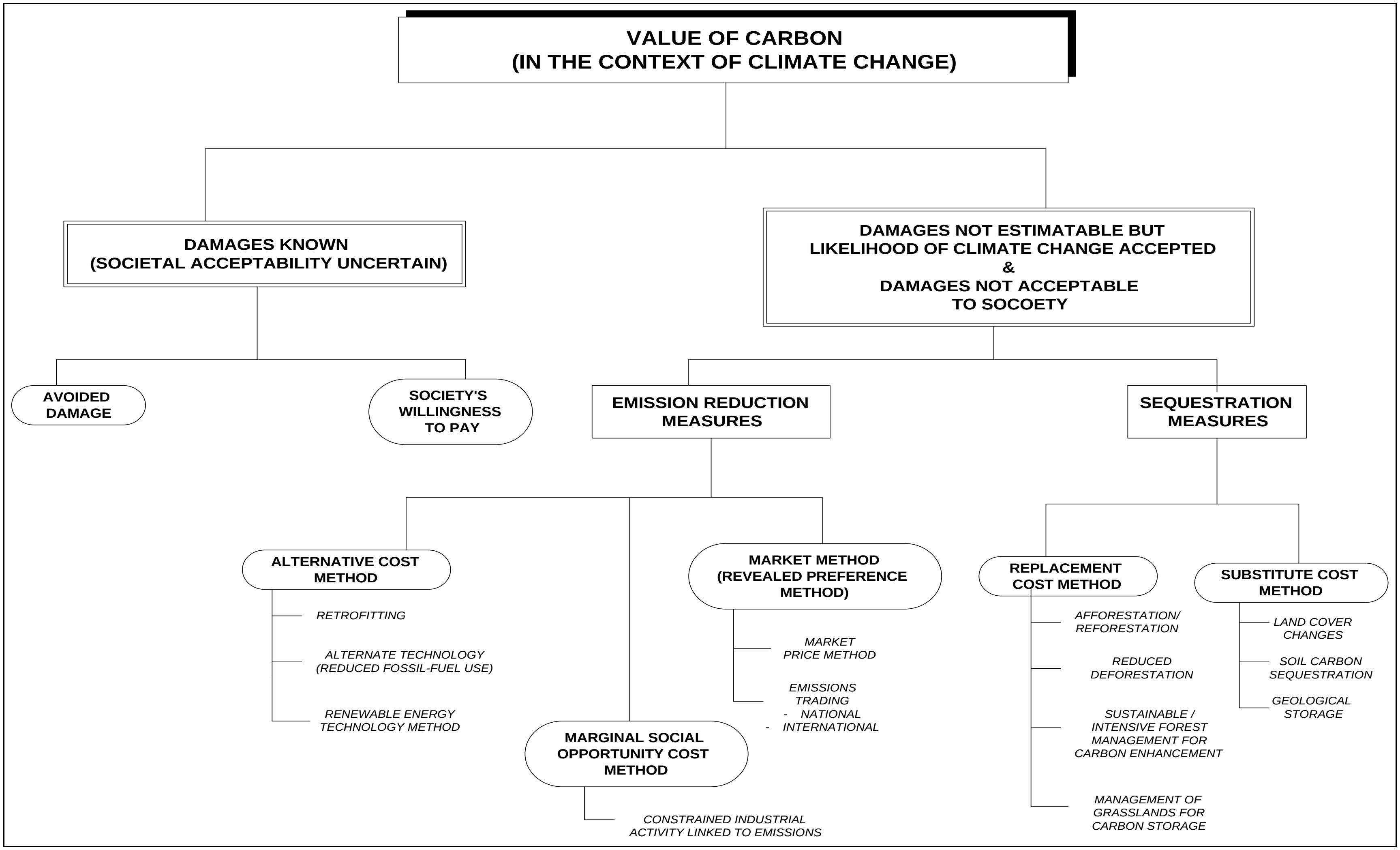
All these changes make all economic activites vulnerable. In addition, the changing climate would also affect human health directly. If the value of these dmages were known, valuation of the carbon stored would be simple. However, unfortunately this is not the case. According to Pearce et al. (1996) social costs of climate change are necessarily uncertain. Apart from the scientific uncertainty, there are uncertainties associated with (1) Limited knowledge of regional and local impacts; (2) Difficulties in measuring the economic value of impacts, even when the impacts are known; (3) Difficulties in predicting future technologocal and socioeconomic developments; and (4) The possibility of catastrophic events and surprises. If such estimates were known, one could apply the Avoided Damages method or the Contingency Valuation method in estimating a value to the stored carbon.

In Figure 2.3, this difficulty is acknowldeged. Thus valuation of stored carbon can be divided into two broad categories: (1) Damages from climate change can be assessed and known to people; and (2) These damages cannot be estimated, although there is public willingness to reduce the harmful impact of climate change. The choice of methods of valuation would differ markedly between the two categories.

Since as noted above, the first category of valuation cannot be empirically applied, more attention was paid to searching for methods that could be used under the second category. Here, in order to reduce the harmful effect of the climate change, society would have to either reduce the emissions of greenhouse gases, or increase the potential for carbon sequestration. In fact, both the approaches will enable the society to reduce the net emissions of greenhouse gases (emissions minus sinks). For Canada, a 6% reduction of greenhouse gas emissions below the 1990 level has been commited by the Government of Canada for the 2008-2012 period.

Among various methods that could be applied to value carbon under the Emission Reduction strategy, three are more prominent: Alternative cost method, Market based method, and Marginal Social Opportunity cost method. Similarly under the sequestration strategy, methods most appropriate are the Replacement cost method, and the Substitutre cost method. These methods are discussed further later on in the Report.

Figure 2.3


VALUE OF CARBON
(IN THE CONTEXT OF CLIMATE CHANGE)
DAMAGES KNOWN
(SOCIETAL ACCEPTABILITY UNCERTAIN)
DAMAGES NOT ESTIMATABLE BUT
LIKELIHOOD OF CLIMATE CHANGE ACCEPTED
&
DAMAGES NOT ACCEPTABLE
TO SOCOETY
AVOIDED
DAMAGE
SOCIETY'S
WILLINGNESS
TO PAY
EMISSION REDUCTION
MEASURES
SEQUESTRATION
MEASURES
ALTERNATIVE COST
METHOD
RETROFITTING
ALTERNATE TECHNOLOGY
(REDUCED FOSSIL-FUEL USE)
RENEWABLE ENERGY
TECHNOLOGY METHOD
MARGINAL SOCIAL
OPPORTUNITY COST
METHOD
CONSTRAINED INDUSTRIAL
ACTIVITY LINKED TO EMISSIONS
MARKET METHOD
(REVEALED PREFERENCE
METHOD)
MARKET
PRICE METHOD
EMISSIONS
TRADING
- NATIONAL
- INTERNATIONAL
REPLACEMENT
COST METHOD
AFFORESTATION/
REFORESTATION
REDUCED
DEFORESTATION
SUSTAINABLE /
INTENSIVE FOREST
MANAGEMENT FOR
CARBON ENHANCEMENT
MANAGEMENT OF
GRASSLANDS FOR
CARBON STORAGE
SUBSTITUTE COST
METHOD
LAND COVER
CHANGES
SOIL CARBON
SEQUESTRATION
GEOLOGICAL
STORAGE

Chapter 3

STUDY METHODOLOGY

3.1 Overview of Methodology

It was noted in Chapter one that the major objective of this study was to estimate the economic value of carbon stored in selected protected areas in Canada. This estimation is done using secondary data for physical and biological aspects of the study and used the method of benefit transfer for the economic valuation. Benefit transfer method is one in which estimation of value is based on value derived from valuation studies that are available to the analyst.

Study methodology is divided into four major parts:

Part One: Selection of Study Protected Areas
Part Two: Carbon sequestration Estimation
Part Three: Economic Value of Stored Carbon
Part Four: Estimation of Total Value of Carbon sequestration

Each of these is described below.

3.1.1 Selection of Study Protected Areas

Although protected areas may include a variety of areas, such as National Parks (including National Park Reserves), Provincial Parks, Parkland Reserves, Ecological Reserves, Wildlife Improvement Reserves, Representative Area Network Reserves, and Community Pastures, in this study estimation was limited to all National Parks, and all Saskatchewan Provincial Parks. This restricted scope of the study was necessitated by the availability of both time and budgetary resources. More details on the sample study areas are provided in Section 3.2.

3.1.2 Estimation of Stock of Carbon Stored

Estimation of carbon stock in various protected areas included in the study was done using data obtained from secondary sources. The total amount of carbon stored in Study's protected areas (TCS) was estimated as a sum of the amount in each of the National and Provincial Parks, as shown in Equation 3.1.

$$TCS = \sum_{i=1}^{Nn} CS_{NPi} + \sum_{j=1}^{Np} CS_{PPj} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where, CS_{NPi} is the carbon stored in the i^{th} national park,
CS_{PPj} is the carbon stored in the j^{th} provincial park,
N_n is the number of National Parks, and
N_p is the number of Provincial Parks.

Total amount of carbon sequestered in a national or a Provincial park, referred to as a site, is first divided into four types of land cover and associated land uses, as shown in Equation (3.2).

$$CS_{NP} = CS_{PS} + CS_{PT} + CS_{SL} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

Where CS_{PS} is the plant-stored carbon, CS_{PT} is the carbon stored in peatlands, and CS_{SL} is the carbon stored in soils. Furthermore, plant-stored carbon can further be split into two: carbon stored in plant biomass (aboveground), and carbon stored in the roots (underground). Depending upon the nature of vegetation system, this carbon can be stored in trees (forested land) or in grass (in grassland ecosystems).

The above methodology was applied to two types of natural ecosystem that exist in protected areas; Forest ecosystems, and Grassland ecosystems. This estimation required two basic sets of information: (1) Physical characteristics of various protected areas; and (2) Estimated carbon sequestration or storage in the various types of biomass. Detailed methodology for this estimation is shown in Section 3.3.

3.1.3 Placing an Economic Value on Carbon Sequestered

Various economic benefits to the society from carbon sequestration can be divided into two major types; Monetizable benefits, and Non-monetizable benefits. The monetizable economic benefits can be quantified, and lead to the value of stored carbon. However, as noted in Chapter 2, since direct market prices for this good do not exist, monetization was based on a survey of various studies that have estimated a value to stored carbon.

A review of the literature was undertaken, which led to pertinent studies for this topic. Studies were classified by method / rationale for valuation, besides location and sector. All Canadian, U.S. and International studies were included. However, this search was limited by the time and budgetary resources available and was confined to those housed at the University of Saskatchewan library, and those obtainable on interlibrary loan within a shorter period of time.

In order to place an economic value to carbon sequestration, a review of available studies was undertaken. These were classified into the following seven category of valuation methodology:

1. Avoided Damage Method
2. Contingent Valuation Method
3. Alternative Cost Method to Reduce Emissions
4. Revealed Preference Method for Reducing Emissions
5. Marginal Social Opportunity Cost Method
6. Replacement Cost Method for Carbon Sequestration, and,
7. Substitute Cost Method to Enhance Carbon Sequestration.

For some methods, empirical studies were limited or non-existent. For these, discussion was limited to a review of the methodology. The economic value of stored carbon was derived through a synthesis of these studies. Details are provided in Chapter 5 of this Report.

3.1.4 Estimation of Total Societal Benefits Related to Carbon Sequestration in Canada's Protected Areas

Under this task, output from Parts two and three were combined. The physical amount of stored carbon as estimated in Part two, was multiplied by an estimated value of carbon, which was estimated in Part three. Since different methods of valuation provide a very different level of value of stored carbon, sensitivity analysis was done using a range of values.

In certain instances, available data were inadequate to follow the methodology developed. In such cases, improvisations were made using comparable information for other areas. Where such was not possible, value of stored carbon was not estimated. Estimated values reflect the stock of carbon, and not the net flux (emissions less sequestration) of carbon dioxide from various protected areas.

3.2 Description of Study Areas

3.2.1 Location of Study=s National Parks

In this study, all Canadian National Parks and National Park reserves were included. This list was based on data contained in Parks Canada (2000). Location of these parks was confirmed using information from Canadian Oxford World Atlas (Stanford, 1998) and a map from the National Parks of Canada (McNamee, 1998). These National Parks are shown in Figure 3.1. The National Marine Conservation Areas were not considered in this study, since they are mostly located over water bodies.

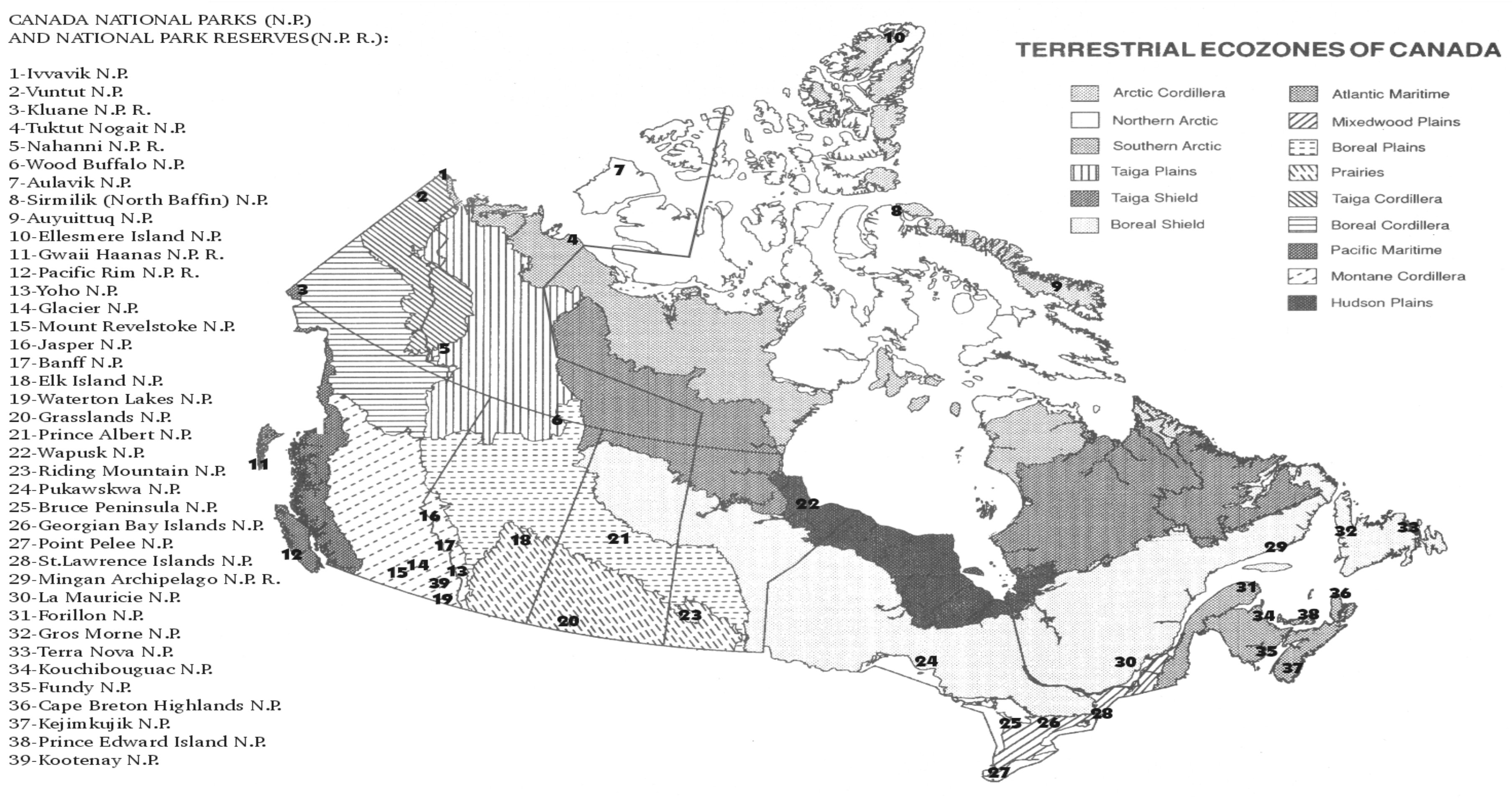
Since rate of carbon sequestration is a function of type of vegetation and climate of the region, National Parks were classified by either ecozone or ecoclimatic provinces. Some of the data used in this Report came from compilations by ecozone and by ecoclimatic provinces. This information was obtained from an ecozone map (Ecological Stratification Working Group, 1996) and an ecoclimatic province map of Canada (Kurz et al., 1992). According to Kurz et al. (1992), there are 11 ecoclimatic provinces. These regions are characterized by distinctive ecological responses to climate as reflected in soils, vegetation, wildlife, and water.

The study included a total of 39 National Parks, as listed in Table 3.1. The respective area of the Park and the location in terms of province and ecozone are also shown in the table. These parks occupy a total of 26 million hectares.

National Parks are located in every province and every ecozone. Some of them are located in more than one ecozone. The latter types of National Parks include Wood Mountain, Auyuittuq, Elsemere Island, Sirmilik, Nahanni, Ivvavik, and Kluane. Similarly some parks are located in more than one province. Examples include Wood Buffalo, which is located in the North West Territories and Alberta.

Six of the 39 National Parks had areas in more than one ecozone. Estimation of carbon stored was based on an explicit consideration of features of each ecozone.

Figure 3.1: Location of Study's National Parks



3.2.2 Location of Study's Provincial Parks

In Saskatchewan, 30 Provincial Parks were studied. Among these parks, four of them are wilderness, ten are recreation parks, eleven are natural environment parks and five are recreation sites. The location of these parks is presented in Figure 3.2. Data for this were obtained from the Saskatchewan Environment and Resource Management (2000). There are nine historic sites in Saskatchewan that were not studied in this study. The primary reason for this was the fact that these areas are very small and covered with buildings, many of which house museums. Although important for historical reasons, their contribution to carbon sequestration was considered negligible.

Area of various Provincial Parks is shown in Table 3.2. Almost one million hectares of land is under these types of protected area in the province of Saskatchewan. A general observation for these parks is that they are relatively smaller in area than the National Parks. The largest Provincial Park is Lac La Ronge, which occupies 336,000 ha. In contrast, 15 of 39 National Parks are larger than this.

3.3 Source of Data for Carbon Sequestration

In this study, estimation of carbon sequestration for various National Parks (including National Park Reserves) and for the Provincial Parks of Saskatchewan was based on a disaggregated approach noted above (Equation 3.1). Amount of carbon was related to the biomass pool (for aboveground and below-ground) and for the soil pool. For forested areas, peatlands were also included.

Table 3.1: List of National Parks included in the Study, by Province and Ecoclimatic Province

Park No.*	Province	Name of Park	Park Type	Ecoclimatic Province (Proportion by Ecozone in %)	Total Area (ha)**
16	Alberta	Jasper	NP	Montane Cordillera (100)	1 087 800
17	Alberta	Banff	NP	Montane Cordillera (100)	664 100
18	Alberta	Elk Island	NP	Boreal Mixedwood Forest ecozone (100)	19 400
19	Alberta	Waterton Lakes	NP	Montane Cordillera (100)	50 500
6	Alberta/NWT	Wood Buffalo	NP	Taiga Plains (20) /Boreal Plains (80)	4 480 200
11	British Columbia	Gwaii Haanas	NPR	Pacific Maritime (100)	1 449 500
12	British Columbia	Pacific Rim	NPR	Pacific Maritime (100)	50 000
13	British Columbia	Yoho	NP	Montane Cordillera (100)	130 000
14	British Columbia	Glacier	NP	Montane Cordillera (100)	143 930
15	British Columbia	Mount Revelstock	NP	Montane Cordillera (100)	25 970
39	British Columbia	Kootney	NP	Montane Cordillera (100)	140 500
22	Manitoba	Wapusk	NP	Hudson Plains (100)	1 147 500
23	Manitoba	Riding Mountain	NP	Boreal Plains (100)	297 310
34	New Brunswick	Kouchibouguac	NP	Atlantic Maritime (100)	23 920

Park No.*	Province	Name of Park	Park Type	Ecoclimatic Province (Proportion by Ecozone in %)	Total Area (ha)**
35	New Brunswick	Fundy	NP	Atlantic Maritime (100)	20 700
32	Newfoundland	Gros Morne	NP	Boreal Shield (100)	180 500
33	Newfoundland	Terra Nova	NP	Boreal Shield (100)	39 900
4	NWT	Tuktut Nogait	NP	Southern Arctic (100)	1 634 000
5	NWT	Nahanni	NPR	Taiga Plains (50) / Taiga/tundra Cordillera (50)	476 520
7	NWT	Aulavik	NP	Northern Arctic (100)	1 220 000
36	Nova Scotia	Cape Breton Highlands	NP	Atlantic Maritime (100)	94 800
37	Nova Scotia	Kejinkuijk	NP	Atlantic Maritime (100)	40 370
8	Nunavut	Sirmilik (North Baffin)	NP	Arctic cordillera (50) /Northern Arctic (50)	2 225 200
9	Nunavut	Auyuittuq	NP	Arctic cordillera (90) /Northern Arctic (10)	1 970 740
10	Nunavut	Ellesmere Island	NP	Arctic cordillera (50) /Northern Arctic (50)	3 775 500
24	Ontario	Pukaskwa	NP	Boreal Shield (100)	187 780
25	Ontario	Bruce Peninsula	NP	Mixedwood Plains (100)	11 000
26	Ontario	Georgian Bay Islands	NP	Mixedwood Plains (100)	2 560
27	Ontario	Point Pelee	NP	Mixedwood Plains (100)	1 500
28	Ontario	St. Lawrence Islands	NP	Mixedwood Plains (100)	8 700
38	PEI	Prince Edward Island	NP	Atlantic Maritime (100)	2 700
29	Quebec	Mingan Archipelago	NPR	Boreal Shield (100)	150 700
30	Quebec	La Mauricie	NP	Boreal Shield (100)	53 610
31	Quebec	Forillon	NP	Atlantic Maritime (100)	240 400
20	Saskatchewan	Grasslands	NP	Prairies (100)	90 640
21	Saskatchewan	Prince Albert	NP	Boreal Plains (100)	387 430
1	Yukon	Ivvavik	NP	Taiga /tundra Cordillera (100)	975 000
2	Yukon	Vuntut	NP	Taiga/tundra Cordillera (100)	434 500
3	Yukon	Kluane	NPR	Boreal Cordillera (60) / Pacific Maritime (40)	2 201 330
Total Canada					26 136 710

NP = National Park NPR = National Park Reserves

* Based on Figure 3.1.

** Area was adopted from the study questionnaire, when it differed from the Parks Canada (2000) estimates.

Figure 3.2: Location of Study's Saskatchewan Provincial Parks

PROVINCIAL PARKS
OF SASKATCHEWAN:

1-Anglin Lake (Recreation Site)
2-Athabasca Sand Dunes (Wilderness)
3-Blackstrap (Recreation)
4-Bronson Forest (Recreation Site)
5-Buffalo Pound (Recreation)
6-Candle Lake (Recreation)
7-Chiteck Lake (Recreation Site)
8-Clarence-Steepbank Lakes (Wilderness)
9-Clearwater River (Wilderness)
10-Crooked Lake (Recreation)
11-Cypress Hills (Natural Environment)
12-Danielson (Recreation)
13-Douglas (Natural Environment)
14-Duck Mountain (Natural Environment)
15-Echo Valley (Recreation)
16-Emma Lake (Recreation Site)
17-Good Spirit Lake (Natural Environment)
18-Greenwater Lake (Natural Environment)
19-Katepwa Point (Recreation)
20-Lac La Ronge (Natural Environment)
21-Makwa Lake (Natural Environment)
22-Meadow Lake (Natural Environment)
23-Moose Mountain (Natural Environment)
24-Narrow Hills (Natural Environment)
25-Pike Lake (Recreation)
26-Regina Beach (Recreation Site)
27-Rowan's Ravine (Recreation)
28-Saskatchewan Landing (Natural Environment)
29-The Battlefords (Recreation)
30-Wildcat (Wilderness)

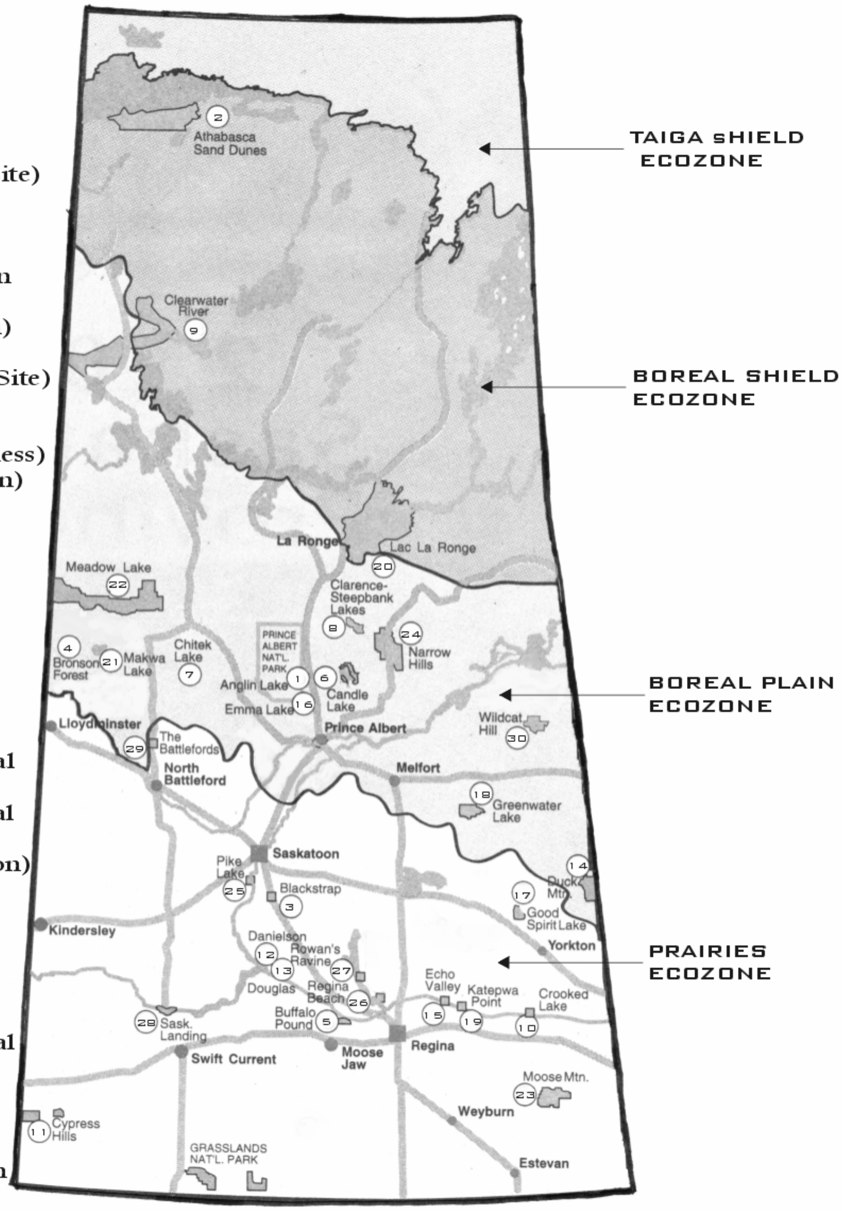


Table 3.2: Area of Provincial Parks included in the Study, Saskatchewan

No.	Name of the Park	Park Type	Ecozone	Area in (ha)*
1	Anglin Lake	Recreation	Boreal Plain	1 360
2	Athabasca Sand Dunes	Wilderness	Boreal Shield	192 500
3	Blackstrap	Recreation	Prairie	656
4	Bronson Forest***	Recreation	Boreal Plain	14 500
5	Buffalo Pound	Recreation	Prairie	1 900
6	Candle lake**	Recreation	Boreal Plain	1 214
7	Chiteck Lake***	Recreation	Boreal Plain	599
8	Clarence-Steepbank Lake	Wilderness	Boreal Plain	17 549
9	Clearwater River	Wilderness	Boreal Shield / Boreal Plain	22 400
10	Crooked Lake	Recreation	Prairie	200
11	Cypress Hills	Natural Environment	Prairie	18 524
12	Danielson	Recreation	Prairie	650
13	Douglas	Natural Environment	Prairie	7 300
14	Duck Mountain	Natural Environment	Boreal Plain	16 250
15	Echo Valley	Recreation	Prairie	650
16	Emma Lake	Recreation	Boreal Plain	35
17	Good Spirit Lake	Natural Environment	Prairie	1 950
18	Greenwater Lake	Natural Environment	Boreal Plain	20 700
19	Katepwa Point	Recreation	Prairie	8
20	Lac La Ronge	Natural Environment	Boreal Shield	336 197
21	Makwa Lake	Natural Environment	Boreal Plain	2 500
22	Meadow Lake	Natural Environment	Boreal Plain	16 000
23	Moose Mountain	Natural Environment	Prairie	40 000
24	Narrow Hills	Natural Environment	Boreal Plain	53 613
25	Pike Lake	Recreation	Prairie	449.8
26	Regina Beach***	Recreation	Prairie	20
27	Rowan's Ravine	Recreation	Prairie	270
28	Saskatchewan Landing	Natural Environment	Prairie	5 500
29	The Battlefords	Recreation	Prairie	600
30	Wildcat	Wilderness	Boreal Plain	21 700
	Saskatchewan			997 394.8

* Estimated area taken from the questionnaire answer, when differed from the Saskatchewan Environment and Resources Management (2000) information.

** Saskatchewan Parks and Renewable Resources (1986).

*** World Conservation Monitoring Centre (2000).

Much of the information on physical attributes for the National Parks was collected from Parks Canada reports and Internet sites. However, although some pertinent information, such as area of the Park, was available, this was not adequate for the purposes of the study. To compliment the available information, a survey of all National Parks and Saskatchewan Provincial Parks was undertaken. The questionnaire used is shown in Appendix A.

Frequently data for individual sites were not available. Under these conditions, choice of carbon sequestration value to be used for the Park was based on a value for an ecozone or ecoclimate province. Failing that, the value for a neighboring Park (in a similar ecozone) was used. If none of the above resulted in an acceptable value of carbon sequestration, total carbon stock for the park was not estimated.

Determination of carbon sequestration required two key sets of information. One of these is the set of models that can be used in determining these rates. The second key information is the nature of land cover / forest inventory, which determines the nature of land cover, forest stand, its age, and species composition. Since this study used data available through secondary sources, a review of these aspects is presented below.

3.3.1 Models for Estimation of Forest Biomass and / or Carbon Stock

Many climate modelers have struggled to represent the terrestrial carbon cycle properly. The lack of data and the computer power required have forced climate modelers to adopt simplified carbon models, with low resolution that compromised the realism of this cycle in their models, as was well reviewed in the Intergovernmental Panel on Climate Change (IPCC WG1 TP2, 1997). The latter factor has forced modelers to also adopt many alternative approaches, such as parameterizations, assumptions, spin-ups and flux adjustments that compromised the reliability of the terrestrial carbon cycle representation[10].

In order to improve the knowledge of physical processes, their measurements and interactions, several new approaches to models and data collection have been considered. However, most are both time and money consuming. This has lead to many localized studies around the world. Some of these are for Canada, and therefore, pertinent to the purposes of this study. Even here, unfortunately, they do not cover all the area and were conducted independently of each other. Various studies had distinct goals and approaches to different data sources. This makes their synthesis to a national model or approach difficult. In spite of this difficulty, a review of these models was conducted in this Study.

The Laurentian Forestry Centre (LFC) has initiated a 5-year project, ECOLEAP, in Saint-Foy, Quebec. This project has the objective to improve the understanding of environmental factors that control the productivity of boreal and sub-boreal forests. Based on this understanding of environment mechanics, the project is to further develop tools for predicting forest ecosystem productivity on a regional scale but with spatial resolution fine enough to be used by forest managers. In this project, modeling of net primary productivity and the cycling of major nutrients are included (Natural Resources Canada, 1998). Since completion of the study is expected to be the end of 2001, no estimated value of carbon sequestration is available.

CENTURY 4.0 soil process model is a process-based biogeochemistry model. It simulates the vegetation-soil dynamic of terrestrial ecosystems based on relationships between climate, soil texture, plant productivity, decomposition, and human management. It also considers carbon and nitrogen dynamics. It was tested for the boreal forest with data from the Boreal Forest Transect Case Study (BFTCS) in Central Canada. The model simulated aboveground biomass and net nitrogen (retained in soil after any emissions). This model, because of the effect of soil texture on soil carbon level, resulted in an underestimation of carbon levels for sandy soils and

[10] A review of terrestrial carbon models is provided in Smith et al. (1993).

overestimation of carbon level for soils with finer texture. It is a satisfactory model when applied in a steady-state condition, but it has inadequate representation of the influence of disturbances (wildfire) and does not differentiate plants C_3 and C_4 (Peng et al.,1998).

FORSKA 2 Forest patch model simulates a negative exponential age-class structure, i.e., the largest proportion of patches are in the youngest age classes. The reported biomass carbon densities are spatially averaged over all patches, resulting in a lower, but more correct, estimate. This method does not account for litterfall or litter and soil decomposition processes. Used with the BFTCS data, this method showed a great sensitivity to aboveground biomass, with more accuracy in predicting biomass than the CENTURY 4.0 (Price et al., 1999). These authors suggested combining CENTURY 4.0 and FORSKA 2. The CENTURY 4.0 could be used to simulate species composition and biomass, while FORSKA 2 could be used to simulate soil and litter carbon densities.

The Boreal Patch Simulator (BOPAS) simulates the development of carbon pools as a function of environmental parameters. This model was developed by dividing the Pukaskwa National Park into patches defined by a unique combination of forest type, age, climatic variables, soil type, and topography. Although it raises questions about the amount of carbon in the forest floor, predictions of aboveground biomass are considered to be satisfactory (Nalder and Merriam, 1995).

Although the ideal model would be a combination of regional models, Canada is not completely represented by regional models. With a goal to compile the best local information in a national level, efforts were made to develop a National carbon model: the Carbon Budget Model of the Canadian Forest Sector. This model was developed to determine the current net change in carbon stocks within the Canadian Forest Sector. The model estimates the carbon stocks and changes among forest biomass, soils and products using data from forest inventories, ecosystem classification, soil surveys and other government and industry statistics (Kurz, 1992).

The Carbon Budget Model of Canadian Forest Sector is considered to be the most complete documentation for Canada’s carbon cycle (IPCC WG1 TP2, 1997). Furthermore, the results are easily accessible and are easy to understand. The results of the Carbon Budget of the Canadian Forest Sector: Phase I, were analyzed in a global carbon balance study by Apps and Kurz (1991). A dynamic version of the Carbon Budget Model (phase 2) simulates forest sector carbon dynamics over several decades and has a more complete database than Phase 1. Average soil decomposition rate is considered to be a weakness of this model.

The Canadian Forest Service is developing an integrative climate change model for Canada, which will link the results of separate studies using a spatially-referenced database and modeling system. Spatial databases will be brought into a common format to enable cross-comparison with other databases created by large-scale dynamic models (Price, 1999). This project will provide more accurate data on a national scale, but results have not been published to date (Price, personal communication).

3.3.2 Forest Inventories

The ideal set of data for the estimation of carbon sequestration would be one that is recent and specific for the park itself. However, this was not the case. In the absence of quality data for various parks, the next best option was to use national studies for the carbon pools georeferenced in a geographical information system, or national compilations of data by ecozone or ecoclimatic provinces. From this information, models could be developed for each park that would update the inventory data taking in account the interactions and carbon flows between the components of the carbon pools. The results of these model predictions for each park could give an estimation of carbon stored in the present date for the parks.

Unfortunately most National Parks do not have recent inventories and most Provincial Parks were not included in any such exercise. Furthermore, studies dealing with land use and vegetation cover for National and Provincial Parks are very few. Two National Parks had some studies done within their boundaries which are somewhat related to this study. Pukaskwa National Park was used in a case study to develop a patch model for boreal forests (see Nalder and Merriam, 1995). Using geographical information systems (GIS) techniques, the park was divided in patches defined by unique combination of forest type, climatic variables, soil type and topography to simulate the carbon dynamics for 150 years. This model did not take into account diseases, roots and shrubs' biomass (Apps and Price, 1995). Because the methodology used is different from the one used in this Report, the values are used for discussion purposes. White (1985) studied the interaction between fire and the biomass in Banff National Park, but did not provide adequate information to calculate the biomass of the park. Thus, although these studies are available, their use for the present study was limited.

The alternative that was pursued was to consult various federal and provincial government agencies that compile information for local areas using a national basis. These queries led to research currently underway at the Canada Forest Service - Pacific Forestry Centre (CFS-PFC). In this research, inventory data for the National Parks was included. Cells with data pertaining to some National Parks could be isolated. This inventory accounted for the aboveground biomass of forestland class 1 (timber productive lands), but included less than 50% of the National Parks included in this study. However, the biomass data were provided by land cover and ecozone. Details on the PFC study can be found in Gray and Powers (1997).

The alternative for the National Parks missing in the inventory was to rearrange the data by ecozone using the cells from the National Parks to estimate the aboveground biomass of the parks that was missing in the inventory. To improve this estimation, and also the estimation for the other components of the carbon pools, a questionnaire was sent to the National Parks to acquire more details about the carbon pools for which information was already available.

The Pacific Forestry Centre (PFC) also provided a biomass inventory for Saskatchewan. However, none of this data could be directly used, since parks were not labeled (clearly identifiable) in it. The alternative that was followed was to rearrange the data from this inventory by ecozones within the province of Saskatchewan.

The aboveground biomass inventories provided by the PFC used the CanFI1991:1994 version (Gray and Power, 1997) and the national biomass inventory (Bonnor, 1985) as the primary data source. The former is a national compilation for Canada of provincial resources inventory data. The database is normally compiled at 5-year intervals, the last being from 1991. A total of 48 inventories were included, choosing the most recent ones for various provincial or federal jurisdictions, and in some cases from joint federal-provincial inventories.

The method used to convert volume estimates (from CanFI1991:1994 version) to biomass used by the PFC is described by Penner et al. (1997). The biomass estimation for timber productive forests includes aboveground biomass in merchantable stem, bark, branches, leaves, stump and top. Also included are derived estimates of biomass for timber unproductive forests. The conversion factors (volume:biomass) are relatively insensitive to changes in stand ages, density, site quality and size distribution. This may be a function of the published biomass and volume prediction equations that use only dbh (diameter to the breast height) and height as the independent variables. Consequently the resulting estimates are relatively stable and should provide good regional summaries of aboveground biomass at the time of the inventory. The conversion factors and fractions were used with CanFI1991:1994 version to produce spatially referenced biomass estimates for the inventoried forestland in Canada (Penner et al., 1997). This document also uses data from the national biomass inventory (1985). Bonnor (1985) used various provincial data sources to estimate the aboveground biomass of live trees for Canada.

3.4 Data Sources for the Estimation of Stored Carbon in Forestlands

The Carbon Budget Model of the Canadian Forest Sector (1992) provided a framework to account for the major carbon pools in the carbon dynamics of Canadian forests and for the forest sector activities. Here, a simulation of a single annual time-step for the reference year 1986 was made.

The primary data source for the model was the inventory of biomass in Canada (Bonnor, 1985), CanFI1986 (Forestry Canada, 1988) and from CanFI1986- technical supplement (Gray and Nietman, 1989). More details on the methodology of data collection and synthesis can be found in Gray and Powers (1997). Various categories of land and vegetation were included in the inventory. These were classified according to the following criteria:

A. **Ownership:** All public and private lands were included. The public lands were the crown lands under the federal, provincial, and native jurisdictions. Private lands include industrial, non-industrial, and municipal lands.

B. **Land Classes:** Eight categories of lands were included in the inventory: (1) Timber productive; (2) Timber unproductive; (3) Forestland (of unspecified productivity); (4) Nonforest lands; (5) Land with unspecified forest or nonforest use; (6) Water bodies less than 4,000 km^2; (7) Water bodies more than 4,000 km^2; (8) Missing values.

Forestlands were primarily intended for growing, or currently supporting, forest. It also included temporarily nonforested lands, such as those a result of clearcut. Nonforest lands are lands not used for, or not primarily supporting forests. These include urban parks, orchards, wooded pastures, and rangelands.

Timber productive lands are those forestlands that are capable of producing a merchantable stand within a reasonable length of time, whereas a Timber unproductive land is incapable of doing such.

C. **Causes of Disturbance:** The inventory included several types of disturbances – cutover, burn, and pest, being the major ones. However, for a single period value of biomass, these factors have no effect.

D. **Forest Type:** For the forestlands, three types of forest were included: Softwood, Mixedwood, and Hardwood forestlands.

Although other factors were also included in the inventory, these were of no interest to the present study, and therefore not presented here.

The Carbon Budget Model takes into account disturbances such as fire, harvesting and pests effects (CBM 1). The area of water surface was not included in the inventory data. Also the data to estimate the carbon content for soils and peatlands, which were independently estimated, came from this model. The soil carbon pools include detritus, forest floor, coarse woody debris, and soil organic matter. The carbon sequestration levels estimated by the carbon Budget Model were applied for various National Parks. More details are described in the next chapter.

Chapter 4

ESTIMATION OF CARBON STORAGE LEVELS IN STUDY AREAS

Having selected the study areas, and possible sources of data for the estimation of carbon storage levels (through various types of sequestration activities in the protected areas), the next step is to describe various tasks involved in the estimation of such levels. This is presented in this chapter for various sources where carbon is stored.

4.1 Overview of Study Tasks for Estimation of Carbon Stored

As noted in Chapter 3, total carbon stored was a sum of carbon stored in any one of the following components: Trees and roots (predominant in forest ecosystems); grass and roots (predominant in grassland ecosystem); and soils. The last category was further classified for purposes of carbon storage into two types: regular soils, and peatlands. For each of these, method of estimation is reported in appropriate sections, as shown in Table 4.1.

Table 4.1: Presentation of Tasks Associated with Estimation of Carbon Storage Levels

Land Cover or Source of Sequestration	**Biomass Estimation**	**Carbon Storage Estimation**
Forest Cover (Plant and Roots)	Section 4.2.1	Section 4.2.2
Grasslands	Section 4.3.1	Section 4.3.2
Soils		Section 4.4.2
Peatlands		Section 4.5.2

Method of estimation for the plants (trees, roots, or grass) was based on biomass level. Carbon stored was a linear function of the appropriate level of biomass. The carbon stored in here was estimated by multiplying all the vegetation oven-dry biomass by a factor of 0.5, as suggested by Kurz et al. (1992). Although this factor has been shown by many authors to be different[11] for each species and within the same species for different ages (depending upon specific gravity), the factor suggested by Kurz et al. (1992) appears to be the most commonly used one.

To accomplish the above calculation, species were grouped into two types: broadleaf species and coniferous species. Since data on the proportion of biomass as carbon for each of them were not available, the same factor was used for both. This factor was used to convert aboveground and underground biomass to units of carbon for forest and grassland. Carbon storage level in soils were directly in terms of carbon, and therefore, did not require an indirect estimation of biomass.

The estimation of carbon stored in the study areas was done for each park (National or provincial) individually. As noted above, total area of the park and the land use were obtained from the questionnaire responses that were received from the park, and failing that using an alternative approach described below.

[11] For more details on carbon sequestration in forest, see Cooper (1982).

4.2 Carbon Storage in Forestlands in Protected Areas

4.2.1 Biomass Estimation for Forestlands in National Parks

Estimation of the Aboveground Biomass

For all National Parks, the biomass data used in this study were provided by the CFS -- PFC. These data originally were obtained from the Canada's National Forest Inventory (Gray and Power, 1997). This biomass inventory accounted for forestland class 1 (timber productive).

The land class 2 (timber unproductive) aboveground biomass was estimated for all National Parks using the average for each province, and within the province for each ecozone provided by Penner et al. (1997). The data provided by Penner et al. (1997) was for productivity class I, which has the same definition as the forestland class 2, and was based in the same source of data, the CanFI 1991:1994 version (Gray and Power, 1997). These averages are shown in the Table 4.1. The range in the biomass level is from 3 tonnes per ha in the Montane Cordillera of Alberta to 98 tonnes per ha in the Montane Cordillera of British Columbia. Most other ecozones had a biomass per ha of 18 – 23 tonnes. These averages for forestland class 2 were published before the creation of the Nunavut Territory. For this territory, averages for the Northwest Territory were used.

No specific biomass data were available for forestland class 3 (forest land-timber productivity not specified). Here an assumption was made that these lands are similar to the forestland class 2. Underestimation of the biomass, and the carbon stored may be a possibility here.

When a particular park was in more than one ecoclimatic province, biomass levels were weighted by the respective area of the park in a given ecozone. The distribution of the National park area is shown in Table 3.1.

Estimation of Underground Biomass

The underground biomass (roots) was estimated for all National Parks as suggested by Kurz et al. (1996). These estimation formulas were based on the data from the national inventory of forest biomass (Bonnor, 1985), for softwood species (76 to 100% of coniferous) and for hardwood species (0 to 25% of coniferous).

Table 4.2: Average Biomass Rates for Forestland (Class 2) by Eco-Climatic Province

Ecozone	Ecoclimatic Province	Biomass Level in (t/ha)
Arctic Cordillera	Nunavut	21
Northern Arctic	Nunavut	11
	Northwest Territories	11
Southern Arctic	Northwest Territories	11
Taiga Plains	Alberta	26
	Northwest Territories	26
Taiga / Tundra Cordillera	Northwest Territories	22
	Yukon Territories	22
Boreal Cordillera	Yukon Territories	19

Ecozone	Ecoclimatic Province	Biomass Level in (t/ha)
Boreal Shield	Newfoundland	32
	Quebec	4
	Ontario	6
Boreal Plains	Northwest Territories	18
	Saskatchewan	18
	Manitoba	23
Prairies	Alberta	19
	Saskatchewan	19
Mixedwood Plains	Ontario	19
Atlantic Maritime	Nova Scotia	34
	Prince Edward Island	22
	New Brunswick	27
	Quebec	13
Pacific Maritime	British Columbia	72
	Yukon Territories	18
Montane Cordillera	Alberta	3
	British Columbia	98
Hudson Plains	Manitoba	17

The total root biomass for coniferous (TRB_{cf}) was estimated as follows:

$$TRB_{cf} = RB_{cf} + P_{cf} \quad \text{(4.1)}$$

Where, RB_{cf} is the estimated root biomass for coniferous in Mg ha^{-1}, and
P_{cf} is the estimated root biomass for fine roots in Mg ha^{-1}.

One should note that one megagram (Mg) is equivalent to one tonne (t).

The coniferous root biomass was estimated using Equation (4.2):

$$RB_{cf} = 0.2317\ AB_{cf} \quad \text{(4.2)}$$

Where, RB_{cf} is the coniferous root biomass (Mg ha^{-1}), and
AB_{cf} is the coniferous aboveground biomass (Mg ha^{-1}).

The fine root proportion of total root biomass for coniferous trees was estimated using Equation (4.3):

$$P_{cf} = e^{1.007}\ RB_{cf}^{-0.841} \quad \text{(4.3)}$$

Where P_{cf} is the proportion of fine roots, and
RB_{cf} is the root biomass (Mg ha^{-1}) of either the coniferous species.

Estimation of root biomass for the broadleaf trees was very similar. These equations are shown below:

The total root biomass for broadleaf (TRB_{bv}) was estimated from:

$$TRB_{bv} = RB_{bv} + P_{bv} \quad \text{.......................} \quad (4.4)$$

Where RB_{bv} is the estimated root biomass for broadleaf (Mg ha^{-1}), and
P_{bv} is the estimated proportion of fine roots (for broadleaf).

The root biomass was estimated Equation (4.5):

$$RB_{bv} = e^{0.359}\ AB_{bv}^{\ 0.639} \quad \text{.......................} \quad (4.5)$$

Where, RB_{bv} is the broadleaf root biomass (Mg ha^{-1}), and
AB_{bv} is the broadleaf aboveground biomass (Mg ha^{-1}).
e is the naperian base equal to 2.71828.

The fine root proportion of total root biomass for broadleaf trees was estimated using Equation (4.6):

$$P_{bv} = e^{1.007}\ RB_{bv}^{\ -0.841} \quad \text{.......................} \quad (4.6)$$

Where P_{bv} is the proportion of fine roots, and
RB_{bv} is the root biomass (Mg ha^{-1}) of either the coniferous species.

To estimate the underground biomass of forestland classes 2 and 3, the biomass of these forestland classes were distributed proportionally in broadleaf and coniferous groups of species based on the values for broadleaf and coniferous biomass in forestland class 1. Since studies for other ecozones were not available, it was assumed, on the basis of findings of Kurz et al. (1996), that Temperate and Boreal Forests are representative of all Canada.

Estimation of Biomass for Individual National Parks

Estimation of biomass for individual National Parks was complicated by the availability of information on two aspects of carbon storage: Land cover, and Carbon storage rates. As noted earlier, an attempt was made to remove the first deficiency through the implementation of a survey for all National Parks. This information was used wherever, it was provided by the respondent. Depending upon the level of information available, procedure for the estimation of biomass was different.

Six categories can be identified, as shown in Table 4.3. The hierarchy of preference of available information was as follows:

One: Inventory data with biomass information

Two, Response to the survey providing all information on area and land cover

Three, Response to the survey providing information on total area and ecozone.

Table 4.3: Categories of National Parks for the Estimation of Biomass

Category	Aboveground Inventory Available	Questionnaire Returned with Land Cover Data	Data on Other Parks in Same Ecozone Available	Average Ecozone Information Available	Information Obtained from Other Sources
One	Yes	--	--	--	--
Two	No	Yes	--	--	--
Three	No	No	Yes	--	--
Four	No	Yes	No	Yes	--
Five	No	No	No	Yes	--
Six	No	No	No	No	Yes

Category One parks were based on the PFC inventory, the first preference. Lacking this information, the remaining parks information availability was checked in the returned questionnaire. If the data on land use and ecozone were available, these were labeled as **category two** parks. For the remaining parks, if land use data for other parks in the same ecozone data were available, these were called **category three** parks.

The remaining parks were divided into those responding to the survey and those not. If the parks responded, they were grouped as **category four** parks. If such information were not available, biomass estimation was based on the assumption that land use is similar to other parks in the same ecozone. These parks were called **category five**. When none of the above was possible, in other words, no information was available, estimation was carried using data obtained from Parks Canada and other secondary data points. These parks are labeled **category six** parks.

The basic rule of thumb in this estimation was as follows: If there was no information available for the province and ecozone, in which the park is located, average for the closest province (within the same ecozone) was used. For example, for the parks in the Arctic Cordillera, an average from Quebec was applied. Similarly, parks in the Northern Arctic used averages from the Southern Arctic, but in the same province – Northwest Territories).

Distribution of the 39 parks by these six categories is shown in Table 4.3. In summary, for 17 parks, information was available in the inventory and used. For another 17 parks, other information was obtained and calculations made. More details on the methodology are provided below.

Category One National Parks: National Parks in the aboveground biomass inventory provided by the PFC

For 17 National Parks, information was available in the PFC biomass inventory. The cells where the National Park is located could be identified and the level of biomass estimated. For these parks, this information was used. However, the area in the inventory and the actual area of the park did not match, and therefore, needed adjustment. Assuming that the cells in the inventory are a good representation of the park, and that the land classes are equally distributed in the cell as in the rest of the park, the area was forced to equal the official area of the park. Since most parks in the inventory were very close to the official area (within ± 10%), this assumption is considered reasonable.

Table 4.4: Categorization of National Parks for Estimation of Biomass

No.	Province	Park Name	Catg. 1	Catg. 2	Catg. 3	Catg. 4	Catg. 5	Catg. 6
16	Alberta	Jasper	X					
17	Alberta	Banff	X					
18	Alberta	Elk Island		X				
19	Alberta	Waterton Lakes			X			
6	Alberta/NWT	Wood Buffalo	X					
11	British Columbia	Gwaii Haanas		X				
12	British Columbia	Pacific Rim	X					
13	British Columbia	Yoho	X					
14	British Columbia	Glacier	X					
15	British Columbia	Mount Revelstock	X					
39	British Columbia	Kootney	X					
22	Manitoba	Wapusk			X			
23	Manitoba	Riding Mountain	X					
34	New Brunswick	Kouchibouguac			X			
35	New Brunswick	Fundy		X				
32	Newfoundland	Gros Morne	X					
33	Newfoundland	Terra Nova	X					
4	NWT	Tuktut Nogait						X
5	NWT	Nahanni	X					
7	NWT	Aulavik						X
36	Nova Scotia	Cape Breton Highlands	X					
37	Nova Scotia	Kejinkuijk	X					
8	Nunavut	Sirmilik (North Baffin)						X
9	Nunavut	Auyuittuq						X
10	Nunavut	Ellesmere Island						X
24	Ontario	Pukaskwa			X			
25	Ontario	Bruce Peninsula				X		
26	Ontario	Georgian Bay Islands					X	
27	Ontario	Point Pelee					X	
28	Ontario	St. Lawrence Islands					X	
38	PEI	Prince Edward Island			X			
29	Quebec	Mingan Archipelago			X			
30	Quebec	La Mauricie			X			
31	Quebec	Forillon			X			
20	Saskatchewan	Grasslands	X					
21	Saskatchewan	Prince Albert	X					
1	Yukon	Ivvavik			X			
2	Yukon	Vuntut			X			
3	Yukon	Kluane	X					
Total No. of Parks			17	3	10	1	3	5

Category Two National Parks: Parks with no biomass inventory, but responded to the survey with appropriate data

The remaining 22 National Parks were not included or could not be identified in the PFC inventory. A questionnaire was sent to all National Parks (including those in Category One). For the National Parks that responded to the survey and that could not be identified in the inventory, data were rearranged by ecozone. Within the ecozone, data for forested land (forestland classes 1 to 3) and non-forested lands (forestland classes 4 to 8) were separated. With the information from the questionnaire, the forested area of the park was multiplied by the average biomass of coniferous and broadleaf species in the forested areas in the ecozone. In this calculation, it is assumed that the National Parks have the same proportional distribution of broadleaf and coniferous species as the ecozone in which the park is located. It is further assumed that the cells in the inventory represent the ecozone.

Category Three National Parks: Parks with no biomass inventory and did not respond to the survey

For the National Parks that could not be identified in the PFC biomass inventory, all data for the National Parks (labeled and not labeled) were rearranged by ecozone to estimate the average biomass for each ecozone for all land classes. Thirteen parks were in this category. For each of these, the average biomass in the ecozone was multiplied by their respective area. This estimation is based on the assumption that the cells in the inventory are a good representation of the ecozone and that the distribution of the land classes within the park is the same as in the ecozone. This assumption also extends to the distribution of the forestlands between broadleaf and the coniferous species groups.

For the National Parks in the Arctic, Northern Arctic and Southern Arctic ecozones, estimation was based on the response of a single National Park. The distribution of vegetation cover was assumed to apply to all other parks in these ecozones.

Category Four National Parks: No biomass inventory, responded to the questionnaire survey with land cover data, but no cells in the biomass inventory representing its ecozone

Only one National Park was in this category. The cells from the aboveground biomass inventory provided by PFC for Provincial / Territorial lands for the province in which the park was located, were isolated for the ecozone. From these cells, the average biomass by ecozone within the province was calculated for the forested area (forestland classes 1 to 3). The forested area of the park (as provided in the questionnaire) was multiplied by this average biomass by ecozone within the province for the forested area. The assumption implicit in this calculation is that the aboveground biomass inventory-based level (and the distribution of coniferous and broadleaf forests) provided by PFC for Provincial / Territorial lands for the respective provinces is representative of the National park. Since the inventories are for lands that were not intended to have commercial plantations, this assumption is tenable.

Category Five National Parks: Parks with no biomass inventory, no response to the survey (no land cover data), and no cells in the National Park's biomass inventory representing its ecozone

Three National Parks were classified in this category. Methodology followed was similar to that for category four National Parks, with one exception. The average biomass for a given ecozone within the province was calculated for all forestland classes (from 1 to 8). The total area of the park was multiplied by this average biomass for the ecozone within the province. In this calculation, it is assumed that the ecozone within a province is representative of the land cover and distribution of type of forest (broadleaf and coniferous) within the park.

Category Six National Parks: Parks with no data

There were five national parks in this category. All of these were located in the northern part of Canada (in the provinces of Northwest Territories and Nunavut). One of the major differences between these and the other national parks was the nature of vegetation. Very little forestlands exist at these higher latitudes. A literature search for studies on the arctic ecosystem was conducted. Although some studies were found, only one (by Bliss, 1997) reported some details on vegetation. However, even details (on the nature of vegetation) were very poor, and therefore, this source was not used.

Details on land cover for these parks were obtained from Parks Canada. This included area under vegetation cover, and that under very low vegetation cover. Details are provided in Table 4.5. These parks had a relatively small area with any type of land cover. In the Auyuittuq and Sirmilik National Parks, almost 80% or more of the area had no vegetation.

Information on the carbon sequestration on these lands was obtained from a study of Alaska vegetative cover by Mead (12995). This study provided such data for eight types of land covers. Details are shown in Table 4.6. Since the data on the national parks' land cover only included two categories, a weighted average level of biomass carbon for these two categories of land covers was needed. This was accomplished by using the land area distribution in the Meade (1995) study, as shown in Table 4.6. Land cover classes 15 to 20 were included in the "vegetation cover", whereas the class 21 was included in the estimation of coefficient for the "very low vegetation cover". The resulting coefficients were 0.8780 t/ha and 0.0093 t/ha for the "vegetation" and "very low vegetation cover" areas.

Table 4.5: Land Cover Data for Northern National Parks

National Park	Percent of Land with Vegetation Cover	Percent of Land with Very Low Vegetation Cover	Percent of Area with no Vegetation
Aulavik	54.5	3.7	41.8
Auyuittuq	3.8	10.6	85.6
Sirmilik	11.7	5.1	83.2
Tuktut Nogait	64.8	1.0	34.2
Ellesmere	0	33.0	67.0

Source: McCanny (Personal Communications)

Table 4.6: Level of Carbon in Biomass for Different Types of Land Cover, Alaska

Cass of Land Cover	Nature of Land Cover	Percent of Area	Level of Carbon in the Biomass in t/ha
15	Wetland / Shrubland – Medium Density	4.3	5.00
17	Shrub and Lichen Dominated – Lichen and Others	1.5	1.00
18	Shrub and Lichen Dominated – Shrub / Lichen Dominant	22.4	0.50
19	Treeless – Heather and Herbs	15.5	0.50
20	Treeless – low vegetation cover	9.9	0.50
21	Treeless – very low vegetation cover	3.7	0.25
22	Treeless – bare soil and rock	39.2	0
31	Snow and Ice	3.4	0

Source: Meade (1995)

Since soils in the north are also different in their soil carbon pool, information was obtained from Tarnocai (2000). These data are shown in Table 4.7. Information in the Tarnocai study was provided by three sub-regions within the Arctic Ecoclimatic Province: High Arctic, Mid-Arctic, and Low Arctic. Although the information was available for the surface and the total pool of carbon, the total pool values were used for the estimation of soil carbon pools for each of the five national parks.

Table 4.7: Amount of Soil Organic Carbon in the Arctic Ecoclimatic Region

Ecoclimatic Region	Surface Carbon Content (kg m^{-3})	Total Carbon Content (kg m^{-3})
High Arctic	7.00	19.66
Mid-Arctic	14.43	34.31
Low Arctic	10.46	29.14

4.2.2 Estimation of Biomass for the Saskatchewan Provincial Parks

Although the Pacific Forestry Centre provided a separate biomass inventory for the province of Saskatchewan, various Provincial Parks were not labeled. These data, according to Gray and Power (1997) reflected biomass on areas under the jurisdiction of a provincial or territorial government or Northern Affairs of the Department of Indian and Northern Affairs. Thus, these data were used indirectly in the estimation of carbon pools.

Subsequently, an attempt was made to obtain data for Provincial Parks from the Canadian Conservation Area Database. However, this information was not used on account of lack of confidence in the accuracy of the data set.[12]

[12] Two major problems encountered with this set of data were: One, some cells in the Provincial Parks showed crop and forage production, which is not possible under the definition of a Provincial Park. Two, the total area of the park using the land cover information far exceeded the total (official) area of the park. For these reasons, this data set was not used.

In order to estimate the biomass for various Saskatchewan Provincial Parks, data for aboveground forestland class 1 for the ecozones in which these parks are located were tabulated. This biomass inventory provided by the PFC for Saskatchewan accounts for the aboveground biomass for forestland class 1 (timber productive). The forestland class 2 (timber unproductive) aboveground biomass was estimated for all Provincial Parks in Saskatchewan using the average for each ecozone within the province of Saskatchewan provided by Penner et al. (1997) for productivity class I. This category of land is exactly the same as the forestland class 2, and was based in the same data source as the biomass aboveground inventory, provided by the PFC. The averages by Penner et al. (1997) for each Provincial Park studied are shown in Table 4.5, along with the ecozones where the parks are located.

The Land Class 3 (forestland-timber productivity not specified) aboveground biomass was estimated for all Provincial Parks with the same data from forestland class 2. Since this forestland class was not classified in productivity, the biomass in these areas may have been underestimated, particularly if these had some timber productive lands.

To estimate forestland classes 2 and 3 aboveground biomass, location of the parks (as shown in Figure 3.2) and the ecozone data for average biomass level were used. The latter were obtained from Penner et al. (1997).

All Provincial Parks in Saskatchewan are located in three ecozones: two parks in Boreal Shield ecozone; 12 parks in the Boreal Plain ecozone, and 15 parks in the Prairie ecozone. One Provincial Park – the Clearwater River, was located in two ecozones – Boreal Shield and Boreal Plain ecozones. For this park, information for both ecozones was used and a weighted average biomass level estimated.

In order to obtain more information on the land cover and other characteristics of Provincial Parks, a survey of all Provincial Parks, similar to that used for the National Parks, was undertaken. Some responses were received. Based on the nature of information available, two categories of Provincial Parks were identified: Category one: Parks that responded to the survey; and Category two: Parks that did not respond to the survey. A list of these parks is shown in Table 4.5. For each of these categories of parks a somewhat different approach to estimation was adopted, which is described below.

Category one Provincial Parks: Parks that responded to the questionnaire survey

Nine Provincial Parks responded to the survey. For these parks, data for three ecozones were tabulated from the PFC Provincial / Territorial inventory. Within the ecozone, the data for forestlands (forestland classes 1 to 3) and non-forestlands (classes 4 to 8) were separated. Using the information from the questionnaire, the forested area of the park was multiplied by the average biomass level of coniferous and broadleaf species in the forested area in the ecozone within the province of Saskatchewan. Same equations as used for the National Parks to estimate underground biomass were used here.

The assumption made in this analysis is that the ecozone averages are good representation of the Provincial Parks, and that the cells in the biomass inventory are reflective of the biomass level in these parks. Similar assumptions were made for the distribution of the broadleaf and coniferous species groups.

Category Two Provincial Parks: Parks that did not respond to the survey

For the Provincial Parks of Saskatchewan for which no response was received, average biomass for the ecozone of all forestland classes within the province of Saskatchewan was multiplied by the park's total area. In this methodology, it is assumed that the forestland classes in the inventory are equally distributed in the ecozone within the province, as they are in the park.

Table 4.8: Estimated Biomass Level by Ecozone and Categorization for the Saskatchewan Provincial Parks

Ecozone	Saskatchewan Provincial Parks	Forestland class 2 average biomass (t/ha)*	Prov. Park Category One	Prov. Park Category Two
Boreal Shield	Athabasca Sand Dunes**	24		X
Boreal Shield	Lac La Ronge	24	X	
Boreal Shield	Clearwater River (~50%)	24		X
Boreal Plain	Clearwater River (~50%)	18		
Boreal Plain	Anglin Lake	18	X	
Boreal Plain	Bronson Forest	18		X
Boreal Plain	Candle Lake	18		X
Boreal Plain	Chitek Lake	18		X
Boreal Plain	Clearence-Steepbank Lakes	18	X	
Boreal Plain	Duck Mountain	18	X	
Boreal Plain	Emma Lake	18	X	
Boreal Plain	Greenwater Lake	18		X
Boreal Plain	Makwa Lake	18		X
Boreal Plain	Meadow Lake	18		X
Boreal Plain	Narrow Hills	18	X	
Boreal Plain	Wildcat	18		X
Prairie	The Battlefords	19		X
Prairie	Blackstrap	19	X	
Prairie	Buffalo Pound	19		X
Prairie	Crooked Lake	19		X
Prairie	Cypress Hills	19	X	
Prairie	Danielson	19		X
Prairie	Douglas	19		X
Prairie	Echo Valley	19		X

Ecozone	Saskatchewan Provincial Parks	Forestland class 2 average biomass (t/ha)*	Prov. Park Category One	Prov. Park Category Two
Prairie	Good Spirit Lake	19		X
Prairie	Katepwa Point	19		X
Prairie	Moose Mountain	19		X
Prairie	Pike Lake	19	X	
Prairie	Rowan's Ravine	19		X
Prairie	Regina Beach	19		X
Prairie	Saskatchewan Landing	19		X

* Source: Penner (1997)

** The only information provided for this park was the total area.

4.2.3 Estimation of Stored Carbon

The carbon sequestered in the forest cover was multiplied by a factor of 0.5. The biomass included here was that for the aboveground and underground (roots) on forestland classes 1, 2 and 3. The 50% factor is used for all vegetation, and is based on an oven-dry biomass, as suggested by Kurz et al. (1992).

4.3 Estimation of Carbon Storage in Grasslands

4.3.1 Source of Data

In Canada, the prairie ecosystem is predominantly grassland. Here three types of grassland ecosystems are encountered: Mixed prairie, Fescue prairie, and the Palouse prairie. The mixed prairie ecosystem occupies southern Saskatchewan, southern Alberta and the south-western portion of Manitoba; the fescue prairie forms an arc around the northern perimeter of the mixed prairie, in the region of transition from open grassland to forest; and the palouse prairie occupies a small part of southern British Columbia (Coupland, 1992). Since most of the parks in this study that had grassland ecosystems were located in Saskatchewan, only the first two of these are of interest here.

Estimates of biomass or of carbon in grassland ecosystems are not readily available. The best local data is that for the Matador Field Station in the International Biological Program (IBP). This study has been conducted since 1970, and was conducted in the ungrazed mixed prairie grasslands (Coupland, 1992). According to this study, the average aboveground biomass was estimated at 1,930 kg / ha. This value was recorded at the time of maximum standing crop. In other words, it represents a portion of biomass production during a portion of the growing season (does not include the production after that date). Thus, this value could be an underestimate of the more recent biomass level in these ecosystems (Coupland, 1992). Furthermore, the aboveground biomass data did not take in account the biomass losses to herbivore, but for 1973, the herbivore in Matador represented a loss of 5% of the total biomass (Coupland, 1992). The average biomass for underground (soils and root zone) was significantly higher and estimated at 21,550 kg / ha. This also pertained to the ungrazed mixed prairie, in Matador, in 1970. It considered roots from zero to 150 centimeters deep in the soil.

The above set of estimates were used in this study for the mixed prairie ecosystem. For the fescue prairie ecosystem, no study was found. As a result, the mixed prairie estimates were used here. Since the mixed prairie grassland type, according to Coupland (1992), has higher forage yields and more mid-grasses than the mixed prairie grassland type, it probably overestimates the biomass for the fescue prairie grasslands.

4.3.2 Estimation of biomass

Identification of Grassland Ecosystems

The type of grassland ecosystem for each of the National and / or Provincial Parks was assigned by overlapping each of the potential parks on the appropriate maps (Figures 3.1 and 3.2). In addition, map of the Canadian provinces by Stanford (1998) and that provided by Coupland (1992) were also used.

Based on the above analysis, two National Parks were found in this type of ecosystem. The Grassland Park in southern Saskatchewan is located in the mixed prairie grassland ecosystem, whereas the Elk Island in central Alberta is located, according to Rowe (1972), in the boreal mixedwood forest ecosystem. Since information on this ecozone is not available, it was treated as a mixed prairie grassland ecosystem.

A similar analysis of location of the 15 Provincial Parks situated within the prairie ecosystem was conducted. With the exception of the Battlefords Provincial Park, parks shown in Table 4.4 within the prairie ecozone were found to be located within the mixed prairie grassland ecosystem. The Battlefords Park is located in the fescue prairie grassland ecosystem.

Although National and Provincial Parks are located in the same grassland ecosystem, the methodology for biomass estimation was different. This is described below.

Estimation of Grassland Biomass for the National Parks

Both the National Parks included in the grassland system responded to the survey administered by the study team. Thus, the grassland area was provided by the respondents. The average aboveground (discounted for the loss on account of the herbivores) and underground biomass was multiplied by the total area of the park that is covered under grassland.

Estimation of Grassland Biomass for Category one Provincial Parks

As reported in Table 4.5, three Provincial Parks in the prairie ecozone had responded to the survey. The methodology for these parks was identical to that reported above for the National Parks.

Estimation of Grassland Biomass for Category two Provincial Parks

For the parks that did not respond to the survey questionnaire, estimation of the grassland area was based on an average of those Provincial Parks that reponded to the survey. From the survey, an average proportion of the total area as grassland was estimated. Values for the aboveground biomass (discounted for the losses by the herbivores) and underground biomass used in this estimation were the same as those for the mixed prairie grassland. The total biomass was estimated by multiplying the average biomass level by the area of the park and the proportion of the park area as grassland.

4.3.3 Estimation of Stored Carbon

A search of the literature resulted in no study that suggested the carbon content of the grassland biomass. In the absence of this information, a proportion of 0.5, as used for the forest biomass, was used.

4.4 Estimation of Soil Biomass

4.4.1 Source of Data

To estimate the carbon content in soils for National and Provincial Parks, the average carbon density of soil carbon pools for each ecoclimatic province, as provided by Kurz et al. (1992), was used. However, the values attached in the carbon budget model are only for the 70% of the inventoried forestlands. There were no data available for the non-forestland within the National or Provincial Parks. Therefore, in this study, the estimated soil carbon may be underestimated.

4.4..2 Estimation of Stored Carbon

The average soil carbon density for the ecoclimatic provinces for the Provincial and National Parks, that represent each ecoclimatic province, are shown in Table 4.8. This table was developed by overlapping various maps – one for National and Provincial Parks (provided by the Saskatchewan Environment and Resource Management, 2000), another for ecoclimatic provinces (Kurz et al., 1992), and the third one for the National Parks (Stanford, 1998). Carbon densities were the highest in the sub-arctic ecozones – taiga / tundra cordillera. Here a hectare of soil contained 338 tonnes of carbon. The lowest densities were estimated for prairie ecozone.

4.4.3 Estimation of Soil Carbon Densities for National Parks

For the purposes of estimation of soil carbon, National Parks were divided into three categories. For each of them, a separate methodology was adopted, as described below.

Table 4.9: Carbon Density in Selected Ecoclimatic Provinces for Soils and Peatlands

Ecoclimatic Province	Ecozone	Soil carbon density* (t / ha)	Peatlands carbon density* (t / ha)
Arctic	Arctic Cordillera (Forestlands)	171	269.7
Subarctic	Taiga / Tundra Cordillera	338	168.1
Boreal Plains	Boreal West	118	471.9
	Boreal East	118	260.7
Cool Temperate	Mixed Plains	92	50.4
	Atlantic Maritime	92	50.4
Moderate Temperate	Mixed Plains	84	14.1
Prairies	Grasslands	49	0
Pacific Cordillera	Pacific Maritime	127	80.3
Montane	Montane Cordillera	138	25.6
Subarctic (Ivvavik National Park)		338	6.5

* Based on vegetated area

<u>National Parks identified in the biomass inventory</u>

For the National Parks included in the aboveground biomass inventory, the forestland cover of each park (forestland classes 1 to 3) was multiplied by the average carbon density for the respective ecoclimatic province. Thus an assumption was made that the carbon density is equally distributed along each ecoclimatic province, and is a good representation of the parks.

National Parks not identified in the biomass inventory, but responded to the questionnaire

For the National Parks not identifiable in the aboveground biomass inventory, but had responded to the survey questionnaire, the forestland cover provided in the questionnaire was used. This was multiplied by the average carbon density for the respective ecoclimatic province.

National Parks not in the biomass inventory, and no response to the questionnaire

For these National Parks, no information was available that would have helped in estimation of their specific carbon density. Here data for National Parks (labeled and not labeled) under the above two categories was rearranged to calculate the average forested land for the ecoclimatic province. The average forested land for the ecoclimatic province was applied to these parks. The forested portion of each park was multiplied by the average carbon density for the respective ecoclimatic province.

4.4.4 Estimation of Soil Carbon Densities for Provincial Parks

Various Provincial Parks were divided into the same two categories as for the estimation of forestland biomass estimation. Estimation of soil carbon density for each of these categories is described below.

Provincial Parks of Saskatchewan Responding to the Survey

For the Saskatchewan Provincial Parks that responded to the survey questionnaire, the forested portion cover used in this estimation was that provided by the respondents. This area was multiplied by the average carbon density for the respective ecoclimatic province. This is based on the assumption that the carbon density is equally distributed along each ecoclimatic province, and is a good representation of the park.

Provincial Parks of Saskatchewan Not Responding to the Survey

Estimation for these parks was based on the information provided by parks in the Category one. The proportion of forest cover for these parks was an average of that proportion for parks in a given ecozone. The average forest cover was multiplied by each park's area. Average carbon density as shown in Table 4.5 were used. It therefore, suggests that the carbon density is equally distributed along the ecoclimatic province as well as within the Provincial Park.

4.5 Estimation of Carbon Stored in Peatlands

4.5.1 Source of Data

Forests in Canada may grow in areas classified as peatlands (peat depth greater than 50 cm). However, not all peatlands are forested. Since these lands are an important storage for carbon, their estimation was very important for this study.

The biomass inventory provided by the PRC did not include peatlands. As a close substitute, data from Kurz et al. (1992) was used. Even here only forestland (Class 1 to 3) were included. Thus, since non-forestlands are excluded here, some underestimation may have resulted.

4.5.2 Estimation of Stored Carbon

Using information in Kurz et al. (1992), carbon density of peatlands was estimated for each ecoclimatic province. The level of stored carbon in the peatlands in a given ecozone (ecoclimatic province) was divided by the inventoried area of forestland. These densities are shown in Table 4.5. The assumption made here is that all parks have the same density of peatlands as within the ecoclimatic province. This average carbon content was multiplied by the rate of peatland area in the inventoried area (for each ecoclimatic province).

Estimated level of carbon stored is highest in the peatland found in the western part of the Boreal ecozone, and smallest in the montane cordillera ecozone. The grasslands were reported to have no peatlands at all.

4.5.3 Estimation of Carbon Stored in Peatlands for National Parks

All National Parks were categorized in the same three types as for soil carbon density estimation. The approach used for the estimation of peatland carbon level is described below.

<u>National Parks included in the biomass inventory</u>

For these National Parks, the area with forestland cover of each park (forestland classes 1 to 3) was multiplied by the average carbon content of peatland for the respective ecoclimatic province. This is based on the assumption that in these parks, the carbon content in peatlands is distributed in the same manner as in the ecoclimatic province.

<u>National Parks not included in the biomass inventory, but responded to the survey</u>

For these National Parks, the forested portion of land cover was based on the estimate provided by the respondents. This was multiplied by the average carbon content in peatlands for the respective ecoclimatic province. The same assumption, as made for the above category of parks, was here as well.

<u>National Parks with no information</u>

For these National Parks, information for a given ecoclimatic province was used. This information was based on the data collected for the above two categories of National Parks. This average forested land for the ecoclimatic province was applied to each of these parks. The forested portion of each park was multiplied by the average carbon content in peatlands for the respective ecoclimatic province. Assumed here is that the carbon density in these parks is distributed in the same manner as in each ecoclimatic province

4.5.4 Estimation for Provincial Parks

The Provincial Parks faced two Categories in this Report that required a different approach to estimate the peatland carbon content.

Provincial Parks of Saskatchewan that answered the questionnaire.

For these Provincial Parks, the forested portion cover provided by the respondent was multiplied by the average carbon content in peatlands for the respective ecoclimatic province.

Provincial Parks of Saskatchewan that did not respond the questionnaire.

The average forest cover for the parks that responded the questionnaire was applied to the Provincial Parks of Saskatchewan that did not respond to the survey questionnaire. Rest of the methodology was identical to that for Category One Provincial Parks.

Methodology described in this chapter was used for the estimation of the amount of carbon sequestered and stored by the various types of vegetation in the selected protected areas. Results are presented in Chapter 6.

Chapter 5

ECONOMIC VALUATION OF CARBON SEQUESTRATION FUNCTION

A conceptual framework for valuation of natural functions of an ecosystem was presented in Chapter 2. Using this framework, a review of available studies was undertaken with the expectation of using the “benefit transfer” approach to valuation. In this approach, valuation of natural ecosystem function is based on values determined for that function for a comparable situation. In this chapter, results of this review are presented.

5.1 Approaches to Valuation

In deciding the appropriate studies for this review, taxonomy of approaches to valuation of carbon sequestration, as presented in Figure 3.2, was followed. Here the valuation function was cast in terms of climate change. Carbon sequestration has a value ever since the IPCC studies have documented the damage that increasing levels of emissions of greenhouse gases are expected to do. This was the cornerstone of deciding the scope of studies to be included in this review. At the very outset, bifurcation based on the knowledge of climate change impacts became a critical parameter. In determining a value for carbon (in the context of climate change), two views are taken: (1) that the society is fully aware of the damages from climate change, and is capable of placing a meaningful value on the carbon sequestration function; and (2) that the society is aware of such damages, and has accepted the premise that carbon sequestration has value to society. However, the exact impact of the damage is not known, and cannot be estimated at this time. From these alternative views come two different sets of approaches to valuation and to determine an economic value for carbon.

If damages from climate change were known, society would have some options open and would be prepared to undertake them. Using this evidence, one could formulate various approaches to valuation. These methods are described in Section 5.1.

The alternative framework would be based on the recognition of climate change, as has been the case with the signing of the Framework Convention for Climate Change (FCCC) by 160 countries, including Canada. It was signed in Rio de Janeiro in 1992 at the time of the Earth Summit. It came into effect in March 1994. The major objective of the FCCC was “… stabilize greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system” (United Nations, 1992). The signatories recognized that various actions to address climate change can be justified in their own right and can also help other environmental problems. The principle behind the acceptance of such action was based on the perceived benefits of present and future generations of humankind, as well as on equity and respective capabilities. Accordingly, the developed countries were expected to take a lead in combating climate changes and the adverse effects thereof[13]. In December of 1999, Conference of the Parties adopted the Kyoto Protocol. It was signed by some 64 countries, including Canada.[14] Canada agreed to reduce its 2008 - 2012 period greenhouse gas

[13] Whether this in the best interest of the developed countries has been questioned by Grafton and Barham (1997), who have suggested that even under the most pessimistic assumptions concerning the costs of global warming, and modest assumptions regarding the costs of mitigation, the North is better off pursuing a business-as-usual strategy rather than fulfilling its commitments to stabilize greenhouse gas emissions at 1990 levels.

[14] For a list of countries, see Bryce, Buckingham and Boehm (1999).

emissions by 6% below the 1990 level of emissions. Policies that could be included to meet the objectives could pertain to:

- Improvements in energy efficiency;
- Protection and enhancement of greenhouse gas sinks;
- Promotion of sustainable forest management practices;
- Promotion of sustainable forms of agriculture with respect to climate change;
- Promotion of new and renewable forms of energy, carbon sequestration, and environmentally sound technology;
- Reduction in market incentives in greenhouse gas emitting sectors that are contrary to the Convention;
- Encouragement of reforms aimed at promoting policies to reduce greenhouse gas emissions; and,
- Reduction of methane through recovery and waste management.

Although the Protocol does not require the adoption of any particular policy, all the above listed measures are indicative of the scope of effort that a country could pursue. Most of these measures would be at some costs to the society – adopters, other parties through externalities, and various levels of governments.

Two sets of activities can be identified in the context of valuation of carbon sequestration: One, measures may aim at reducing the source of greenhouse gas emissions. Here activities would be such that the level of emissions are reduced. Two, sink enhancement measures. Here the activities aim at reducing the greenhouse gas emissions through increasing the level of sinks in the system. However, the cost of such measures depends on the type of target – land transfers and afforestation being more important for the long-term, and management adjustments for the near-term (Adams et al., 1999). Alig et al. (1997) have also shown that shifting of lands to forest and more intensive forest management should be primary focus to meet targets of greenhouse gas emissions. Forests however, provide a multitude of goods and services, and these need to be kept in focus. A review of various approaches to valuation of forests is provided by Gregersen et al. (1995). Various methods of valuation related to these themes are described in Section 5.2 and 5.3, respectively.

A number of studies (for example, Hoen and Solberg, 1997; Pearce, 1991; van Kooten, Binkley and Delcourt, 1995) have used the approach of imposing a tax on carbon dioxide emissions to the atmosphere. In these studies, imposition of the tax results in more afforestation or better management, resulting in more stored carbon. The cost to the society is then estimate to yield a value of the carbon. These studies, although relevant, are not included in the estimation of value of stored carbon.

5.2 Valuation Methods with Knowledge of Climate Change Related Damages

With the knowledge of climate change damages, value of carbon can be inferred either from the actions of people, or through response to a contingent question related to their willingness to pay. The first method assumes that climate change has already taken place. This method is called method of damage cost avoided. The second type of method is based on the assumption that climate change has not taken place, and the society can decide what measures to take. Their willingness to pay can then be used as a value of carbon. Each of these is described below.

5.2.1 Approach 1 – Method of Avoided Damages or Defensive Expenditures

When a change in environmental quality occurs, households are able to react. Frequently such reactions are called adaptation to the change. The damages avoided method estimates values of ecosystem services based on the costs of avoiding damages due to lost services. It assumes that the cost of avoiding damages provides useful estimates of the value of ecosystems or services. This is based on the assumption that, if people incur costs to avoid damages caused by lost ecosystem services, then those services must be at least what people paid to replace them. The damages avoided method uses either the value of the costs of actions taken to avoid damages, as a measure of the benefits provided by an ecosystem[15].

Using a global perspective, Azar and Sterner (1996) have suggested a value of carbon in the range of $348 to $790 per ton (in U.S. funds). This will yield a 2000 period value in Canadian funds of $632 to $1,435 per tonne. This valuation is higher compared to the Nordhaus (1991) value of $US 5.30 per tonne of carbon. In this study, much of the reduction comes from reduced chlorofluorocarbons (CFC).

Some adaptation may involve expenditures in new methods / technology to mitigate the effects, and protect the household from welfare reductions (Hanley and Spash, 1993). The value of an ecosystem function can be indirectly inferred from reductions in expenditures in defensive activates.

It is difficult to apply this method to the valuation of carbon sequestration. This is because climate change has not taken place, and therefore, there is no information on the defensive expenditures available for Canada or for other parts of the world. A review of studies also indicated that even at a conceptual level there has not been a study using this method.

5.2.2 Approach 2 - Society's Willingness to Pay using Contingent Valuation Method

The contingent valuation method is used to value a wide range of goods and services that are not traded in the market place (i.e., non-market goods). In this method, a sample of households (customers) is solicited directly for their willingness to pay for receiving a given environmental amenity (welfare improving), or for not receiving a certain environmental disbenefit (welfare decreasing). Thus, it involves asking people how much they would be willing to pay for specific environmental services. Since people do not reveal their willingness to pay for them through their purchases or by their behavior, the only option for estimating a value is by asking them questions[16].

Although this method has its foundation in utility functions, and measure of compensating and equivalent variation, they are heavily dependent on how well the study is designed, carried out and interpreted. If these tasks are performed properly, the method is a useful technique for placing values on goods and services (Hanley and Spash, 1993).

Carbon sequestration in the context of climate change poses a challenge while estimating its value using this method. This is because climate change is still somewhat uncertain (in the minds of some people) and its exact implications for them are not wellknown. One could formulate a very comprehensive, yet hypothetical, scenario of the nature of such impacts, and ask people their willingness to pay. However, this type of attempt has not been made. No study was found to reflect this type of application. This is not to say that this methodology has not been applied for protected areas. For example, Kulshreshtha and Loewen (1997) using Saskatchewan sample estimated the existence value for forestlands. However, these values

[15] http://www.ecosystemvaluation.org/cost_avoided.html
[16] http://www.ecosystemvaluation.org/cost_avoided.html

are not directly transferable since forest provide a multitude of benefits besides carbon sequestration.

5.3 Unquantified Climate Change Damages Options: Mitigation Option

Since the previous types of studies were either not available or not directly relevant for establishing the value of carbon, search was now extended to the second situation – climate change accepted although some uncertainty remains. This situation is reflective of the current state of affairs under the FCCC and the subsequent Kyoto Protocol. Here the society has two courses of action open: One, reduce the emissions of greenhouse gases – Mitigation Option; or Two, Increase the sequestration level of carbon – Sinks Option. Valuation method following the first option are discussed here, while those following the second option are described in Section 5.3.

Under the mitigation option, there are various methods available to value carbon sequestration. Here mitigation is taken as analogous to sequestration – i.e., they are totally substitutable. Mitigation, however, attacks the source of emissions and attempts to reduce emissions of greenhouse gases (where carbon dioxide the major one). A number of alternatives exist:

1. Emitters of greenhouse gases (particularly carbon dioxide) may change / reduce level of carbon dioxide released into the atmosphere;
2. Firms may employ a more operate at a socially optimal level in terms of capacity of the atmosphere; or,
3. Firms may participate is some market based trading schemes, if such were to exist.

The first alternative is called the “Alternative Cost Method” of valuation, while the other two are called “Marginal Social Opportunity Cost Methods” and “Market-Based Methods”, respectively. Each of these are described below.

5.3.1 Approach 3 - Alternative Cost of Mitigation

Recapture

Recapturing involves the improvement of systems in an attempt to decrease the amount of carbon dioxide (CO_2) that is being released into the atmosphere. These improvements help to capture CO_2 before it reaches the atmosphere, thus decreasing the amount of CO_2 emissions. The value of carbon is equivalent to the additional cost to the firm of employing these alternatives.

A number of studies using this approach have been reported in the context of power generation for the USA. For example, processes exist for CO_2 capture using amine scrubbing. Based on published data from ABB Lummus[17], the cost of CO_2 captured by using an amine scrubber to an existing power plant is \$35-\$71/ton CO_2 captured. Since CO_2 capture requires a significant expenditure of energy, with the production of additional CO_2 if fossil fuels are used for power generation, not all of the CO_2 captured is CO_2 avoided. In other words, the latter is the original amount of CO_2 that would have been emitted into the atmosphere without CO_2 capture.

Based on a study of a pulverized coal power plant, a 35% reduction in electrical power output can be expected when the plant is equipped for CO_2 capture and disposal. Therefore, the total

[17] cited in Bergman et al. (1997)

CO_2 captured is greater than the avoided CO_2 by a factor of approximately 1.5. A cost of \$35/ton of CO_2 captured translate into \$53/ton of CO_2 avoided (Bergman et al., 1997).

The cost of capturing CO_2 from a gas plant is higher than from a coal boiler because of the lower concentration of CO_2 in the flue gas from gas turbines. Assuming \$15/ton for liquefaction and disposal, the cost of CO_2 capture and disposal from a coal plant would be approximately \$50/ton and from a gas turbine plant approximately \$65/ton CO_2. In terms of the avoided CO_2, costs are estimated to be \$75 and \$100/ton CO_2, respectively (Bergman et al., 1997)

Alternative Technology

One approach to decrease carbon emissions is to reduce the carbon release from personal-use vehicles. This may be achieved (hypothetically) by getting rid of the less fuel-efficient vehicles, i.e., all automobiles of model 1982 or earlier. By replacing them with newer one's, it is possible to reduce carbon emissions by 4.54 Mt/year. If each pre-1983 vehicle has a value of \$1200, then the cost of scrapping all these vehicles is \$4.505 billion (van Kooten et al., 1992). Thus, the value of carbon using this method is \$Cdn 992 per tonne.

A second alternative for reduction sequestration involves conversion of all passenger automobiles in Canada to natural gas. Assuming conversion costs are \$1500/vehicle, the total cost would be \$12.2 billion. If the average vehicle life is assumed to be 10 years, the strategy of converting vehicles to natural gas would cost approximately \$322/tonne of carbon reduced (van Kooten et al., 1992).

Renewable Fuel Use

A number of alternative fuels have been developed to substitute the use of fossil fuels, which are responsible for a large portion of the Carbon dioxide emissions. According to Neizert, Olsen and Collas (1999), some 76% of the all greenhouse gas emissions (measured in terms of CO_2 – equivalent[18] levels) are in the form of carbon dioxide. Within the various sources of carbon dioxide emissions, fuel use contributes a little over a third of the total directly.

Various types of substitute fuels have now been developed that have the potential of reducing greenhouse gas emissions. Among these biodiesel and ethanol are the most commonly cited ones. Unfortunately not many studies have developed cost of such projects and estimated the total cost and greenhouse gas emissions mitigation using a systems context[19]. However, studies have suggested a great deal of potential to reduce emissions of CO_2. For example, for Ontario, Levelton Engineering Ltd. (1999) has reported a reduction of 1.53 tonne of CO_2 for every 1,000 litres of ethanol used as a blend with gasoline.

Retrofitting

Retrofitting is a term applied to activities that involve modification made to reflect a late day technology. In the context of carbon sequestration, retrofitting involves activities that improve the energy efficiency of buildings and equipments, so as to reduce the power generation needs in an economy. A number of studies have been undertaken for the Building Climate Change Issues Table. To improve the energy efficiency of currently regulated equipment, it is estimated that the cost would be \$4 per tonne of carbon dioxide sequestered, which translates into \$14.67

[18] This equivalence is based on a 100-year warming potential of each gas. For methane, the factor is 21, and for nitrous oxide it is 310.

[19] A system's context here refers to estimation of greenhouse gas emissions to include all direct, indirect and induced emissions. For details of such a technique for the agriculture sector, see Kulshreshtha, Junkins, and Desjardins (Forthcoming).

per tonne of carbon sequestered. Furthermore, replacement of new equipment through encouragement of new equipment would bring forth additional carbon sequestration at a cost of $12 per tonne of carbon dioxide, or $44 per tonne of carbon.

To improve energy efficiency of building, it is estimated that encouraging purchase of energy efficient homes would bring forth carbon sequestration at a cost of $40 per tonne of carbon dioxide ($161.32 per tonne of carbon).

Summary of Estimates

Value of carbon using this approach is shown in Table 5.1. Estimates range widely, depending upon the option chosen to sequester carbon. Some of the cheaper options are through retrofitting of both equipment and buildings. Here the costs may range between $15 to $161 per tonne of carbon sequestered. However, the amount of carbon that can be sequestered is rather small, in the neighborhood of 3 – 5 Mt. Somewhat more expensive options include changes in the energy production sector. Estimates range here from a low of $226 per tonne of carbon to $645 per tonne of carbon. These higher costs are reflective of the challenge faced by the power generation sector for reducing emissions of greenhouse gases. However, no precise estimates of cost are available for the Canadian situation.

5.3.2 Approach 4 – Marginal Social Opportunity Cost

This approach to valuation is in terms of foregone ecological services that are currently derived from the natural ecosystem. These services would be lost if a natural resource, such as the forest, were not there. Among various services provided by the forest is the carbon uptake service. Value of this service from the forest can be made equivalent to the value of industrial output, which is interpreted as the value added in industry generating the same amount of CO_2 that the forests are capable of processing. The value added here is defined as the monetary value of the economy's output minus the value of inputs. Thus, a portion of the cost to society of harvesting forests could be represented by foregone industrial output through lost carbon sequestration. The shadow price of forests is a function of carbon emissions to carbon sequestered (Dore and Johnston, 2001).

Table 5.1: Summary of Value of Carbon Based on Alternative Cost Method

Type of Activity	Author	Year of Estimate	Unit	Estimated Value	Cost per tonne C in $Cdn	Value in Cdn.$ per tonne (2000)*
Recapture						
Power plant	Bergman et al.	1997	$US /Ton CO_2	35 - 71	215.58-437.33	225.82-458.10
Coal Power Plant	Bergman et al.	1997	$US /Ton CO_2	53	326.46	341.97
Coal power plan (capture and disposal)	Bergman et al.	1997	$US Ton CO_2	75	461.97	483.91
Gas turbine plant (capture and disposal)	Bergman et al.	1997	$US /Ton CO_2	100	615.96	645.22

Type of Activity	Author	Year of Estimate	Unit	Estimated Value	Cost per tonne C in $Cdn	Value in Cdn.$ per tonne (2000)*
Alternative Technology						
Conversion to natural gas	Van Kooten et al.	1992	$Cdn /Tonne C	322	322	362.93
Retrofitting						
Equipment	Building Issue Table	2000	$Cdn /Tonne C			14.67 – 44.00
Residences	Buildings Issue Table	2000	$Cdn /Tonne C			161.32

* Based on the following conversion factors: 1 tonne = 1.12 tons; $US 1 = $Cdn 1.50; and 1 tonne of carbon = 3.6664 tonnes of carbon dioxide. To convert study period estimate to year 2000 estimates, inflationary factors were used, which are shown in Appendix C.

The value of the carbon uptake service provided by Canadian forests in the year 1986 was determined to be $27 billion. This translated into a value of $937 per tonne of carbon uptake service (Dore, Johnston, Stevens, 1997, p. 205). The marginal social opportunity cost value of a hectare of forest is between $350-$412 in 1986 constant dollars (Dore and Johnston, 2001). Adjusting these values to reflect 2000 period costs would yield an estimate of $981.50 per tonne of carbon sequestered or between $371 and $527 per hectare of forestland.

5.3.3 Approach 5 – Market Method

At the outset one disclaimer should be made. There is no market yet in place where buyers and sellers could physically interact and agree on a certain value of carbon. Most attempts are either theoretical, or experimental. Nonetheless they do come close to this method of valuation and therefore, described here.

The value of some ecosystem goods or services can be measured using market prices. As noted in Chapter 3, this value is equivalent to the level of consumer and producer surplus as with any other market good[20].

Market Price Method

The Costa Rican and Norwegian governments have recently reached an agreement under the joint implementation initiative. Costa Rica has issues carbon bonds (Greenhouse Gas Emissions Mitigation Certificates) under this agreement (Segura and Lindegaard, 2001). Costa Rica would sell 200,000 tonnes worth of carbon bonds to Norway for a price of $US 2,000,000. This translates to a value of $US 10/tonne (or $Cdn 15/tonne). In terms of 2000 cost, this would yield a value of $15.43 per tonne of carbon.

Since this type of "trade" is new, many questions exist over how to quantify the amount of carbon sequestered in trees. This was worked out by calculating the economic benefit a farmer can get from soil, if it is being used for something other than to keep a forest alive or to plant

[20] http://www.ecosystemvaluation.org/1-03.htm

trees. The result was an average of $US 50/ha over one year. Experts then estimated that every hectare of woodland can capture 5 tonnes of carbon/year, and arrived at a value of $US 10/tonne. The 200,000 tons of carbon sold to Norway will be sequestered for 25 years through reforestation and forest conservation projects, covering a total of 142 km^2 area.

Suncor, the Canadian energy company, has also already purchased 100,000 metric tonnes of CO_2 from U.S.-based Niagara Mohawk Power Corp. This deal was one of the world's first international emission trades[21]. No further details, particularly the financial ones, on this deal are available.

Another variant of market price method has been suggested for forestry by Solberg (1998). In this method, value of carbon is estimated by placing a shadow price on carbon fixation and emissions. The marginal value of fixing one unit of atmospheric CO_2 in forest biomass equals the marginal cost of reducing the emission of CO_2 in the most costly project which is implemented for that purpose (Solberg, 1997). In countries where a carbon tax is introduced (such as all Scandinavian countries and several EU countries), this marginal cost is equal to the carbon tax if markets are functioning reasonably well (Solberg, 1998). In Norway, in 1991 a CO_2 price (tax) was introduced (Solberg and Hoen, 1996). In 1997, the level of this tax was NOK0.82 (Norwegian krones), which is equal to about $US 0.12, per litre of gasoline, which corresponded to NOK 343 /tonne CO_2. This study also estimated that to stabilize the CO_2 emission at the respective 1989 level in Norway, a national carbon tax corresponding to NOK 900 /tonne would be required (Solberg, 1997). In 1992, the tax was increased to $US 0.50/gallon of gasoline, which is equivalent to a price of NOK 250/tonne CO_2 emitted into the atmosphere (Solberg and Hoen, 1996). Based on a macroeconomic analysis, it was estimated that in order to maintain the level of emissions in 2000 same as that in 1990, a tax of approximately NOK 650/tonne of CO_2 (in 1990 prices) would be required. This tax would have to rise to NOK 1,450/tonne of CO_2 in year 2025 (1990 price level).

<u>Emission Trading</u>

Emission trading may not reduce the total amount of carbon being emitted to the atmosphere, except unless the allowable traded amounts are decreased over a period of time. "Carbon trading" is simply the buying and selling of "allowances" to emit CO_2 and its equivalents[22]. Trading of these carbon credits occur between companies, provinces, or nations. The high cost emitter may decide to purchase a credit from another producer that can reduce emissions at a lower cost. The idea is that areas that produce greater amounts of emissions buy credits from other areas that are able to support their emissions at a lower cost.

In Canada, and in fact in North America, there are no such trading systems for carbon. The closest actual trading is for sulfur emissions, where trading takes place in San Francisco.

Trading in carbon is in the planning stages. It is expected to commence at the Sydney Futures Exchange (SFE) in mid-2000. Trading would be consistent with Article 3.3 of the Kyoto Protocol to the United Nations Framework Convention on Climate Change[23]. Under Article 3 of the Kyoto Protocol, carbon sequestration is an acceptable mechanism for lowering a country's net carbon emissions and meeting their Kyoto emissions target. However, significant restrictions apply: carbon sequestration will be credited only for forests (Kyoto-consistent forests) planted after January 1, 1990 and only for carbon sequestered during the commitment period of 2008-

[21] http://www.carbonmarket.com/FAQs.html
[22] http://www.carbonmarket.com?FAQs.html

[23] http://www.forest.nsw.gov.au/Business%20…_Release/SFE_SF_carbontradingmarket.htm

2012[24]. The forest also has to be a forest that is planted and managed by human activity and results in land use change. This land use change is limited to afforestation, reforestation, and deforestation. The amount of carbon sequestered by Kyoto-consistent forests would be the amount traded. The unit for trade would be defined as the perpetual storage of 1 tonne of carbon dioxide (CO_2) equivalent emissions. It would be in the form of an “electronic certificate” with a unique serial number that would identify its country of origin and highlighted that it was derived from sequestration[25].

The SFE will provide global distribution of the product for trade. This could be through dedicated trading links in major financial centers such as Chicago, Hong Kong, and New York, as well as through established distribution channels in Australia and New Zealand. The SFE will also provide registry services to track ownership of certificates and the electronic trading platform that will execute trades and clearing services to settle carbon trades[26]. Since the emissions trading and related developments are still in the formative stages, no precise value of carbon sequestered can be estimated using this method of valuation at least at this time.

On an international level, carbon trading, according to C*TRADE[27] cost per unit of sequestering carbon is lower in many tropical countries, a result substantiated by Boscolo, Buongiorno and Panyotou (1997). For example, cost per tonne in various countries is lower, as shown in Table 5.2. In Canadian dollars, this cost ranges from a low of $3.36 to a high of $20.16 per tonne.

Table 5.2: Cost of Sequestering Carbon, Selected Countries

Country	Type of Activity	Level of Sequestration	Cost per ton in $US	Cost per tonne in $Cdn
Fiji	Reforestation	6,400 ha	$4	$6.72
Indonesia	Reforestation	1 million tons	$4	$6.72
India	Sustainable forestry	2,500 acres	$4	$6.72
Malaysia	Sustainable forestry	1 million tons	$2	$3.36
Mexico	Sustainable forestry	2,400 ha	$12	$20.16
Paraguay	Sustainable forestry	10,000 ha	$5	$8.40

Source: C*TRADE

Although the cost of sequestering carbon may be low in many of these countries, a number of issues, such as problem of poverty, expanding population, and climate change, as suggested by Binkley et al. (1997), are important to consider. Some of these differences are on account of potential carbon storage, as suggested by Dixon et al. (1994). Furthermore, in the context of forests, although these estimates include the value form timber production, value of nontimber products are also important (Binkley and van Kooten, 1994). In other words, increasing carbon sequestration may be at a further cost to the society-at-large, which are not included in the above estimates.

5.4 Unquantified Climate Change Damages Options: Enhanced Sequestration Option

Another approach to valuation of carbon sequestration function of a natural ecosystem is to use the information concerning alternative ways in which carbon can be sequestered. This approach and its associated methods are described in this section. Two types of methods are included here: Replacement cost method, and Substitute cost method. Each of these are described in this section.

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24 http://www.weathervane.rff.org/trading_post/SFECarbonMarket.htm
25 http://www.carbontrading.com.au/Content/docs/General/q_and_a.html
26 ibid.
27 For details see, http://www.Ctrade.org/forestry.html

5.4.1 Approach 6 – Replacement Cost Method

This method is most commonly used in settling damage disputes (Koop and Smith, 1993). The appropriate compensation for a damage that is already done is the cost of replacing the original function, provided that it can be replaced in its original shape.

In the context of carbon sequestration, this method would estimate the value of carbon based on the cost of replacing these services in some alternative manner. It assumes that the costs of replacing ecosystems or their services provide useful estimates of the value of these ecosystems or services. This is based on the assumption that if people incur costs to replace the services of the ecosystem, then those services must be worth at least what people paid to replace them[28].

For the carbon sequestration function of protected lands, there are at least four ways of sequestering such carbon: (1) Through afforestation; (2) Through reduced deforestation; (3) Through sustainable forest management; and (4) Through proper management of grasslands. Although creation of additional grasslands could also be another manner in which additional carbon can be sequestered, this would be identical to a protected area, and therefore, excluded from this list.

Forestation (Afforestation and Reforestation)

Carbon dioxide is important for plant growth, and because trees remove CO_2 from the atmosphere and store it as carbon in biomass, forests play a significant role in helping the global community mitigate climatic change, at least in the short run (van Kooten et al., 1995). Increasing the amount of forests through reforestation and afforestation is an obvious alternative to slow or offset the increase in atmospheric CO_2 (Schroeder, 1991). Furthermore, in order to be effective, according to Schroder and Ladd (1991), it must be practiced globally. The rate of net carbon uptake by a forest is proportional to the growth of the forest. It is not the age of trees or standing timber volume that is important, but rather the rate of tree growth. As trees grow they sequester carbon, but once carbon has been sequestered, no further benefits are forthcoming (van Kooten et al., 1995). Afforestation on lands capable of supporting trees such as some grasslands, pasture lands and land degraded or abandoned following other land uses such as grazing or cropping would significantly expand forest resources and increase the level of terrestrial carbon storage (Sampson et al., 1993).

Canada's current forestland is not as productive as it could be, primarily because much of the area is forested by mature timber. It is estimated that there is approximately 19.74 million ha of backlog NSR (not satisfactorily restocked) lands in Canada, which could sequester 13.285 million tonnes of carbon. Assuming that it costs $800 to $1200 per ha to reforest backlog, the total cost would be $15.8-$23.7 billion (van Kooten et al., 1992). If a forest rotation of 80 years is used, the cost of reforestation can be estimated at $8 – 12 per tonne of carbon on NSR lands in British Columbia. If such a ratio is applied to rest of Canada, cost would range between $15 – 23 per tonne of carbon (van Kooten et al., 1992). This would yield a value of $16.90 and $25.92 per tonne of carbon sequestered.

Van Kooten, Thompson, and Vertinsky (1993) employed three estimates of the value of carbon to calculate the costs and benefits of reforesting backlog NSR lands in British Columbia. These values were $20, $50, and $300/tonne, along with discount rates of 2.5% and 5%. They found

[28] http://www.ecosystemvaluation.org/cost_avoided.htm

that a carbon value of $20/tonne along with a discount rate of 5% resulted in no sites being economically feasible to rehabilitate. At $20 and 2.5% discount rate, an additional 154 thousand hectares would be worthwhile to reforest. At $50 and 2.5%, almost all NSR sites would be economically justified. At 5% discount rate, only 71 thousand hectares would become feasible on good quality land. At $300 and 2.5%, almost all sites were worth rehabilitating, while at 5% all medium and good quality sites were worthwhile, a total area of 274 thousand hectares (van Kooten et al., 1993).

In U. S., McCarl and Callaway (1993) analyzed carbon sequestration through tree plantings on agricultural lands. Their analysis indicated that the cost of carbon sequestration rises as amount sequestered increases. Cost would range between $17.38 and $25.96 per tonne in U.S. funds. This is equivalent to $29.38 and $43.88 per tonne in Canadian funds for the year 2000. In addition, Newell and Stavins (1999) have shown that the cost would be higher if periodic harvest of timer is undertaken.

The Sinks Issue Table (see Sinks Table Options Report, 1999) also commissioned studies to estimate the cost of afforestation in Canada. These costs have been estimated to $2.30 per tonne of carbon sequestered for eastern Canada, $2.40 per tonne for British Columbia, and $3 per tonne for the Prairies. Assuming that these values reflect 1999 situation, and converting them to 2000 year cost, would yield a range of $2.35 to $3.06 per tonne of carbon sequestered.

Based on implementation costs, reforestation and natural regeneration can sequester carbon at $US 11 and $US 6/Mg, respectively (Winjum et al., 1993). For boreal forest systems, natural regeneration and artificial reforestation could sequester carbon most efficiently at a cost of $US 90 to $US 325/ha. At sequestration values of about 17t C/ha and 39t C/ha for a 50 year period, the initial costs for the two practices are $5 ($4-$11)/ t C and $8 ($3-$27)/ t C (Schroeder et al., 1993).

In Canada, there is almost no agricultural land set aside; land only marginally suited to annual crop production continues to be farmed. The agricultural land types considered suitable for afforestation are primarily those associated with forage production and pasture. The total costs of afforestation are the direct planting costs plus the annual foregone agricultural benefits. In addition to marginal lands being farmed, the agricultural regions of Prairie Provinces contain about 16.64 million ha of unimproved lands. Some of these areas could be managed as forests. If afforestation costs are $500-$700/ha, the total cost would be $2.1 to $2.9 billion. With a 60-year rotation, the costs of planting the unimproved lands would be $12.80 to $18.00/tonne of carbon (van Kooten et al., 1992).

Reduced Deforestation

Mature forests store large quantities of organic carbon in their living and dead trees, forest floor, and soil. Therefore, a large emission of CO_2 to the atmosphere occurs whenever mature forests are disturbed. Over recent years, most deforestation has been occurring in tropical regions of the world (Freedman and Keith, 1996). By reducing the amount of deforestation that occurs, less CO_2 is emitted into the atmosphere by forests.

No study has been undertaken as to the marginal social opportunity cost of keeping these lands under a forest cover.

Sustainable / Intensive Forest Management for Carbon Sequestration (Including Multiple Benefit Management) Enhancement

Sustainable forest management can lead to enhancement of sequestration of carbon. Forests are constantly changing, from causes such as fire, insects, disease, and age. As the forests change, management of the forest must also change in such a manner that will help to preserve the forest. As forests are maintained, the amount of carbon they sequester increases with time. Forests can also be managed for multiple benefits. For example, Englin and Callaway (1995) have analyzed a forest system with the production of three goods: timber, carbon sequestration, and amenities.

In 1991, the International Tropical Timber Organization (ITTO) council adopted the following definition of sustainable forest management:

> "Sustainable forest management is the process of managing permanent forest land to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services without undue undesirable effects on the physical and social environment" (Jepma et al., 1997).

Increasing the amount of forests through reforestation and afforestation is an obvious alternative to slow or offset the increase in atmospheric CO_2. Each of these should be thought of as components of a CO_2 response strategy. Another component of such a response strategy has been suggested by Marland (1998)[29]. He proposed not only planting trees, but also managing forests more intensively to promote faster growth and increased rates of carbon fixation (Schroeder, 1991).

Swisher (1991) defines sustainable forestry as forest sector practices that maintain or increase both the forest resource stock and the flow of forest products over time. There are different types of forest projects, each with different costs and different carbon flows. Seven different forestry projects include forest reserves, natural forest management, forest restoration, timber plantations, agroforestry, fuelwood farms, and biomass energy plantations. He applied his methodology to a set of project in Central America, and found that the costs of carbon savings in the forestry projects studied in Central America mostly fall between \$5 and \$13/t C (in US dollars).

Forestland can be managed in different ways and produce different outputs, (e.g., timber, wildlife, berries, landscape, and biomass), which is why it is considered a multi-input/multi-output production process (Hoen and Solberg, 1994). If the management objective is to find a policy to reduce the amount of atmospheric CO_2 for a given period of time, there are two available options related to forestry:

1. To increase the amount of CO_2 fixed from the atmosphere in photosynthesis; and

2. To reduce the amount of CO_2 emitted to the atmosphere as a consequence of decay of organic material (Hoen and Solberg, 1994).

Hoen and Solberg (1994) proposed using marginal costs, measured as the change in net present value, as a measure of ranking alternative projects. Their results showed that at a real rate of discount (RRD) of 4%, 80% of the increase in NPV_{CO2} (discounted value of a flow of net CO_2 fixations) could be reached for a marginal cost of around NOK 150 (\$US 21) per ton NPV_{CO2}. Measured per ton carbon (t C), their marginal cost was NOK 551/t C, or \$US 79/t C.

[29] Marland, 1998, cited by Schroeder, 1991.

Dixon (1997) performed a 40 nation assessment of silvicultural practices and techniques, which revealed that forest drainage, thinning, fertilization, weeding and modified harvesting can be employed to sequester or conserve 1-64 Mg C/ha. The economic data used by Dixon is reported in 1994 US dollars. Application of silvicultural practices can achieve sequestration or conservation of carbon in forest systems for a cost ranging from $2 to $56 /tonne of C. In Canada, the initial project costs ($/ha) and costs per unit ($ /tonne of C) of implementing silvicultural practices to conserve and sequester carbon in Canada are $188/ha and $19 /tonne of C for fertilization, and $350/ha and $30 /tonne C for thinning. The mean for the 40 nations were $186/ha, and $13 Mg C. The project costs were highly variable in all nations ranging from $8-573/ha with labor cost being the dominant economic factor (Dixon, 1997).

Dixon, Winjum, and Schroeder (1993) report that the initial costs of forest establishment and management are least expensive in boreal regions. For boreal forest systems, natural regeneration practices and artificial regeneration could be implemented most effectively at a cost of $90-$325/ha. At carbon storage values of approximately 17 tonnes/ha and 39 tonnes/ha, respectively, the initial cost of carbon sequestration for the two practices is $5 ($4-$11)/tonne and $8($3-$27)/tonne. Silvicultural treatments are also a cost-effective means to manage boreal forest systems at $74/ha. At a sequestration value of 10.5 tonnes of C/ha for intermediate silvicultural treatments, the initial cost of carbon sequestration ranged from $5-$76/tonne (Dixon et al., 1993).

The “inventory-based procedure” is an economic approach that is used to estimate the costs of carbon conservation and sequestration through forest management. The procedure is applicable on large geographic scales such as nations or regions within continents. This scale requires consideration of three elements:

1. Forest inventory;
2. Integration of biological, social and economic components; and
3. The distribution of impacts.

Managing the forests to mitigate increases in atmospheric carbon involves two processes simultaneously:

1. Conservation of carbon in the forest inventory; and
2. Fixation of carbon by the inventory.

By recognizing the forest inventory as a capital stock, both processes are accounted for by recognizing the forest inventory and forest growth as a flow to the forest inventory (Lewis et al., 1996).

The inventory-based procedure adopts the standard for measurement of physical inputs and outputs for the evaluation of stand treatments for timber production and for comparison of forest vegetation management alternatives. This standard requires the measurement of all inputs and outputs on an interval scale and the unit of measure must be associated with a real price expressed on a ration scale. The procedure meets the economic requirements for comparing the efficiency of forest management alternatives and compatibility with regional input-output analysis. The procedure includes: (1) the summary of all inputs and outputs on an annual or periodic basis recognizing the costs of capital inputs; (2) management costs as they occur; and (3) outputs. The study found, for the US, that the total annual net costs were $28,103 million, the average to hold[30] was $0.75/t C, and the average to sequester was $364/t C (Lewis et al., 1996).

For single or small mitigation projects, a "bottom-up" methodology has been suggested by Sampson and Sedjo (1997). It involves the identification of all the various carbon flows or stocks that will be impacted by the project, and calculating the amount of carbon stock with and without the project. The costs of carbon storage in a forestry project should be expressed in terms of tons-carbon (t C) stored by the project (Swisher, 1991). The costs should include the net opportunity cost of the land used for the project, rather than the land use that the project replaces, and an endowment sufficient to cover the project's establishment and the expenses and incentives for its on-going operation, including maintenance, management and monitoring, sufficient to assure the sustainability of the project and its carbon storage (Swisher, 1997).

Sustainable Management of Grasslands

Similar to the sustainable forest management, grasslands if managed for carbon sequestration, can also lead to additional carbon sequestered. Community pastures in the prairie provinces are managed for a joint production of commercial services (grazing) as well as for conservation of soil resources. The latter leads to higher rates of carbon sequestration. Unfortunately no study has been reported on the cost of the non-grazing objective. No other study was found in the literature that employed this method.

Summary of Results for the Approach

Afforstation and reforestation activities are closest to protected area carbon sequestration function than any of the other activities. Here carbon sequestration takes place in the same manner as on the protected areas. As shown in Table 5.3, here the costs range between $2.30 per tonne to $54.80 per tonne of carbon. The amount of carbon that can be stored with these methods can also be large, subject of course, to the availability of suitable lands. Forest management can also lead to additional carbon sequestered, but the costs are somewhat higher. These range from $3.71 to $103.96 per tonne of carbon.

5.4.2 Approach 7 – Substitute Cost Method

The substitute cost method estimates values of ecosystem services based on the costs of providing substitute services[31] that can perform the same services as those of the ecosystem. Thus, in the context of carbon sequestration, this would involve similar type of sequestration but in measures that do not involve forests or grasslands – the two common types of protected areas.

[30] The study does not make the meaning of the phrase "average to hold" very clear. In this study it is interpreted as a practice no harvesting is allowed, and all the carbon sequestered is stored in the biomass.

[31] ibid.

Table 5.3: Alternative Estimates of Value of Carbon using the Replacement Cost Method

Type of Activity	Author	Year of Estimate	Unit	Estimated Cost	Cost per tonne C in Cdn.$	Value in Cdn.$ per tonne (2000)
Afforestation and Reforestation						
Reforestation (NSR lands)	Van Kooten et al.	1992	$Cdn /Tonne C	8-23	8-23	9.02-25.92
Afforestaton (Unimproved lands)	Van Kooten et al.	1992	$Cdn /Tonne C	12.80-18.00	12.80-18.00	14.43-20.29
Reforestation	Winjum et al.	1990	$US /Mg C*	11	18.48	20.46
Natural regeneration	Winjum et al.	1990	$US /Mg C*	6	10.08	11.16
Natural Regeneration (initial costs)	Schroeder et al.	1993	$US /Ton C	4-11	6.72-18.48	8.12-22.32
Artificial Reforestation (initial costs)	Schroeder et al.	1993	$US /Ton C	3-27	5.04-45.36	6.09-54.80
Sinks Issue Table	Sinks Options Report	1999	$Cdn /t C (Eastern Canada)	2.30		2.35
		1999	$Cdn /t C (British Columbia)	2.40		2.45
		1999	$Cdn /t C (Prairies)	3.00		3.06
Sustainable Forest Management						
Forestry Projects (Central America)	Swisher	1991	$US /Ton C	5-13	8.4-21.84	9.61-24.99
Fertilization	Dixon	1994	$US /Mg C*	19	31.92	35.27
Thinning	Dixon	1994	$US /Mg C*	30	50.40	55.69
Silvicultural practices	Dixon	1994	$US /Mg C*	2-56	3.36-94.08	3.71-103.96

* 1 Mg of carbon is equivalent to 1 tonne of carbon

<u>Land Cover Changes</u>

The idea behind land cover changes is that carbon can be sequestered in the soil as well as grasses, shrubs, and other types of vegetation. This is considered a substitution measure since changing the land cover is still performing the same services (sequestration of carbon) as would a forest. Methodology that can be followed in evaluating the value is described in Parks et al. (1997).

Carbon sequestration activities convert agricultural land into carbon at a fixed rate (tons carbon/acre/year) by planting trees. This rate varies by region and by land type. The variability

in sequestration rates reflect both composition of forest types suitable for carbon sequestration under different climatic conditions and variations in soil productivity (Adams et al., 1993).
Dudek and LeBlanc (1990)[32] considered offsetting new CO_2 emissions in the US by planting trees on land put into the Conservation Reserve Program (CRP) under the Food Security Act of 1985. The option was estimated to cost between $US 25 and $US 45/tonne of carbon removed from the atmosphere (van Kooten, 1995).

For trees planted on marginal agricultural lands enrolled in a natural carbon sequestration program modeled after the CRP, marginal sequestration costs increase relatively slowly up to roughly 120 million tons, then increase sharply beyond that point. Marginal costs increase from $34/ton to $699/ton in this range; the annual equivalents of these costs range from $4.19/ton to $82.49/ton (Parks and Hardie, 1995).

A carbon sequestration program involving the conversion of 263 thousand hectares of land to forest in Southwestern Wisconsin is evaluated by Plantinga (1997). For a sequestration rate of 4.35 tons C/ha/yr and interest rate of 10%, the marginal costs for the program range from $18 to $38/ton when all 263 thousand ha are converted. For a sequestration rate of 5.56 tons C/ha and a rate of interest of 4%, marginal costs are between $6 and $13 /ton C when all hectare are converted.

Adams et al. (1993) found that the marginal costs per ton increase as the carbon-fixing goals increase, from a low of about $18/ton for 140 million tons to approximately $55/ton for a goal of 700 million tons. The rising costs/ton reflect rising opportunity costs of agricultural land as farmers divert more land and higher quality land from crop growing to tree planting (Adams et al., 1993).

Stavins (1999) developed a method by which the costs of carbon sequestration can be estimated on the basis of evidence from landowners' behavior when confronted with the opportunity costs of alternative land use. The forest revenues associated with this management regime result in a small amount of net forestation taking place in the baseline simulation, a gain of about 52,000 acre. Baseline net carbon sequestration is approximately 4.6 million tons annually. Marginal costs of carbon sequestration increase gradually, until these costs are about $66/tonne, where annual sequestration relative to baseline has reached approximately 7 million tonnes. This level of sequestration is associated with a land use tax/subsidy of $100/acre and net forestation, relative to baseline, of 4.7 million acres. Beyond this point, marginal costs depart more rapidly from a linear trend. Beyond $200/tonne, they turn steeply upward.

One of the major weaknesses of the approach, such as tree planting for purely carbon sequestration purposes, is their focus on undertaking a particular action. An alternative question to ask, according to Sjedo (1995), to ask the question of what additional costs (through subsidies or other incentives) would be required to generate additional carbon sequestering activities.

There are 15 thousand Permanent Cover Program sites in the prairie provinces of Canada, covering 522 thousand hectares of land that is converted from annual cultivation to forages under the Prairie Farm Rehabilitation Administration's (PFRA) Permanent Cover Program (PCP). The PCP was implemented primarily for soil conservation and grain program expenditure reduction by the government. There are 168 thousand hectares enrolled in PCP1 and 354 thousand hectares in PCP2. The program cost to Canada totaled $74 million in payments for forage establishment and land use restrictions. Since the amount of carbon sequestered is 4.82 Mt, value per tonne of carbon is estimated at $15.34 in Canadian funds (Luciuk et al., undated)[33].

[32] Cited in van Kooten (1995)
[33] Unfortunately the year of valuation is not provided in the study, therefore, no adjustment for the year 2000 could be made.

Soil Carbon Sequestration

Soil is one option for storing carbon. Some of the strategies for maintaining, restoring, and enlarging soil carbon pools may include minimizing site disturbance and retaining organic matter in soil, preservation of wetlands and conservation tillage practices to reduce soil aeration, heating, and drying (Dixon et al., 1994). In spite of the obvious relevance of this type of sequestration, its study for Canada remains to be a rare topic.

Gheidi (1997) using a carbon sequestration model (Century) and an economic optimization model showed that conservation tillage would lead to higher carbon sequestration through an increase in the organic matter in the soils, but at the cost of reduced returns to producers. A 30% increase in the conservation tillage would lead to a 12.5% increase in soil organic matter, whereas producer returns would decline by 9.3%.

Geological Storage

Geological storage can be used as a substitute for carbon sequestration as captured CO_2 could be concentrated into a gas or liquid stream that could be transported and injected into the ocean or deep underground geological formations such as oil and gas reservoirs, deep saline reservoirs, and deep coal seams and beds[34] for long term storage. Lackner, Butt and Wendt (1997) have also proposed a process for disposal of carbon dioxide in the form of carbonate minerals. Since carbonate minerals are already common, their disposal is safe.

The global capacity for storage in disused gas fields could be as much as 140 Gt C, and in disused oil fields perhaps 40 Gt C. A hypothetical scheme for storage in an abandoned on-shore gas field has been costed at $8.2/t C (Fruend and Ormerod, 1997).
The first of two large offshore gas field developments in which the underground disposal of CO_2 is a major feature; the Sleipner Vest project, operated by Statoil started inlate August 1996. A second, even larger, scheme is planned as part of the development of the Natuna gas field, in the South China Sea, by Pertamina and Esso Exploration and Production Natuna, Inc. In these schemes, CO_2 will be stripped from the hydrocarbon gases on the platform before disposal (Holloway, 1997).

The main obstacle to the underground disposal of CO_2 from fossil fuel power plant is its high cost. Most of the cost is incurred by the necessity to separate the CO_2 form, or concentrate it in, the flue gas. This cost varies widely, depending on the type of power plant and separation technology considered, but is in the range $27-$65 per tonne avoided (Holloway, 1997).

Total underground disposal costs (including capture, transport, and injection underground) have been estimated at around $52/tonne of CO_2 in Alberta (Gunter et al., 1997).

Aquifers are a possibility for underground storage. A hypothetical scheme for injection into an onshore aquifer indicated costs of about $4.7/t C. The Sleipner Vest natural gas field contains 9.5% CO_2; this gas is being separated and re-injected into the Utsira formation under the North Sea, in the world's first commercial-scale CO_2 storage in an aquifer (Fruend and Ormerod, 1997).

The technology for the capture and storage of CO_2 is relatively new. CO_2 capture at power stations incurs significant costs and uses substantial amounts of energy. The cost of CO_2 capture and storage in a post-combustion setting where flue gas scrubbing is used is $0.015-

[34] http://www.fe.doe.gov/coal_power/sequestration/index_rpt.html

0.02/kWh, while pre-combustion synthesis gas clean-up is less at $0.01-0.015/kWh (Electricity Industry Issue Table, 1999).

Statoil of Norway initiated the first commercial-scale system dedicated to CO_2 storage in 1996. The company has since been injecting about 1 million tonnes of CO_2 per year from the Sleipner West gas field into a deep saline formation about 800m beneath the bed of the North Sea. Costs of the operation are approximately $US 15/tonne of CO_2 avoided (Electricity Industry Issue Table, 1999).

Injecting dense-phase CO_2 into deep water could delay return to the atmosphere by several hundred years. Depth of discharge and length of pipeline are two key influences on the cost of ocean storage, which has been estimated at $4.1/t C for shallow depths rising to $21/t C for deeper schemes (Fruend and Ormerod, 1997).

A terrestrial-based concept envisages use of thermally insulated artificial stores containing solid CO_2. However, a store with capacity of $10^8 m^3$ would cost around $500/t C (Fruend and Ormerod, 1997).

A study of the potential for CO_2 capture and use for enhanced oil recovery (EOR) was conducted in the early 1990's by the Alberta Oil Sands Technology and Research Authority (AOSTRA) and a consortium of industry and government agencies. The study reviewed CO_2 capture from a variety of emission sources. In addition, CO_2 flooding of a variety of reservoirs representative of oil fields in Alberta and Saskatchewan, and storage in a depleted gas reservoir were also investigated. The economics of implementing such projects were evaluated based on the costs of CO_2 capture and delivery to the field, and the benefits arising from EOR (Electricity Industry Issue Table, 1999). The measure is limited to investment in Alberta and Saskatchewan because of geological potential is limited outside the region, and the cost of pipelining captured CO_2 is prohibitive. The cost per tonne CO_2 is estimated in the U.S. at $US 20-25, whereas the AOSTRA found that pipelining costs to Saskatchewan to be $Cdn 0.58 to 0.76 /t CO_2 (Electricity Industry Issue Table, 1999).

Another manner in which CO_2 can be captured and sequestered in deep aquifers for enhanced oil recovery in Southeast Saskatchewan. The CO_2 will be captured form the Saskatchewan coal electric power generation. The cost of this operation is estimated at $38 per tonne of CO_2 sequestered[35].

Solid Material Storage

For agricultural byproducts, recent studies have suggest several possibilities for carbon sequestration. Included here are manufacturing of strawboards from crop byproducts, use of flax fiber in plastic composites, and use of straw bales for buildings. All these method lead to sequestration of carbon over the life of the product. Depending upon their disposal, there may still be some gain in the level of carbon sequestered. Strawboards could be used for furniture, automobiles, and other durable goods manufacture (Campbell and Coxworth, 1999). Similarly, flax fiber replaces the present fiber components in automobile parts, such as door panels (Isman, 1999). Use of straw bales for buildings is an even more recent development. Here the walls are made of straw bales in either weight bearing construction or post and beam type construction (Steen and Steen, 1996).

[35] Based a personal communication with David Hanly, Saskatchewan Power Corporation.

Summary of Substitute Cost Method studies

Substitute cost method provides another perspective on the value of carbon. In this method, value of carbon is equated to what would it cost to replace (substitute) the carbon already stored in the protected areas. A summary of these studies is shown in Table 5.4. This value, similar to the alternative cost method is highly variable. Range in these estimates is from $Cdn 8 to $Cdn 375 per tonne. For the geological storage option, technology is emerging, and therefore, present costs may be somewhat higher. These could be expected to come down in the future.

Table 5.4: Estimated Value of Carbon based on the Substitute Cost Method Studies

Type of Activity	Author	Year of Study	Unit	Costs	Cost per tonne C in Cdn.$	Value in Cdn.$ per tonne (2000)
Land Cover Change						
CRP	Dudek and LeBlanc	1990	$US / Tonne C	25-45	37.50-67.50	30.20-54.36
CRP type Program	Parks and Hardie	1993	$US / Tonne C	4.19-82.49	7.04-138.58	7.79-153.44
Land converted to forest	Plantinga	1997	$US / Tonne C	6-38	10.08-63.84	11.16-70.68
Tree planting program	Adams et al.	1993	$US / Tonne C	8.30-55.01	13.94-92.42	15.43-102.33
Revealed Preference	Stavins	1999	$US / Tonne C	66.05	110.96	113.18
Permanent Cover Program	Luciuk et al.	Undated	$Cdn / tonne		15.34	
Geological Storage						
Underground storage (disused gas field)	Fruend and Ormerod	1997	$US / Tonne C	8.20	13.78	14.43
Underground Storage (aquifer)	Fruend and Ormerod	1997	$US / Tonne C	4.70	7.90	8.28
Underground storage	Holloway	1997	$US / Tonne CO_2	27-65	148.49-357.47	155.54-374.54
Ocean Storage	Fruend and Ormerod	1997	$US / Tonne C	4.1-21	6.89-35.28	7.22-36.96
Deep aquifer storage for Enhanced oil recovery	Hanly	2000	$Cdn / tonne			38.00

In this chapter, various approaches to valuation of carbon – conceptual or empirical were discussed. Some of these methods did produce estimates of values. For many studies deciphering such estimates is hard. A synthesis of these results is presented in the next chapter.

Chapter 6

STUDY RESULTS AND DISCUSSION

In the previous two chapters, methodology for the estimation of level of carbon sequestered (stored) in the protected areas of Canada (mainly the National Parks and Saskatchewan Provincial Parks) and that for estimating the economic value of carbon were discussed. In this chapter, these two pieces of methodologies are brought together to estimate the total economic value of stored carbon in these protected areas.

The chapter is divided in three sections. Section 6.1 presents the estimated of the amount of stored carbon, which is followed by estimated economic value of carbon sequestration function of protected areas. The last part includes a discussion and implications of the results.

6.1 Estimated Level of Stored Carbon in National Parks of Canada

As noted in Chapter 4, all parks included in this study were classified according to the availability of data. To start with, parks were separated out as National Parks and Provincial Parks. Within each of these categories, parks were divided into categories according the nature of information available for the estimation of stored carbon.

6.1.1 Nature of Stored Carbon in National Parks

For the 39 National Parks, estimates were made for the two major pools of carbon: (1) Biomass pool, which included trees, underground root zone, and grass; (2) Soil pool, which included forestlands and peatlands. Calculations were done for each park and then aggregated to various provinces and ecozones. Details on individual parks are shown in Appendix D (Table D.1).

All the National Parks of Canada store approximately 4,432 megatonnes (million tonnes) of carbon in various parts of the ecosystem. As shown in Figure 6.1, 47% of the total stored carbon is in the soils, another 8% in the plant biomass, and the remaining 45% in the peatlands. The soils are the major pool of stored carbon in various national parks, although their location may vary from park to park.

A perusal of regional distribution of the stored carbon indicates that western Canadian provinces (territories) have the largest amount of carbon stored. A regional distribution is shown in Figure 6.2 (see page 66). Alberta National Parks lead the way in term so relative contribution to total carbon stored. These parks stored 36% of the total Canadian carbon storage in National Parks of four gigatonnes. British Columbia and Northwest Territories, and Nunavut are the next three regions with a higher amount of stored carbon in National Parks.

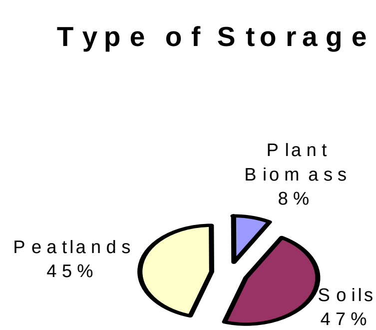

Figure 6.1: Distribution of Stored Carbon in Canada's National Parks by Type of Stored Carbon

Relative contribution of various regions is related to at least three factors: One, number of National parks in the region; Two, relative size of the National parks; and ecozone in which the park is located. Joint effect of these factors lead to higher contribution for western and northern provinces /

territories, as compared to the eastern Canadian provinces. In fact, provinces such as Newfoundland, Nova Scotia, and New Brunswick have a very small, and in fact negligible stored carbon in their respective National Parks.

6.1.2 Distribution of Stored Carbon by Location of the Park

Estimates of total stored carbon in Canadian National Parks located in various provinces and territories are shown in Table 6.1. Of the total 4.43 gigatonnes (billion tonnes) of stored carbon, two gigatonnes are stored in the peatlands. A larger proportion of such lands are present in National Parks in Alberta and the Northwest Territories. A similar amount of stored carbon is in the soils – forest soils and grassland soils. This source is responsible for a storage of 2.1 gigatonnes of carbon. The remaining 365 megatonnes of carbon is stored in the plant biomass.

Table 6.1: Estimated Level of Stored Carbon in Canadian National Parks, by Province and Territories

Province	Biomass Pool (Plant and Roots) Mt C	Soil Pool		Total Carbon Stored* t C
		Soils Mt C	Peatlands Mt C	
Alberta	41	403	1,128	1,572
British Columbia	265	223	125	612
Manitoba	11	46	124	181
New Brunswick	1	3	2	6
Newfoundland	4	19	42	65
Northwest Territories	16	753	339	1,109
Nova Scotia	4	9	5	18
Nunavut	1	492	0	493
Ontario	2	8	16	26
Prince Edward Island	--	--	--	--
Quebec	5	23	50	78
Saskatchewan	15	44	171	230
Yukon	2	30	9	42
Canada	**365**	**2,054**	**2,012**	**4,432**

* Numbers may not add due to rounding

-- Less than one Mt

Alberta National Parks are estimated to store 1.5 gigatonnes of carbon in the three types of storage – plant, soils and peatlands. Peatlands here store almost 72% of the total. In British Columbia, although the total stored carbon is 612 Mt, a majority of this (43% of the total) is stored in the plant biomass. This is a result of the nature of vegetation found in these parks, made up primarily of forests.

Generally speaking, northern territories store a larger quantity of carbon in their National Parks than the corresponding southerly-located parks. For example, both Northwest Territories and Nunavut National Parks stored 1,109 and 493 Mt of carbon, respectively. In these regions, peatlands are not very commonly found, and most of the carbon is stored in the undisturbed arctic soils.

6.1.3 Distribution of Stored Carbon by Ecozones

As already alluded to, National Parks located in the northernmost ecozones are the major source of stored carbon. Distribution of the total stored carbon in National Parks of Canada is shown in Table 6.2. Two western ecozones – Boreal Plains, and Pacific Maritimes, dominate the total, as shown in Figure 6.3. These two ecozones account for about 53% of the total Canadian stored carbon in the National Parks. In the Boreal Plains, the major type of storage is peatlands, which are very commonly found. The next larger amount of carbon is stored in the Northern Arctic ecozone. Here National Parks are very large, and soils are carbon rich. Four National Parks are located with a combined total area of almost 4.4 million ha. Total stored carbon in this ecozone is estimated at 468 megatonnes. The other ecozone where storage of carbon in peatlands is relatively high is the Taiga Plains ecozone. Here the total amount stored is estimated at 451 Mt, of which 68% is in the peatlands. In parks located in these and other northern ecozones, it is estimated that almost half of the area is under some type of vegetation (shrubs, moss, lichen, among others). The soils in this ecozone are very rich in carbon, as shown in Table 4.5.

Table 6.2: Estimated Level of Stored Carbon in Canadian National Parks, by Ecozones

Ecozone	Biomass Pool (Plant and Roots) Mt C	Soil Pool		Total Carbon Stored Mt C
		Forest Soils Mt C	Peatlands Mt C	
Atlantic Maritimes	9	27	40	76
Arctic Cordillera	--	268	0	269
Boreal Cordillera	1	6	4	10
Boreal Plains	52	349	1,392	1,792
Boreal Shield	5	34	74	113
Hudson Plains	1	17	8	26
Mixedwood Plains	1	1	1	3
Montane Cordillera	31	162	30	222
Northern Arctic	1	467	0	468
Pacific Maritimes	247	191	121	558
Prairies	2	1	0	3
Southern Arctic	1	313	0	314
Taiga / Tundra	5	84	35	124
Taiga Plains	11	133	308	451
Canada	**365**	**2,054**	**2,012**	**4,432**

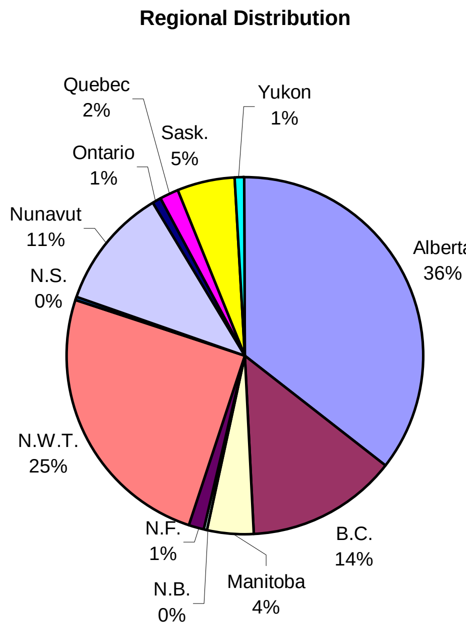

Figure 6.2: Distribution of Stored Carbon in National Parks of Canada, by Region

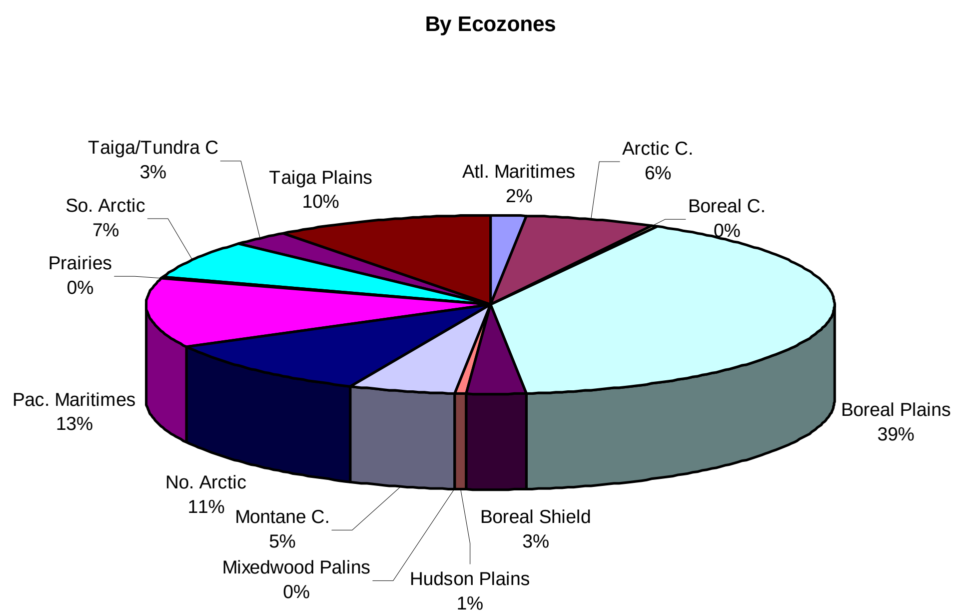

Figure 6.3: Distribution of Stored Carbon in Canada's National Parks, by Ecozones

6.1.4 Stored Carbon Density in National Parks

The distribution of total carbon stored can be distorted by the relative size differences of the parks in various regions or ecozones. To correct for this bias, total stored carbon in various provinces and territories was divided by the area of the park. Results are shown in Table 6.3.

According to these estimates, National Parks located in Saskatchewan store the largest amount of carbon on a per hectare basis. This amount is estimated to be 481 tonnes per hectare. The lowest amount of storage is in the parks in the Yukon Territory, at 12 tonnes per hectare. Alberta, British Columbia and Newfoundland National Parks tend to store a higher level of carbon than those located in the rest of the country.

Consistent with the provincial stored carbon levels is the distribution of carbon density by ecozones, which are shown in Table 6.4. National Parks located in the Boreal Plains ecozone have the highest amount of stored carbon level estimated at 418 tonnes per ha. In contrast, those located in the Boreal Cordillera provide the least amount of storage for carbon. Here the level is only 7 tonnes per hectare.

As shown in Figure 6.4, parks located in the northern territories store carbon at a higher level relative to most other ecozones. However, in many of these parks, the area under some type of vegetation is relatively small, resulting in an overall lower level of stored carbon per hectare of area of the park.

Table 6.3: Estimated Density of Stored Carbon in Canadian National Parks, by Province and Territories

Province	Total Pool of Carbon t C /ha
Alberta	291
British Columbia	316
Manitoba	125
New Brunswick	127
Newfoundland	297
Northwest Territories	262
Nova Scotia	130
Nunavut	62
Ontario	122
Prince Edward Island	94
Quebec	176
Saskatchewan	481
Yukon	12
Canada	**170**

6.4 Carbon in Canadian National Parks, by Ecozone

Province	Total Pool of Carbon t C /ha
Atlantic Maritimes	181
Arctic Cordillera	56
Boreal Cordillera	7
Boreal Plains	418
Boreal Shield	185
Hudson Plains	23
Mixedwood Plains	132
Montane Cordillera	99
Northern Arctic	106
Pacific Maritime	235
Prairies	36
Southern Arctic	192
Taiga/Tundra Cordillera	75
Taiga Plains	398
Canada	**170**

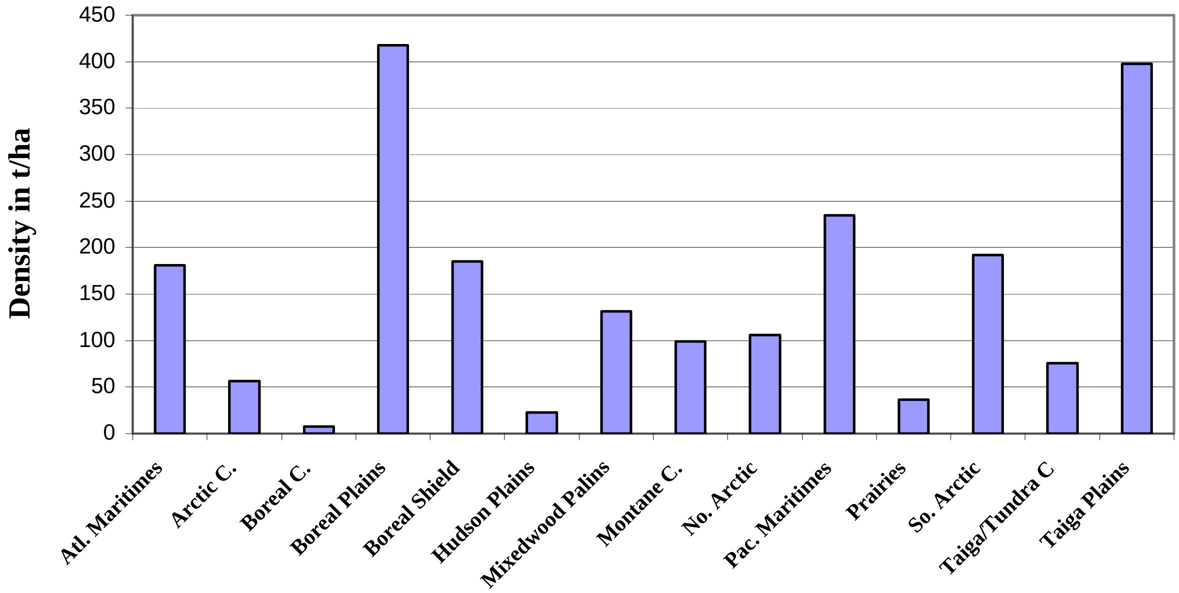

Figure 6.4: Carbon Density in National Parks, by Ecozones

6.2 Level of Stored Carbon in Saskatchewan Provincial Parks

The exact same methodology, as adopted for the National Parks, was followed for the Saskatchewan Provincial Parks. Stored carbon was estimated for the plant and root biomass, and in the soils (both peatlands and others). Results are summarized by ecozones in Table 6.5. Details on individual parks are provided in Appendix E.

Table 6.5: Estimated Level of Stored Carbon Levels in Saskatchewan Provincial Parks, by Ecozones

Ecozone	**Biomass Pool (Plant and Roots) Mt C**	**Soil Pool**		**Total Carbon Stored Mt C**
		Soils Mt C	**Peatlands Mt C**	
Boreal Plain	9	36	145	191
Boreal Shield	15	55	221	292
Prairies	3	3	0	5
Saskatchewan	27	94	366	488

Total amount of carbon stored in 30 Provincial Parks analyzed in this study stored about 488 megatonnes (or almost one half gigatonne) of carbon. Compared to the level stored in National Parks (estimated at 4 gigatonnes), this amount is almost 12% of the total. A part of the explanation is the relatively smaller size of these parks, and their southern location. Much of this carbon is stored in the peatlands that are found in the Provincial Parks located in the Boreal Shield and Boreal Plain ecozones. Parks located in the Prairies ecozone have a very small quantity of carbon stored. Two reasons could be speculated here: (1) There are no peatlands found in these parks. Peatlands, as shown in Table 4.5, store more carbon per ha than other soils. (2) The parks located here are relatively smaller than in the other two ecozones.

Table 6.6: Stored Carbon Density in Saskatchewan Provincial Parks

Ecozone	Density in tonnes C per ha
Boreal Plains	634
Boreal Shield	543
Prairies	68
Saskatchewan	489

Average storage of carbon in Saskatchewan Provincial Parks is estimated to be 489 tonnes per ha. (Table 6.6). Parks located in the Prairies ecozone store the lowest amount of carbon (estimated at 68 tonnes per hectare), whereas those located in the northern part of the province (such as the Boreal Plains and Boreal Shield ecozones) provide a higher level of carbon storage in various pools (plant biomass and soils mostly).

Relative distribution of the type of carbon storage in various Saskatchewan Provincial Parks is shown in Figure 6.5. Here, almost three-quarters of the total carbon stored is found in peatlands, while the plant biomass stores only 5% of the total carbon in these parks.

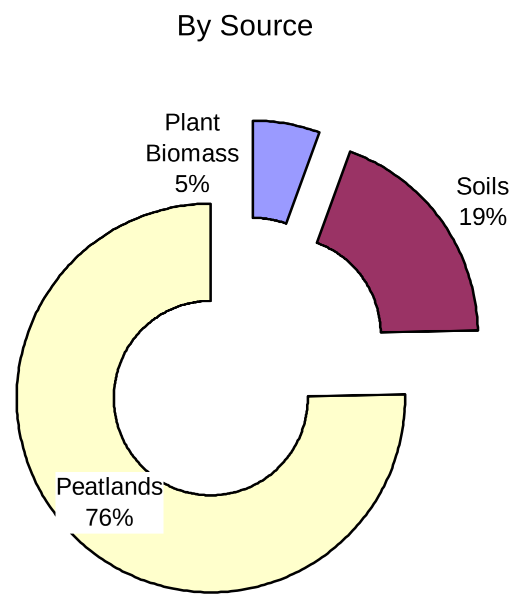

Figure 6.5: Distribution of Carbon Storage in Provincial Parks by Type

6.3 Economic Value of Stored Carbon

6.3.1 Synthesis on Economic Value of Carbon

Based on the review of existing studies on the value of carbon, the conclusion that such values are highly variable is obvious. In Chapter 5, seven different approaches to valuation were reviewed. For two of them – Avoided Damage method, and the Willingness-to-pay using contingency valuation method, did not lead to any empirical studies. Thus, these methods were not used any further.

The other five methods produced a range of values that was wide, as shown in Table 6.7, ranging anywhere from a low of $Cdn 8 to a high of $Cdn 982 per tonne of carbon in 2000 dollars.

Table 6.7: Estimated Value of Carbon Using Different Method of Valuation

Method	Value of Carbon in $Cdn per tonne
Alternative Cost Method	15 – 645
Marginal Social Opportunity Cost Method	982
Quasi- Market Method	15 – 55
Replacement Cost Method	2 – 104
Substitute Cost Method	8 - 375

To choose a single value of carbon stored in a protected area, such as National or a Provincial Park, based on this evidence turned out to be a challenge. Many of these methods are still experimental in nature; their associated technology is constantly changing and therefore, it is conceivable that their respective costs would come down in the future. Second problem faced was that some of these methods would sequester only a smaller quantity of carbon, and may not be that well suited to value a larger level of carbon sequestration, as provided by the protected areas.

To overcome the above considerations, alternative values of carbon were estimated. The median value of carbon was based on the Substitute cost and Replacement cost methods. For the replacement cost method, it was assumed that new afforestation on marginal agricultural lands would be a logical replacement. This cost was assumed to be $17.50 per tonne of carbon sequestered.

A second median value of carbon was selected using the substitute cost method. As a close substitute to the protected areas, it was assumed that reforestation could be undertaken in various parts of Canada. Furthermore, it was assumed that 70% of this area would be natural regeneration, and the remaining 30% artificial (tree farming or similar) regeneration. The cost per tonne of carbon sequestered under natural regeneration is estimated at $12.50, whereas for the artificial reforestation, doubling of the cost is typical. Therefore, a cost of $25 per tonne was assumed for the latter type of forests. Weighing these by their respective areas, an average value of $16.25 per tonne was arrived at.

Although these costs are realistic of the options that would likely be undertaken to replace the carbon storage in protected areas, society may place alternate value on the climate change and it effects. To reflect this, two other estimates of values – low value and high value were selected. The low value was based on the Sinks Option Report, where a cost per tonne of carbon sequestered is estimated to $2.30 in eastern Canada, $2.40 in British Columbia, and $3.00 in the Prairies. These values were used to estimate total value of carbon stored in the National and Provincial Parks.

On the higher end of the scale, a value of $500 per tonne of carbon was used. This value was guided by the cost of sequestration using the alternative cost method, as well as by the marginal social opportunity cost method.

Valuation of stored carbon was done for each park. Details on individual National Parks are presented in Appendix D, whereas those for the Saskatchewan Provincial Parks in Appendix E.

6.3.2 Economic Value of Stored Carbon in Canada's National Parks

Under the two median values of carbon, value of National Parks for carbon sequestration is estimated between $72 and $78 billion. A large portion of this value is in terms of soil carbon, as expected from the estimated level of carbon stored. Distribution of this total economic value by provinces and territories is shown in Table 6.8 and that by ecozones in Table 6.9.

Relative distribution over the location of park either based on province (or territory) or ecozone provides the same insights as provided by the level of carbon sequestration. National Parks located in Alberta and Northwest Territories are valued at respectively, $27.5 and $19.4 billion. Parks located in Maritimes region of Canada have much smaller value, estimated to be less than $1.5 billion.

On average, it is estimated the National Park lands are worth $2,967 per ha, ranging from a low of $202 in the Yukon Territory, to a high $8,413 per ha in Saskatchewan. Similarly on an ecozone basis, National Park land in the Boreal Shield and the Taiga Plains are estimated to have a higher value (Table 6.9).

6.3.3 Saskatchewan Provincial Parks

Saskatchewan Provincial Parks stored a total of $8.5 billion worth of carbon in various biomasses – plants, and soils. Much of this carbon was in the Boreal Shield and the Boreal Plain ecozones. Value of carbon on a per hectare basis is estimated at $8,556, which is much higher than that estimated for the National Parks (Table 6.10). The primary reason of this is the location of these parks, and their respective land use. Many of these parks are located in the Boreal Plains and in the Boreal Shield, where peatlands are more common, and the plant biomass is dense (forestlands vs. grasslands).

Table 6.8: Estimated Economic Value of Stored Carbon Levels in Canadian National Parks, by Province

Province	**Value using Median Value 1 Mill. $**	**Value using Median Value 2 Mill. $**	**Value per ha in $ (Median Value 1)**
British Columbia	10,718	9,952	5,525
Manitoba	3,171	2,944	2,194
New Brunswick	99	92	2,216
Newfoundland	1,145	1,063	5,196
Northwest Territories	19,403	18,017	4,591
Nova Scotia	307	285	2,268
Nunavut	8,628	8,012	1,082
Ontario	453	421	2,143
Prince Edward Island	4	4	1,652
Quebec	1,367	1,269	3,075
Saskatchewan	4,022	3,764	8,413
Yukon	728	676	202
Canada	**77,556**	**72,016**	**2,967**

Table 6.9: Estimated Economic Value of Stored Carbon Levels in Canadian National Parks, by Ecozones

Ecozone	Value using Median Value 1 Mill. $	Value using Median Value 2 Mill. $	Value per ha in $ (Median Value 1)
Atlantic Maritimes	1,338	1,242	3,164
Arctic Cordillera	4,705	4,369	985
Boreal Cordillera	172	160	130
Boreal Plains	31,358	29,119	7,312
Boreal Shield	1,982	1,841	3,238
Hudson Plains	460	427	401
Mixedwood Plains	55	51	2,303
Montane Cordillera	3,888	3,610	1,734
Northern Arctic	8,196	7,611	1,855
Pacific Maritimes	9,770	9,072	4,105
Prairies	58	54	638
Southern Arctic	5,499	5,106	3,365
Taiga / Tundra	2,173	2,018	1,319
Taiga Plains	7,898	7,334	6,963
Canada	**77,556**	**72,016**	**2,967**

Table 6.10: Estimated Economic Value of Stored Carbon Levels in Saskatchewan Provincial Parks, by Ecozones

Ecozone	Value using Median Value 1 Mill. $	Value using Median Value 2 Mill. $	Value per ha in $ (Median Value 1)
Boreal Plain	3,334	3,096	11,099
Boreal Shield	5,106	4,742	8,259
Prairies	93	87	1,182
Saskatchewan	**8,534**	**7,925**	**8,556**

6.4 Sensitivity Analysis of Economic Value of Stored Carbon to Value Estimates

6.4.1 National Parks

Depending upon the assumption of societal value of carbon one chooses, value of protected areas carbon sequestration function can vary significantly. This is shown in Tables 6.11 and 6.12 for the National Parks (classified by province and territories, and by ecozones).

Table 6.11: Estimated Economic Value of Total Stored Carbon Levels in Canadian National Parks, by Province, Alternative Values of Carbon

Province	Valued in Mill. $		Average Value per Ha $	
	Low Price Scenario	High Price Scenario	Low Price Scenario	High Price Scenario
Alberta	4,716	786,005	872	145,395
British Columbia	1,470	306,224	758	157,856
Manitoba	544	90,599	376	62,707
New Brunswick	13	2,825	291	63,309
Newfoundland	150	32,718	683	148,446
Northwest Territories	2,661	554,371	630	131,164
Nova Scotia	40	8,759	298	64,797
Nunavut	1,183	246,517	148	30,925
Ontario	60	12,549	282	61,217
Prince Edward Island	1	127	217	47,203
Quebec	180	39,069	404	87,853
Saskatchewan	689	114,908	1,442	240,359
Yukon	100	20,818	28	5,765
Canada	**11,806**	**2,215,890**	**451**	**84,781**

Table 6.12: Estimated Economic Value of Stored Carbon Levels in Canadian National Parks, by Ecozones

Province	Valued in Million $		Average Value per Ha $	
	Low Price Scenario	High Price Scenario	Low Price Scenario	High Price Scenario
Atlantic Maritimes	176	38,227	416	90395
Arctic Cordillera	645	134,440	135	28,161
Boreal Cordillera	24	4,920	18	3,725
Boreal Plains	5,376	895,967	1,254	208,933
Boreal Shield	261	56,656	426	92,502
Hudson Plains	79	13,148	69	13,148
Mixedwood Plains	7	1,564	303	1,564
Montane Cordillera	630	111,104	281	111,104
Northern Arctic	1,124	234,182	254	53,013
Pacific Maritimes	1,340	279,145	563	117,286
Prairies	10	1,652	109	18,231
Southern Arctic	754	157,117	462	96,155
Taiga / Tundra	298	62,101	181	37,688
Taiga Plains	1,083	225,666	955	198,947
Canada	**11,807**	**2,215,890**	**452**	**84,781**

Under the price of $500 per tonne of carbon stored, National Parks are very valuable to Canadian society. Their value can be as high as $2.2 trillion. However, on the low end of the scale is value of $12 billion. Somewhere within this range lies the true value of carbon sequestration function provided by the National Parks. On a per hectare basis, the range in the value is from $452 to $84,781. National Parks located in the western and northern parts of Canada command a higher per hectare value.

6.4.2 Saskatchewan Provincial Parks

For the Saskatchewan Provincial Parks, the range in the economic value of carbon sequestration function is estimated to be from $1.5 to $244 billion. The value of the parks on a per hectare basis could be as low as $203 for the Prairies ecozone to a high of $317,124 for the Boreal Plains ecozone. Details are shown in Table 6.13.

6.5 Relative significance of Protected Areas' Carbon Storage

Apps (1998) reported that the Canadian forests stored a total of 215 gigatonnes of carbon. This was distributed as: 14 gigatonnes of carbon in the plant biomass; 71 gigatonnes of carbon in the soils, and over 100 gigatonnes in the peatlands. According to the results of this study, the National Parks and National Park reserves of Canada, together with the

Table 6.13: Estimated Economic Value of Stored Carbon Levels in Saskatchewan Provincial Parks, by Ecozones

Province	Valued in Million $		Average Value per Hectare in $	
	Low Price Scenario	High Price Scenario	Low Price Scenario	High Price Scenario
Boreal Plains	572	95,270	1,903	317,124
Boreal Shield	875	145,900	1,416	235,971
Prairies	16	2,669	203	33,924
Saskatchewan	**1,463**	**243,840**	**1,467**	**244,477**

Saskatchewan Provincial Parks, stored 0.39 gigatonnes of carbon in the vegetation, 2.15 gigatonne of carbon in the soil, and 2.38 gigatonnes of carbon in the peatlands. Although the data source and methodology used in this Report may be different from the carbon budgets prepared for the Canadian forests, the carbon sequestered in the studied parks represent approximately 2.28% of the total carbon stored in the Canadian forests.

The contribution of the vegetation in the parks seems to play a little role in the total amount of carbon stored in these parks. It appears that the soil pool is a more important store of carbon in these areas.

In terms of value of these protected areas for carbon sequestration, it can be concluded that these areas are highly variable. Using median prices, value of $ 80 - 86 billion cannot be totally ignored. Since the societal value of carbon can be so variable, a range was estimated which suggests that these areas could be worth between $13 to $2,460 billion.

Chapter 7

SUMMARY AND CONCLUSIONS

7.1 Summary

The primary objective of this study was to place an economic value on one of the several functions (service) provided by a natural ecosystem within a protected area. The focus of this study was on the carbon sequestration. One of the major consideration involved in the development of methodology for this study was the use of secondary data.

The carbon sequestration function has come into some prominence since the release of the works by the Intergovernmental Panel on Climate Change (IPCC). This information became the basis for organizing a Green Summit in Rio de Janeiro in December of 1992. At that point, a major development took place. About 167 countries signed on a Framework Convention on Climate Change. Among other things, these signatories agree to develop greenhouse gas emissions inventory resulting from various anthropogenic activities. Emissions of greenhouse gases are estimated, in these inventories as net emissions. In other words, these are the levels of greenhouse gases emitted to atmosphere less any amount sequestered. Carbon sequestration therefore, is a major consideration in this context.

Natural ecosystems provide several benefits to the society. Some of these are commercial goods. These benefits, by virtue of the fact, being received by the society directly, are recognized by decision makers and by the public at large. However, in addition to the commercial goods, many ecosystems provide, what is known as the ecosystem services. Some of these services are critical for the attainment of economic activities and to a certain extent, for the survival of the human kind. Carbon sequestration is one such function that is provided by the protected areas world over.

The Federal-Provincial Parks Council of Canada is engaged in a documentation of the total value of protected areas in Canada. Since carbon sequestration is an important function, and since economic valuation of ecosystem services is replete with problems, a study of this subject was sponsored.

The primary objective of this study were:

- To determine the total stock of carbon stored (sequestered) in the protected areas of Canada, using secondary data sources and models;
- To review various approaches to economic valuation of carbon sequestration; and,
- To estimate the economic value of protected areas for carbon sequestration.

The protected areas selected for further investigation in this study were all the National Parks (including National Park Reserves) and all Saskatchewan Provincial Parks.

The study was divided into two distinct phases: One, estimation of the physical quantity of carbon being stored in the study parks; and Two, economic valuation of the stored carbon.

Since measurement of carbon stock in National and Provincial Parks is almost non-existent, an alternative way of estimating it had to be devised. A survey of various models used for the estimation of carbon sequestration lead to the selection of the Carbon Budget Model of the Canadian Forestry Service. This model included some cells for the National and Provincial

Parks in Canada. However, its coverage was not comprehensive, and depended on the provincial and territorial inventories of the forested areas. For the non-forested regions, unfortunately no inventory could be found for the southern parks. However, since this information was the best available, it was retained for estimation.

Total amount of carbon sequestered in a protected area is affected by three things:

4. Physical area of the entity;
5. Nature of the land cover; and
6. Location of the entity in terms of ecoregion.

The last two factors affect the level or density of carbon stored.

Carbon is stored in two major pools: plant biomass pool and the soil pool. The former includes aboveground and root biomass, and the latter one includes peatlands and other soils. Level of carbon density in these pools varies by type of vegetation – forestlands, grasslands, non-forest or grasslands. Within the forests, the carbon density is affected by the type of forest: coniferous or broadleaf.

Since land cover for various National and Provincial Parks was not available, a survey of these areas was undertaken using a mail-in questionnaire. Response rate was somewhat poor. Of the 39 National parks, 17 responded to the survey, where as out of 30 Provincial Parks, only nine responded to the survey. This made the response rate for the survey at 37.8%. Response of the most northerly parks was very poor. As a substitute, data on land cover was obtained from Parks Canada. Secondary data on the level of stored carbon were obtained from a study for the state of Alaska.

Failing to obtain desired information from the Carbon Budget Model and the survey, the following methodology for the estimation of carbon stocks was adopted: If there was information available both in the Carbon Budget Model and through the survey, this information was used. If these information were not available, data for the other parks within the same ecozone were used. If such parks were not present, data were obtained from the adjoining ecozone(s) or provinces. Failing all the above options, information was obtained from published sources.

Economic value of carbon was conceived in terms of its value in stopping the detrimental effects of climate change. It was based on a review of the literature. A conceptual framework for valuation was designed. Various studies were divided into one of the following seven types:

1. Avoided damage method
2. Contingent valuation method
3. Alternative cost method
4. Marginal social opportunity cost method
5. Market method (or quasi-market method)
6. Replacement cost method, and
7. Substitute cost method.

No studies were found for the first two methods. For the rest, studies have been conducted for North America. Results vary partly because these studies apply different methodologies, estimated for different units of measurement, were done for a different period of time, and were in different currencies. These limitations were partially overcome by converting their results into Canadian dollars per tonne in 2000 dollars.

Average value of carbon in this study was based on the replacement and substitute cost method. Forests were taken as the most logical replacement for carbon sequestration. Reforestation was assumed to be the vehicle chosen. A cost of $16.25 per tonne was estimated for this option. The next best option was that of converting the marginal agricultural lands into forests through afforestation. This option was costed at $17.50 per tonne.

In addition to the median values, carbon sequestered was evaluated at a low price scenario -- $2.3 to $3.00 per tones and under a high price scenario -- $500 per tonne.

7.2 Major Conclusions

One of the inescapable conclusion of this study is that the protected areas in Canada play a significant role in terms of carbon sequestration and its value to Canadians. Major conclusions of the study are as follows:

1. The 39 National Parks in Canada have sequestered a total of little over four gigatonnes (4.43 gigatonnes) of carbon in various pools.

2. Soils and peatlands in various national parks are the most important pool of carbon, storing slightly over 90% of the total carbon stored in all the National Parks.

3. Although plant biomass does store carbon, its relative share is only 8.2% of the total. This carbon pool is estimated to have only 365 megatonnes of carbon in trees, understory as well as in the root zone.
4. Average density of carbon in National parks is very high at 170 tonnes per ha. However, a wide range in this level of carbon was estimated. This range was between 7.5 to 584.6 tonnes per hectare. The northernmost National Parks are relatively rich in this resource.

5. Total economic value of stored carbon in the National Parks is estimated to be $72 - 78 billion. However, this value could range between $11 to $2,215 billion, depending upon society's valuation of carbon sequestration function of the protected areas.

6. Boreal Shield and Taiga Plains ecozones have a relatively higher value of carbon stored per hectare.

7. Provincial Parks do store carbon but in smaller quantities. Here, the total amount is 487 Mt, valued between $1.5 to $244 billion.

7.3 Limitations of the Study and Areas for Further Research

Much of this analysis is based on secondary information, and much of which is incomplete. In the future, attempts should be made to improve the physical database for National and Provincial Parks. These improvements would require first hand measurement of carbon stored in the soil, and a development of an improved inventory of the forestlands, and grassland ecosystems. More attention needs to be placed on the parks located in the northern ecozones.

The field data are needed for the type of vegetation cover (trees, shrubs and native grassland) and for both aboveground and underground biomass. Published information on the parks located in the Arctic Cordillera, Northern Arctic and Southern Arctic ecozones is relatively more deficient in this respect. The parks in these ecozones are in the province of Nunavut and in the Northwest Territories.

Proper accounting of peatlands is the other major deficiency in the data and information base required for such a study. The assumption that was made in this study was that peatlands in the parks are of the same proportion as the ecozone. This may have resulted in a possible double-counting of stored carbon pool. Field data are also needed for the average peatland carbon density in the grassland ecoclimatic province.

All parks are reserved lands, therefore harvesting is not permitted within the parks' boundaries. However, the incorporation of new lands to the parks' areas that used to be harvested is somewhat frequent. Bruce Peninsula National Park, according to the questionnaire response, has 30% of its land acquired, of which 22% is currently harvested (Parks Canada, 2000). Although in this study, the current area of the park was used (which did not include the area to be acquired), this category of land could be present in other parks and not noticed in this study.

During the review of secondary data, very few case studies were encountered. The only National Park for which a case study existed was the Pukaskwa National Park. However, here the results based on this study and those from the case study are different. In this study, Pukaskwa National Park was estimated to have contributed 22.7 Mt of carbon to the total carbon pool of the Canadian National Parks. The results found in the BOPAS (Apps and Price, 1995) accounted for eight Mt of carbon stored in this park. The BOPAS model did not consider soil, peatlands, roots and shrubs, which were taken in account in this study. This may explain the different values. Similarly, the aboveground carbon (for trees and shrubs) density of this park in this Report of 1.4 kg/m^2 was lower than the aboveground carbon (for trees) density for this park in BOPAS for 1983 (3.62 kg /m^2). The same average by Kurz et al. (1992) for the eastern region of Canadian boreal forests was 2.7 kg/m^2. It is possible that different data and methodologies may have resulted in different averages. Nevertheless, it's also possible that the methodology used in this Report underestimates the aboveground biomass of trees. More case studies of this type would be very useful.

Collection of primary data from the Park Managers (or vegetation managers) was very helpful. However, such efforts require time and resources. Time is needed to compile more information and data from these agencies, and to break the data into more details to improve the estimates.

The knowledge is needed in the processes that take part in the carbon sequestration and in their interactions, as well as in technology to adapt the field data available to this study. Studies involving field data collection in the parks and models of carbon cycles either developed or tested in the parks' areas that take in account diseases and fire should be undertaken. In addition, studies that compile information related to the carbon cycle components should also be developed. Studies for the conversion factors of volume:biomass and biomass:carbon, especially for grasslands, are needed. In a national level, compilation of information by ecoclimatic province and by ecozone would be very helpful.

Finally, this study is a pilot study of the type of methodology that needs to be followed in order to develop an estimate of the carbon pool for the protected areas in Canada. There may exist other categories of protected areas in various regions of Canada that could not be included in this study. In future studies, the marine conservation parks and also other provincial parks and protected areas should be analyzed and incorporated to studies of carbon sequestration. Extension of the methodology to these regions would also help develop a more comprehensive role of the protected areas in Canada for carbon sequestration.

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Appendix A

QUESTIONNAIRE USED FOR SURVEY OF NATIONAL AND PROVINCIAL PARKS

Dear Sir/Madam:

Re: SURVEY OF NATIONAL PARKS FOR CARBON SEQUESTRATION

We have been contracted by the Federal Provincial Parks Council of Canada to undertake a study of value of carbon sequestration in Protected Areas in Canada. We have chosen to limit our investigation to National Parks of Canada. The project is under the direct of Dr. Suren Kulshreshtha (Department of Agricultural economics, University of Saskatchewan), and Dr. Mark Johnston (Forest Ecologist, Forest Ecosystem Branch, Saskatchewan Environmental and Resource Management, Prince Albert), with Silvia Lac and Chris Kinar as Research Assistants. During the past month or so, we have made every attempt to secure secondary data from various internet and published sources available to us on National Parks. However, these sources have left some critical gaps in our database. These are listed below.

Although we realize that it is a major imposition on your time, we do not appear to have any other choice but to contact you on these matters. It would be a great help if you could take a few moments of time, from your busy schedule, and answer the questions below. If you have a Vegetation Manager, he / she would be a little more intimately familiar with this set of information.

We thank you very much, in advance, for your kind cooperation in this very important project.

Suren Kulshreshtha
Mark Johnston
Silvia Lac
Chris Kinar

QUESTIONNAIRE

1. What's the total area of the park? (ha or km^2)
   ____

2. What ecozones are represented in the park? ______________________________

   If more than one ecozones, please provide us with an approximate distribution by each ecozone (ha, km^2 or % of the total area of the park):

   ____________ ________________ ___________________

3. What is the nature of land cover distribution for the park? (ha, km^2 or % of the total area of the park). *Please circle or highlight the unit that you used*.
   Forest ____________ Grasslands _________________
   Peatlands* ____________ Water Bodies _______________
   Other ____________

* (all lands containing peat thicker than 50 cm)

4. Of the total forested area in the Park, how much of that is under Coniferous and Broadleaf type trees? (ha, km^2 or % of the total area of the park). *Please circle or highlight the unit used.*

   Coniferous _____________ Broadleaf ___________________

5. Has there been a biomass inventory developed for the park? If yes, how can we obtain a copy?

____
____

6. Is timber harvesting permitted in your park? ________________

7. If yes, In what would be approximate area that this practice would apply to? (ha, km^2 or % of the total area of the park).: *Please circle or highlight the unit used.*

Coniferous ____
Broadleaf ____

7. Is there any other information you find useful for us to have? This information could be a web site address, a document or some other information about the park itself.

____
____
____

Appendix B

ANNOTATED BIBLIOGRAPHY OF ECONOMIC VALUE OF CARBON SEQUESTRATION

Adams, R. M., Adams, D. M., Callaway, J. M., Chang, C-C., McCarl, B. A. 1993. Sequestering carbon on agricultural land: Social cost and impacts on timber markets. *Contemporary Policy Issues*, 11: 76-87.

This paper examines social costs of sequestering carbon in tree plantations on US agricultural land and investigates harvesting effects on timber prices and on private timber producer's welfare. The analysis links a model of the US agricultural sector that includes the land base in major production areas with a model of the US softwood economy. The models estimate the price and welfare effects of alternative carbon sequestration goals.

The analysis generates a supply curve for sequestered carbon by modifying the Agricultural Sector Model to simulate competition between carbon sequestration and traditional crop and livestock activities for available land under different levels of carbon sequestration targets, ranging from 0 to 700 million short tons per year. Table B.1 presents estimates for the four carbon goals with respect to location of carbon fixing activities and the use of cropland versus pastureland within each region.

Table B.1: Marginal cost ($/ton) and Agricultural Acreage to Sequester carbon via tree plantations

Evaluation	Total Carbon Sequestered (10000000 short tons Carbon)							
	140		280		420		700	
	$/ton	Acres	$/ton	Acres	$/ton	Acres	$/ton	Acres
Case 1	18.31	49.62	25.19	103.79	34.17	162.35	55.01	274.44
Case 2	18.5	49.36	25.11	103.21	37.21	157.92	95.06	270.83
Case 3	18.5	49.36	25.11	103.18	38.18	157.78	200.45	267.63
Moulton & Richards	16.57	70.9	20.69	138.4	23.24	197.6	34.73	303.4

Case 1: Restricts tree planting activities to regions where rainfall exceeds 18 inches per year.
Case 2: Same as case 1 but also restricts pastureland to not more than 50% of total acreage in tree plantations.
Case 3: Same as case 1 but removes Southern Plains from solution

Moulton & Richards are from Moulton and Richards (1990)

All acres are 10^6.

The marginal costs per ton increase as the carbon fixing goals increase, from a low of about $18 per ton for 140 million tons to approximately $55 per ton for a goal of 700 million tons. The rising costs per ton reflect rising opportunity costs of agricultural lands as farmers divert more land and higher quality land from crop growing to tree planting.

Bergman, P. B., Winter, E. M., Chen, Z-Y. 1997. Disposal of power plant CO_2 in depleted oil and gas reservoirs in Texas. *Energy Conversion and Management*, 38(Suppl.): S211-S216.

This study describes preliminary evaluations of technical, economic, and regulatory factors limiting CO_2 disposal in on-shore oil and gas reservoirs in Texas.

Oil reservoirs are economically preferred to gas reservoirs since operators are willing to buy the CO_2 for enhanced oil recovery. One economic limitation for both oil and gas reservoir disposal is distance from power plants to disposal sites and the associated cost of transporting the CO_2 by pipeline. Pipeline costs, based on one published cost estimate are about $0.02/mile/ton.

Based on published data, the cost of CO_2 capture by retrofitting an amine scrubber to an existing power plant is $35 to $71/ton CO_2 captured[36] (refer to Table B.2). These costs are based on the CO_2 captured from power plant flue gases. Since CO_2 capture requires a significant expenditure of energy, with the production of additional CO_2 if fossil fuels are used for power generation, not all of the CO_2 captured is CO_2 avoided, that is, the original amount of CO_2 that would have been emitted into the atmosphere without CO_2 capture. According to an estimate for a pulverized coal power plant, a 35% reduction in electrical power output can be expected when the plant is retrofitted for CO_2 capture and disposal. Therefore, the total CO_2 captured is greater than the avoided CO_2 by a factor of approximately 1.5. A cost of $35/ton of CO_2 captured translate into $53/ton of CO_2 avoided.

Table B.2: Costs of Retrofitting for CO_2 Capture

	Coal	Broiler	Gas turbine	Plant
	Food Grade (liquid)	**Chemical Grade (gaseous)**	**Food Grade (liquid)**	**Chemical Grade (gaseous)**
Cents/kWh	6.2	3.9	4.1	2.9
$/ton CO2	$54	$35	$71	$52

The cost of capturing CO_2 from a gas plant is higher than from a coal boiler because of the lower concentration of CO_2 in the flue gas from gas turbines. The cost of removing a pound of CO_2 from a gas turbine will be significantly higher than from coal boilers because a much larger volume of gas must be processed, making the equipment larger and more expensive to operate. However, less CO_2 is given off per unit of energy in a gas turbine plant than in a coal boiler. The net result is that, on a basis of a unit CO_2 removed ($/ton CO_2), it is more expensive to capture CO_2 from a gas turbine power plant than from a coal fired plant. Based on the values in Table B.2 and $15/ton for liquefiction and disposal, the cost of CO_2 capture and disposal from a coal plant would be approximately $50/ton and from a gas turbine plant approximately $65/ton CO_2. Avoided costs would be $75 and $100/ton CO_2, respectively. On the basis of a unit of electricity generated (cents/kWh), the lower CO_2 production in the gas turbine plant more than offsets the higher cost of CO_2 capture.

Disposal in oil reservoirs would cost about $10-$15/ton CO_2 captured ($60-$83/ton CO_2 avoided). CO_2 capture in new, integrated plants, based on advanced technologies, will be significantly less expensive, estimated in the range of $15-$25/ton CO_2 captured. This would be the cost for CO_2 disposal in gas reservoirs. The net cost of disposal in oil reservoirs would be $5-$15/ton CO_2 captured Table B.3).

Table B.3: CO_2 Disposal Costs

$/ton CO2captured	**Current Retrofit Technology**		**Future Integrated Technologies**
	Coal-Fired Plant	**Gas Turbine Plant**	
Into Oil Reserves	$40	$55	$5-$15
Into Gas Reserviors	$50	$65	$15-$25

Note: Transportation (pipeline) costs not included.

[36] ABB Lummas Crest cited by Bergman et al., 1997.

Dixon, R. K., Winjum, J. K., Andrasko, K. J., Lee, J. L., Schroeder, P. E. 1994. Integrated land-use systems: Assessment of promising agroforest and alternative land-use practices to enhance carbon conservation and sequestration. *Climatic Change* 27: 71-92.

The paper was written in the early 1990's in the US. Agroforestry systems, alternative land-use systems, and soil management were emphasized in this assessment. Economic data are reported in 1990 US dollars. The net interest rate used was 5%. The cost per Mg C was calculated as the present value of all establishment costs over a 50 year period divided by mean C storage. This assessment revealed a range of land use practices in 94 nations, which could be used to conserve and sequester C in the terrestrial biosphere. The author's found that the initial costs of establishing management practices to conserve and sequester C in agroforest systems ranged from $1 - $69/Mg C with a median value of approximately $13/Mg C. The mean initial cost of soil rehabilitation and revegetation ranges from $500-$3000/ha, for the nations surveyed. Natural regeneration of woody vegetation or agro-afforestation establishment costs on non-degraded soils were less than $1000/ha in temperate and tropical regions.

Dore, M. and Johnston, M., 2001. The carbon cycle and the value of Canadian forests. *Journal of Sustainable Forestry.* 12(1 & 2): 123-151

The paper is based on an analysis for the year 1995, and pertains to Canadian forests. The authors present three different models to determine the value of forests, one being the ARIMA model. With this model, they find the marginal social opportunity cost value of a hectare of forests to be between $289.8 to $412.4, with $351.1 as an estimate. These are found using a shadow price between 1.17 and 1.33, with an estimate of 1.25. These values are in 1986 Canadian constant dollars.

Freund, P. and Ormerod, W. G. 1997. Progress toward storage of carbon dioxide. *Energy Conversion and Management*, 38(suppl.): S199-S204.

A summary of the recent progress in CO_2 storage is giving, including an overview of work on aquifer storage, ocean storage, and the storage role of forests. The paper discusses the external influences on decisions about CO_2 storage, the opportunities for further research to progress technologies, and future possibilities for practical work on storage of CO_2.

Capture and storage of CO_2 has been seriously considered as an option for reducing greenhouse gas emissions only in recent years. Because of the large quantities that need to be stored, the options most often discussed are those using natural reservoirs underground or in the deep ocean. CO_2 could be stored on land, either through the natural growth of plants, or in artificial store.

Use of disused oil or gas fields to store CO_2 is attractive, not only because of the conceptual tidiness of using space left b removal of hydrocarbons, but also because the knowledge gained about such fields from their previous use gives confidence in their use for storing CO_2. The global capacity for storage in disused gas fields could be as much as 140Gt C, and in disused oil fields 40Gt C. A hypothetical scheme for storage in an abandoned on-shore gas field has been costed at $8.2/tC[37].

Aquifers are another possibility for underground storage. A hypothetical scheme for injection into an on-shore aquifer indicated costs of about $4.7/tC[38].

[37] IEA GHG, 1994. cited by Freund and Ormerod, 1997.
[38] IEA GHG, 1994. cited by Freund and Ormerod, 1997.

The capacity of oceans for storing CO_2 has been estimated to be upwards of 1000 Gt C[39]. Injecting dense-phase CO_2 into deep water could delay return to the atmosphere by several hundred years. Depth of discharge and length of pipeline are two of the key influences on the cost of ocean storage, which has been estimated at $4.1/tC for shallow depths, rising to $21/tC for deeper schemes[40].

Natural terrestrial carbon stores absorbs CO_2 from the atmosphere using the energy in sunlight to drive the photosynthesis process. Estimated costs can be as low $1/tC, but depends on the cost of land. Another terrestrial-based concept envisages use of thermally insulated artificial stores containing solid CO_2[41]. However, a store with capacity of $10^8 m^3$ would cost around $500/tC[42].

For most of these options, the cost of storing a tonne of carbon is little less than the cost of capturing it.

Gunter, W. D., Gentzis, T., Rottenfusser, B. A., Richardson, R. J. H. 1997. Deep coalbed methane in Alberta, Canada: A fuel resource with the potential of zero greenhouse gas emissions*. Energy Conversion and Management*, 38(suppl.): S217-S222.

The subject of the paper is focused on the production of coalbed methane by enhanced recovery techniques utilizing injection of CO_2.

When produced, coalbed methane is commonly recovered by means of reservoir pressure depletion. This method is not efficient, as reduction in reservoir pressure deprives the fluids of the energy necessary to flow to the wellbore. Due to the presence of a gas phase, methane gas recovery can be enhanced either reducing the partial pressure of CH_4 through the introduction of a lower adsorbing gas such as N_2[43] or displacement by the introduction of a higher adsorbing gas such as CO_2[44]. Injecting gas at the start of the recovery process not only allows reservoir pressure to be maintained but also has the potential to produce methane gas quickly. A two-step injection process involving a strongly-absorbable fluid (CO_2) followed by a weakly-absorbable gas (N_2) can be used to stimulate the release of residual methane from the coal bed. The CO_2 displaces and desorbs the CH_4, while the N_2 forces the excess CO_2 to move through the coal bed.

The authors believe that the development of CO_2 EGR technology will lead to a synergy between an increased supply of fossil fuel and decreased global warming. Recovery of coalbed methane will lead to increased total gas reserves. Utilization of this coalbed methane in fuelling power plants and disposal of the waste CO_2 in deep coal reservoirs which act as a huge geological sink leads to reduction in emitted CO_2.

Holloway, S. 1997. An overview of the underground disposal of Carbon Dioxide. *Energy Conversion and Management* 38 Suppl.: S193-S198.

The underground disposal of industrial quantities of CO_2 is entirely feasible. The fundamental reason for considering CO_2 disposal underground is that it could lessen the environmental damage caused to the planet by disposing of all anthropogenic CO_2 into the atmosphere.

[39] IEA GHG, 1994. cited by Freund and Ormerod, 1997.
[40] IEA GHG, 1994. cited by Freund and Ormerod, 1997.
[41] Seifritz, 1992. cited by Freund and Ormerod, 1997.
[42] IEA GHG, 1994. cited by Freund and Ormerod, 1997.
[43] Puri and Yee, 1990. cited by Gunter et al., 1997.
[44] Arrie et al., 1992. cited by Gunter et al., 1997.

The main obstacle to the underground disposal of CO_2 from fossil fuel fired power plants is its high cost. Most of the cost is incurred by the necessity to separate the CO_2 from, or concentrate it in, the flue gas. This cost varies widely, depending on the type of power plant and separation technology considered, but is in the range of $27-$65 per tonne CO_2 avoided[45]. A realistic cost of $40 per tonne of CO_2 avoided would increase the cost of electricity generation by at least $0.02/kWh[46]. Total CO_2 underground disposal costs (including capture, transport, and injection underground) have been estimated at around $52/tonne CO_2 in Alberta, Canada.

There are two main problems associated with estimating the global underground storage capacity for CO_2. Firstly, storage concepts for CO_2 have evolved over the last few years and, secondly, little is known about the basic parameters (e.g. distribution, thickness, porosity, permeability) of deep reservoirs in the subsurface outside of the major petroleum provinces.

Luciuk, G. M., Bonneau, M. A., Boyle, D. M., Viberg, E. (Undated). Carbon sequestration– Additional environmental benefits of forages in the PFRA Permanent Cover Program. Regina: Prairie Farm Rehabilitation Administration.

The paper evaluates the carbon sequestration potentials of the 522 thousand hectares converted from annual cultivation to forages under the Prairie Farm Rehabilitation Administration (PFRA) Permanent Cover Program (PCP).

The PCP was implemented primarily for soil conservation and grain program expenditure reduction by the government. It was estimated that some 4.9 million hectares of marginal lands were used in annual cultivation where a more environmentally sustainable management practice would be permanent cover.

Producers were first provided with a financial incentive to convert eligible lands from annual crops to perennial forage or tree cover. Farmers who signed a 10 or 21 year land use agreement received a one-time payment after cover was established.

There are 168 thousand hectare enrolled in PCP I and 354 thousand hectare in PCP II. This represents over 15 thousand contracts. The program cost to Canada totaled $74 million in payments for forage establishment and land use restrictions.

Three methodologies are used to estimate the potential of land in PCP to sequester carbon.

The first method assigns average native carbon and current carbon levels to each of the 15 thousand PCP sites. It is assumed that since approximately 5.4 millions tonnes of carbon have been lost during an assumed 80 years of cultivation, that with proper management this land has the potential to sequester at least this amount.

The second method is based on an estimation of native and current carbon levels, but by soil type and texture. Since each PCP parcel falls into one estimated soil type and texture, a total percentage loss of carbon on the PCP site can be estimated.

The third method is the use of the SLC Carbon Layer Table. This table has the SLC polygon broken down into a number of sub-regions. Using the ratios of soil type and texture to relate calculated current carbon levels to the native carbon, the amount of carbon lost by each PCP site is calculated.

[45] Doherty and Harrison, 1996. cited by Holloway, 1997.
[46] Riemer, 1996. cited by Holloway, 1997.

The results of these three methodologies are presented in the Table B.4.

Table B.4: Detailed Data on Carbon Loss on Croplands

Province	Hectare	Total Loss tonnes	Method I			Method II		Method III	
			Tonnes per ha	Kg/ year	% loss	% loss	Total Loss tonnes	Tonnes/ ha	% loss
Alberta	144,190	2,559,783	17.75	209	24.5	24.9	2,591,737	19.97	25.1
Sask.	179,837	2,872,194	15.97	188	23.6	22.5	2,015,500	11.21	22.2
Manitoba	54,935	1,453,453	26.46	311	25.5	26.0	1,116,877	20.33	25.6
TOTAL	324,028	5,431,976	18.20	214	24.3	23.9	5,740,422	15.15	23.9

The results of the three methodologies show that the potential of the PCP land to sequester carbon to be between 5.4 and 5.7 million tonnes of carbon. PCP converted 522 000 hectares, leaving an estimated 4.4 million hectares of marginal land currently in annual cultivation that if converted to permanent cover could potentially sequester an additional 50 million tonnes of carbon.

Further incentives designed to promote land use conversion must consider carbon values, in addition to more immediate conservation benefits. The price range of $13.40 to $67 per ton of carbon results in PCP carbon sequestration ranging from $72-$362 million.

Parks, P. J., and Hardie, I. W. 1995. Least-cost forest carbon reserves: Cost-effective subsidies to convert marginal agricultural land to forests. *Land Economics*, 71(1): 122-136.

The paper uses supply schedules for forests planted on marginal agricultural lands to simulate a national carbon sequestration program. They find that a program similar to the CRP would sequester 48.6 million tons of carbon per year on 22.2 million acres. Costs would include $3700 million in land rental costs and forest establishment costs. Tons in this paper are short tons (2000 pounds). One short ton equals 0.9080 metric ton (1 metric ton equals 10^6g). The paper develops a model of long-run carbon supply from forest biomass grown on lands that have been planted to maximize profit.

The environmental goals of the CRP are to reduce wind and water erosion, reduce sedimentation, and to create better habitat for fish and wildlife through improved food and cover. The enrollment target is 40 million acres; of this the enrollment target for planting trees is 5 million acres. If lands are eligible for enrollment, a contract is negotiated that enrolls the land into the CRP for 10 years. The government makes annual rental payments to the landowners during this period. In their analysis, the authors use $3700 million as the present value of the budget for rental and establishment costs.

The results of simulation show that the program could subsidize the conversion of 8-20% of the eligible lands in a national pool. Average annual equivalent costs per acre range from $19.75/acre (when pasture is eligible) to $48.35/acre (when only cropland and potential cropland are eligible). The results suggest that carbon sequestration programs should select lands based on minimizing cost per ton selected. A program similar to the CRP would sequester an average of 48.6 million tons per year of carbon on 22.2 million acres.

Marginal sequestration costs increase slowly up to roughly 120 million tons, then increase sharply. The annual equivalents of these costs range from $4.19/ton to $82.49/ton.

Plantinga, A. 1997. The cost of carbon sequestration in forests: A positive analysis. *Critical Reviews in Environmental Science and Technology* 27(Special): S269-S277.

The paper was written in the mid 1990's in the US. In the paper, carbon cost schedules are derived using land use elasticities from an econometric analysis of forest and agricultural land use. The paper tries to indicate that normative analysis underestimates the true costs of C sequestration programs. Plantinga writes that the carbon cost estimates are based on the assumption that landowners will accept compensation for converting their land to forest. The cost of C sequestration may be determined by estimating how much the stumpage price must increase to induce landowners to convert a given amount of land to forest. A carbon sequestration program involving the conversion of 263 000 ha of land to forest in Southwestern Wisconsin is evaluated. The results of the paper show that when all 263 thousand ha are converted at a sequestration rate of 4.35 and an interest rate of 0.10, the annual carbon storage is approximately 1150 tons, while the marginal costs of the program range from $18 to $38/ton. At a sequestration rate of 5.56 and an interest rate of 0.04, the annual carbon storage is approximately 1465 tons, while the marginal costs ranged from approximately $6 to 13/ton. All marginal costs were measured in $US /short ton, and the annual carbon flows are measured in 1000 short tons per year.

Schroeder, P. E., Dixon, R. K., Winjum, J. K. 1993. Forest Management and agroforestry to sequester and conserve atmospheric carbon dioxide. *Unasylva 173*, 44:52-60.

This paper is a summary of the assessment by the Global Change Research Program of the United States Environmental Protection Agency (USEPA), in which the evaluation of forest establishment and management options to sequester carbon and reduce the accumulation of greenhouse gases in the atmosphere. The assessment focuses on 16 key countries, Canada being one of them.

Cost estimates were based on implementation cost per hectare for various forestry and agroforestry practices. The site-level cost of implementing promising carbon sequestration options was one of the primary objectives of the overall assessment. Implementation or initial costs of forest establishment and management generally appear to be lowest in boreal regions.

For the boreal forest system, natural regeneration and artificial reforestation could sequester carbon most sufficiently at a cost of $US 93 to $US 324/ha. At sequestration values of about 17t C/ha and 39t C/ha for a 50 year period, the initial costs for the two practices are $5($4-11) and $8($3-27)/t C, respectively.

A marginal cost analysis integrated data on carbon storage, establishment costs and land area. Forest management practices and their associated potential land areas were ranked in ascending order from the least to most expensive per tonne of stored carbon. This approach showed that the marginal cost of storing 45-65 gross tonnes (Gt) of carbon (1Gt = 10^9t) would be about $3/tC with a total cost of $135 000 million to $195 000 million. At more than 70 Gt C the marginal cost escalated sharply to over $100/tC. Storing 45-65 Gt C would require from 400 to 950 million hectares.

van Kooten, G. C. 1995. Climatic change and Canada's Boreal Forest: Socio-Economic issues and implications for land use. *Canadian journal of Agricultural Economics*, 43: 133-148.

This paper reviews the effect of climatic change and policies to sequester carbon on forest land use. It is argued that, from both an economic and social perspective, conversion of the southern boreal forest to grassland or agriculture might be a better policy.

In a review of carbon sequestration programs by the author, he finds that Dudek and LeBlanc (1990) considered offsetting new CO_2 emissions in the US by planting trees in the CRP at an estimated cost between $US 25 and $US 45 per tonne of carbon removed from the atmosphere. Moultons and Richards (1990) estimated costs of $US 18.50/Mg when 125Tg of carbon are to be sequestered annually. He cites Adam et., (1993), McCarl et al., (1993), and Adams and Hayes (1980) as estimating that the marginal costs of sequestering carbon rise from $US 18.50 to $US 60.00 per Mg for reductions in carbon release of 125 Tg and 640 Tg, respectively. By growing trees on agricultural land, total costs of reducing US carbon emissions by 2.5% were estimated to be $US 500 million per year, while they were $US 21 billion per year to reduce emissions by almost half.

Global warming is projected to have the greatest impact on northern latitudes, with Canada warming to a greater extent than the US. The cropping area in northern Manitoba will increase by almost 4.5 million hectares, while Saskatchewan and Alberta will increase by about 0.4 and 1.1 million hectares, respectively.

The paper also examines issues related to the economics of climatic change on forestry, giving particular consideration to the effect of carbon subsidies and taxes on management of boreal forests, adaptation versus avoidance, and socio-economic issues arising from forest land use changes.

van Kooten, G. C., Arthur, L. M., Wilson, W. R. 1992. Potential to sequester carbon in Canadian forests: Some economic considerations. *Canadian Public Policy*, 18(2): 127-138.

This paper examines the potential role of reforestation policies in reducing Canada's contribution to atmospheric CO_2. The results indicate sequestering carbon by reforestation of forestlands may be a cost-effective means for Canada to offset domestic emissions of CO_2 from other sources, and that planting forests on marginal agricultural lands also warrants consideration. They also find that reforestation is more costly than policies to increase the fuel efficiency of automobiles, but economically more efficient than converting vehicles to natural gas.

One way to expand forest area or the productivity of current forestlands is to capitalize on the accumulated backlog of forestland that remains poorly stocked or unproductive, the so called Not Satisfactorily Restocked lands. Recent estimates indicate that there are approximately 840000 ha of NSR in British Columbia. Based on a carbon fixation rate of 260 kg per m^3 of timber, reforesting B.C.'s NSR lands would result in sequestering an additional 1 million tonnes (Mt) of carbon per year. Approximately 18.9 million hectares of NSR forestlands are estimated for the rest of Canada. If the productivity of such land is poor, reforesting this area would result in the sequestration of an additional 12.3 Mt/year. Assuming that it costs $800 to $1,200 per hectare to reforest the backlog, the total cost would be $15.8 to $23.7 billion. Details are shown in Table B.5.

Table B.5: Carbon Sequestration Costs

Proposal	Growth Rate (m3/ha)	Area (mil. Ha.)	Annual amount of C sequestered (mil. Tonnes)	cost ($ bil.)	cost per tonne of C ($)
Rehabilitating Backlog NSR forest lands					
British Columbia	8/4.5/2.5	0.84	1.005	0.7-1.0	8.36-12.54
Rest of Canada	2.5	18.9	12.285	15.1-22.7	15.38-23.08
Plantation forests on the Prairies					
marginal land converted from cropland	3	4.41	3.44	1.3-2.2	6.4-10.70
current unimproved land	2.5	4.16	2.704	2.1-2.9	12.80-18.00
Total		**28.31**	**19.433**	**19.2-28.8**	**6.40-23.08**

One approach to reducing C emissions is to scrap the less fuel-efficient vehicles, for example, all automobiles of model year 1982 or earlier. By replacing pre-1983 models with newer ones, it is possible to reduce carbon emissions by 4.54 Mt/year. If each vehicle has a value of $1200, then the cost of scrapping all these vehicles is $4.505 billion. A second alternative to sequestration involves the conversion of all passenger automobiles in Canada to natural gas, which could reduce emissions by 25% or 3.8 Mt. Assuming conversion costs are $1500 per vehicle, the total cost would be $12.2 billion, which comes to a cost of $322/tonne reduction.

Winjum, J. K., Dixon, R. K., Schroeder, P. E. 1993. Forest management and carbon storage: An analysis of 12 key forest nations. *Water, Air, and Soil Pollution*, 70: 239-257.

The paper suggests a starting approach to a global effort to expand forest management to increase carbon sequestration. It is assumed that the implementation phase of such an effort would begin in the next few decades so that climate considerations would not be greatly different than at present.

The paper states that three-fourths of Canada's almost 1000 x 10^6 ha lie in the boreal region. Approximately 44% of Canada is occupied by natural forests and woodlands. The mean carbon storage can be as high as 39Mg C/ha for reforested lands. Based on implementation costs, reforestation and natural generation can sequester carbon at $US 11 and $US 6/Mg C, respectively.

Appendix C

INFLATION FACTORS USED IN THE CONVERSION OF VALUE OF CARBON FROM VARIOUS STUDIES TO YEAR 2000

Table C.1: Consumer price index for the period 1990-2000

Year	Consumer Price Index (1992 = 100)
1990	93.3
1991	98.5
1992	100.0
1993	101.8
1994	102.0
1995	104.2
1996	105.8
1998	107.6
1998	108.6
1999	110.5
2000	112.7*

* Assumes a 2% increase over the previous period.

For conversion to Cdn.$ (2000), the CPI was used.

2000 value = 19XX value x (2000CPI / 19XX CPI)

Appendix D

DETAILED DATA ON CARBON STORAGE
FOR NATIONAL PARKS

Table D.1: Level of Stored Carbon and Carbon Density in National Parks of Canada

Province	Park	Ecozone	Area (ha)	Plants C Stored (Mt)	Soil C Stored (Mt)	Peatland C Stored (Mt)	Total C Stored (Mt)	Carbon Density (kgC/ha)
Alberta	Jasper	Montane Cordillera	1,087,800	7.27	77.76	14.42	99.45	91.42
	Banff	Montane Cordillera	664,100	3.83	47.31	8.78	59.92	90.22
	Elk Island	Boreal Plains	19,400	0.44	0.62	0.00	1.06	54.51
	Waterton Lakes	Montane Cordillera	50,500	0.81	1.31	0.00	2.12	42.07
	Wood Buffalo (80%)	Taiga Plains/ Boreal Plains	3,584,160	28.67	276.21	1,104.59	1,409.46	393.25
British Columbia	Gwaii Haanas	Pacific Maritime	1,449,500	243.44	184.05	116.37	543.87	375.21
	Pacific Rim	Pacific Maritime	50,000	2.74	3.14	1.99	7.86	157.30
	Yoho	Montane Cordillera	130,000	5.35	9.25	1.72	16.31	125.45
	Glacier	Montane Cordillera	143,930	5.10	9.90	1.84	16.84	117.02
	Mount Revelstock	Montane Cordillera	25,970	1.30	2.54	0.47	4.31	165.84
	Kootney	Montane Cordillera	140,500	6.89	13.81	2.56	23.26	165.55
Manitoba	Wapusk	Hudson Plains	1,147,500	0.86	16.99	8.45	26.30	22.92
	Riding Mountain	Boreal Plains	297,310	9.78	29.03	116.09	154.90	521.01
New Brunswick	Kouchibouguac	Atlantic Maritime	23,920	0.43	1.18	0.65	2.26	94.31
	Fundy	Atlantic Maritime	20,700	0.65	1.77	0.97	3.39	163.96
Newfoundland	Gros Morne	Boreal Shield	180,500	2.90	15.27	33.74	51.91	287.61
	Terra Nova	Boreal Shield	39,900	0.75	3.98	8.79	13.52	338.89

Province	Park	Ecozone	Area (ha)	Plants C Stored (Mt)	Soil C Stored (Mt)	Peatland C Stored (Mt)	Total C Stored (Mt)	Carbon Density (kgC/ha)
Northwest Territories	Tuktut Nogait	Southern Artic	1,634,000	0.93	313.31	0.00	314.23	192.31
	Nahanni	Taiga Plains/ Taiga/tundra Cordillera	476,520	7.71	127.04	63.18	197.93	415.37
	Aulavik	Northern Artic	1,220,000	0.60	243.62	0.00	244.21	200.17
	Wood Buffalo-20%	Taiga Plains/ Boreal Plains	896,040	7.17	69.05	276.15	352.37	393.25
Nova Scotia	Cape Breton Highlands	Atlantic Maritime	94,800	2.45	6.04	3.31	11.79	124.40
	Kejinkuijk	Atlantic Maritime	40,370	1.10	2.99	1.64	5.72	141.79
Nunavut	Sirmilik (North Baffin)	Artic Cordillera/ Northern Artic	2,225,200	0.26	73.50	0.00	73.75	33.14
	Auyuittuq	Artic Cordillera/ Northern Artic	1,970,740	0.12	55.79	0.00	55.91	28.37
	Ellesmere Island	Artic Cordillera/ Northern Artic	3,775,500	0.31	363.06	0.00	363.37	96.24
Ontario	Pukaskwa	Boreal Shield	187,780	0.80	6.85	15.13	22.77	121.27
	Bruce Peninsula	Mixwood Plains	11,000	0.37	0.80	0.44	1.61	146.57
	Georgian Bay Islands	Mixwood Plains	2,560	0.11	0.13	0.07	0.31	121.76
	Point Pelee	Mixwood Plains	1,500	0.06	0.07	0.01	0.15	97.40
	St. Lawrence Islands	Mixwood Plains	8,700	0.37	0.44	0.24	1.06	121.53
Prince Edward Islands	Prince Edward Islands	Atlantic Maritime	2,700	0.05	0.13	0.07	0.25	94.41
Quebec	Mingan Archipelago	Boreal Shield	150,700	0.62	5.49	12.14	18.25	121.10
	La Maurice	Boreal Shield	53,610	0.23	2.06	4.56	6.86	127.88
	Forillon	Atlantic Maritime		4.33	15.18	33.53	53.03	220.60

Province	**Park**	**Ecozone**	**Area (ha)**	**Plants C Stored (Mt)**	**Soil C Stored (Mt)**	**Peatland C Stored (Mt)**	**Total C Stored (Mt)**	**Carbon Density (kgC/ha)**
			240,400					
Saskatchewan	Grasslands	Prairie	90,640	1.82	1.48	0.00	3.30	36.46
	Prince Albert	Boreal Plains	387,430	12.92	42.72	170.86	226.51	584.65
Yukon	Ivvavik	Taiga/tundra Cordillera	975,000	0.66	14.40	0.28	15.33	15.73
	Vuntut	Taiga/tundra Cordillera	434,500	0.29	6.42	3.19	9.90	22.79
	Kluane	Boreal Cordillera/ Pacific Maritime	2,201,330	0.94	9.47	5.99	16.40	7.45
Canada			**26,136,710**	**365.41**	**2,054.15**	**2,012.22**	**4,431.76**	169.56

Table D.2: Total Value of Stored Carbon in National Parks of Canada

			Case 1 ($17.50)	Case 2 ($16.25)	Case 3 ($2.30 – $3.00)	Case 4 ($500)
Province	**Park**	**Ecozone**	**Total C**	**Total C**	**Total C**	**Total C**
			(Mill. $)	**(Mill. $)**	**(Mill. $)**	**(Mill. $)**
Alberta	Jasper	Montane Cordillera	1,740.32	1,616.01	298.34	49,723.30
	Banff	Montane Cordillera	1,048.56	973.66	179.75	29,958.85
	Elk Island	Boreal Plains	18.50	17.18	3.17	528.70
	Waterton Lakes	Montane Cordillera	37.18	34.52	6.37	1,062.20
	Wood Buffalo (80%)	Taiga Plains/ Boreal Plains	24,665.61	22,903.78	4,228.39	704,731.64
British Columbia	Gwaii Haanas	Pacific Maritime	9,517.64	8,837.81	1,305.28	271,932.65
	Pacific Rim	Pacific Maritime	137.63	127.80	18.88	3,932.40
	Yoho	Montane Cordillera	285.40	265.01	39.14	8,154.20
	Glacier	Montane Cordillera	294.75	273.70	40.42	8,421.50
	Mount Revelstock	Montane Cordillera	75.37	69.99	10.34	2,153.45
	Kootney	Montane Cordillera	407.05	377.98	55.82	11,630.10
Manitoba	Wapusk	Hudson Plains	460.20	427.33	78.89	13,148.65
	Riding Mountain	Boreal Plains	2,710.77	2,517.15	464.70	77,450.70
New Brunswick	Kouchibouguac	Atlantic Maritime	39.48	36.66	5.19	1,127.90
	Fundy	Atlantic Maritime	59.39	55.15	7.81	1,696.95
Newfoundland	Gros Morne	Boreal Shield	908.48	843.59	119.40	25,956.60
	Terra Nova	Boreal Shield	236.63	219.73	31.10	6,760.90
Northwest Territories	Tuktut Nogait	Southern Artic	5,499.11	5,106.31	754.16	157,117.35
	Nahanni	Taiga Plains/ Taiga/tundra Cordillera	3,463.80	3,216.39	475.04	98,965.75
	Aulavik	Northern Artic	4,273.68	3,968.41	586.10	122,105.05
	Wood Buffalo-20%	Taiga Plains/ Boreal Plains	6,166.40	5,725.94	845.68	176,182.91
Nova Scotia	Cape Breton Highlands	Atlantic Maritime	206.38	191.64	27.12	5,896.65
	Kejinkuijk	Atlantic Maritime	100.17	93.02	13.17	2,862.00
Nunavut	Sirmilik (North Baffin)	Artic Cordillera/ Northern Artic	1,290.68	1,198.49	177.01	36,876.50
	Auyuittuq	Artic Cordillera/ Northern Artic	978.43	908.54	134.18	27,955.00
	Ellesmere Island	Artic Cordillera/ Northern Artic	6,359.00	5,904.79	872.09	181,685.75
Ontario	Pukaskwa	Boreal Shield	398.51	370.05	52.38	11,386.10
	Bruce Peninsula	Mixwood Plains	28.22	26.20	3.71	806.15
	Georgian Bay Islands	Mixwood Plains	5.45	5.07	0.72	155.85
	Point Pelee	Mixwood Plains	2.56	2.37	0.34	73.05
	St. Lawrence Islands	Mixwood Plains	18.50	17.18	2.43	528.65
Prince Edward Islands	Prince Edward Islands	Atlantic Maritime	4.46	4.14	0.59	127.45
Quebec	Mingan Archipelago	Boreal Shield	319.37	296.56	41.97	9,124.85
	La Maurice	Boreal Shield	119.98	111.41	15.77	3,427.95
	Forillon	Atlantic Maritime	928.07	861.77	121.97	26,516.15
Saskatchewan	Grasslands	Prairie	57.84	53.70	9.91	1,652.45
	Prince Albert	Boreal Plains	3,963.95	3,680.82	679.54	113,255.85

Table D.2 (Continued)						
			Case 1 ($17.50)	**Case 2 ($16.25)**	**Case 3 ($2.30 – $3.00)**	**Case 4 ($500)**
Province	**Park**	**Ecozone**	**Total C**	**Total C**	**Total C**	**Total C**
			(Mill. $)	**(Mill. $)**	**(Mill. $)**	**(Mill. $)**
Yukon	Ivvavik	Taiga/tundra Cordillera	268.36	249.19	36.80	7,667.35
	Vuntut	Taiga/tundra Cordillera	173.29	160.92	23.77	4,951.25
	Kluane	Boreal Cordillera/ Pacific Maritime	286.98	266.48	39.36	8,199.45
Canada			**77,556.16**	**72,016.43**	**11,806.80**	**2,215,890.20**

Table D.3: Economic Value of Stored Carbon in National Parks of Canada under Alternative Prices, Dollars per hectare

Province	Park	Ecozone	Area (ha)	Total C Stored (Mt)	Case 1 ($17.50)	Case 2 ($16.25)	Case 3 ($2.30 - $3.00)	Case 4 ($500)
					Value/ha ($/ha)	Value/ha ($/ha)	Value/ha ($/ha)	Value/ha ($/ha)
Alberta	Jasper	Montane Cordillera	1,087,800	99.45	1,599.85	1,485.57	274.26	45,709.97
	Banff	Montane Cordillera	664,100	59.92	1,578.92	1,466.14	270.67	45,111.96
	Elk Island	Boreal Plains	19,400	1.06	953.84	885.71	163.52	27,252.58
	Waterton Lakes	Montane Cordillera	50,500	2.12	736.18	683.59	126.20	21,033.66
	Wood Buffalo (80%)	Taiga Plains/ Boreal Plains	3,584,160	1,409.46	6,881.84	6,390.28	1,179.74	196,623.93
British Columbia	Gwaii Haanas	Pacific Maritime	1,449,500	543.87	6,566.16	6,097.14	900.50	187,604.45
	Pacific Rim	Pacific Maritime	50,000	7.86	2,752.68	2,556.06	377.51	78,648.00
	Yoho	Montane Cordillera	130,000	16.31	2,195.36	2,038.55	301.08	62,724.62
	Glacier	Montane Cordillera	143,930	16.84	2,047.89	1,901.61	280.85	58,511.08
	Mount Revelstock	Montane Cordillera	25,970	4.31	2,902.22	2,694.92	398.02	82,920.68
	Kootney	Montane Cordillera	140,500	23.26	2,897.18	2,690.24	397.33	82,776.51
Manitoba	Wapusk	Hudson Plains	1,147,500	26.30	401.05	372.40	68.75	11,458.52
	Riding Mountain	Boreal Plains	297,310	154.90	9,117.67	8,466.41	1,563.03	260,504.86
New Brunswick	Kouchibouguac	Atlantic Maritime	23,920	2.26	1,650.36	1,532.47	216.90	47,153.01
	Fundy	Atlantic Maritime	20,700	3.39	2,869.24	2,664.29	377.10	81,978.26
Newfoundland	Gros Morne	Boreal Shield	180,500	51.91	5,033.14	4,673.63	661.50	143,803.88
	Terra Nova	Boreal Shield	39,900	13.52	5,930.61	5,507.00	779.45	169,446.12
Northwest Territories	Tuktut Nogait	Southern Artic	1,634,000	314.23	3,365.43	3,125.04	461.54	96,155.05
	Nahanni	Taiga Plains/ Taiga/tundra Cordillera	476,520	197.93	7,268.95	6,749.74	996.88	207,684.36
	Aulavik	Northern Artic	1,220,000	244.21	3,503.01	3,252.80	480.41	100,086.11
	Wood Buffalo-20%	Taiga Plains/ Boreal Plains	896,040	352.37	6,881.84	6,390.28	943.79	196,623.93
Nova Scotia	Cape Breton Highlands	Atlantic Maritime	94,800	11.79	2,177.03	2,021.53	286.12	62,200.95
	Kejinkuijk	Atlantic Maritime	40,370	5.72	2,481.30	2,304.06	326.11	70,894.23
Nunavut	Sirmilik (North Baffin)	Artic Cordillera/ Northern Artic	2,225,200	73.75	580.03	538.60	79.55	16,572.22
	Auyuittuq	Artic Cordillera/ Northern Artic	1,970,740	55.91	496.48	461.01	68.09	14,185.03
	Ellesmere Island	Artic Cordillera/ Northern Artic	3,775,500	363.37	1,684.28	1,563.97	230.99	48,122.30
Ontario	Pukaskwa	Boreal Shield	187,780	22.77	2,122.24	1,970.65	278.92	60,635.32

Province	Park	Ecozone	Area (ha)	Total C Stored (Mt)	Case 1 ($17.50)	Case 2 ($16.25)	Case 3 ($2.30 - $3.00)	Case 4 ($500)
					Value/ha ($/ha)	Value/ha ($/ha)	Value/ha ($/ha)	Value/ha ($/ha)
	Bruce Peninsula	Mixwood Plains	11,000	1.61	2,565.02	2,381.81	337.12	73,286.36
	Georgian Bay Islands	Mixwood Plains	2,560	0.31	2,130.76	1,978.56	280.04	60,878.91
	Point Pelee	Mixwood Plains	1,500	0.15	1,704.50	1,582.75	224.02	48,700.00
	St. Lawrence Islands	Mixwood Plains	8,700	1.06	2,126.75	1,974.84	279.52	60,764.37
Prince Edward Islands	Prince Edward Islands	Atlantic Maritime	2,700	0.25	1,652.13	1,534.12	217.14	47,203.70

Appendix E

DETAILED DATA FOR CARBON STORAGE IN SASKATCHEWAN PROVINCIAL PARKS

Table E.1: Level of Stored Carbon and Carbon Density in the Provincial Parks of Canada

Ecozone	**Park**	**Area (ha)**	**Plants C Stored (Mt)**	**Soil C Stored (Mt)**	**Peatland C Stored (Mt)**	**Total C Stored (Mt)**	**Total t C/ha**
Boreal Plain	Anglin Lake	1,360.0	0.01	0.05	0.19	0.25	186.40
	Bronson Forest	14,500.0	0.34	1.30	5.20	6.84	471.84
	Candle Lake	1,214.0	0.03	0.11	0.44	0.57	472.08
	Chitek Lake	599.0	0.01	0.05	0.21	0.28	472.12
	Clearence-Steepbank Lakes	17,549.0	0.49	1.88	7.54	9.91	564.98
	Clearwater River	13,440.0	5.26	19.97	79.85	105.08	781.82
	Duck Mountain	16,250.0	0.36	1.71	6.82	8.89	546.90
	Emma Lake	35.0	0.00	0.00	0.02	0.02	622.86
	Greenwater Lake	20,700.0	0.49	1.86	7.42	9.77	471.82
	Makwa Lake	2,500.0	0.06	0.22	0.90	1.18	472.00
	Meadow Lake	16,000.0	0.38	1.43	5.74	7.55	471.84
	Narrow Hills	53,613.0	1.49	5.69	22.77	29.95	558.72
	Wilcat	21,700.0	0.51	1.95	7.78	10.24	471.82
Boreal Shield	Athabasca Sand Dunes	192,500.0	6.05	22.67	90.66	119.38	620.16
	Clearwater River	8,960.0	3.51	13.31	53.23	70.05	781.82
	Lac La Ronge	336,197.0	5.19	19.44	77.74	102.37	304.49
Prairie	Blackstrap	656.0	0.01	0.01	0.00	0.03	39.48
	Buffalo Pound	1,900.0	0.07	0.07	0.00	0.14	75.63
	Crooked Lake	200.0	0.01	0.01	0.00	0.02	76.00
	Cypress Hills	18,524.0	0.36	0.47	0.00	0.83	44.70
	Danielson	650.0	0.029	0.03	0.00	0.05	75.85
	Douglas	7,300.0	0.27	0.28	0.00	0.55	75.45
	Echo Valley	650.0	0.02	0.03	0.00	0.05	75.85
	Good Spirit Lake	1,950.0	0.07	0.08	0.00	0.15	75.59
	Katepwa Point	8.0	0.00	0.00	0.00	0.00	75.00
	Moose Mountain	40,000.0	1.45	1.56	0.00	3.01	75.33
	Pike Lake	449.8	0.01	0.01	0.00	0.02	41.57
	Regina Beach	20.0	0.00	0.00	0.00	0.02	750.00
	Rowan's Ravine	270.0	0.01	0.01	0.00	0.02	75.93

Ecozone	Park	Area (ha)	Plants C Stored (Mt)	Soil C Stored (Mt)	Peatland C Stored (Mt)	Total C Stored (Mt)	Total t C/ha
	Saskatchewan Landing	5,500.0	0.20	0.21	0.00	0.42	75.47
	The Battlefords	600.0	0.02	0.02	0.00	0.05	75.83
Saskatchewan		**795,794.80**	**26.71**	**94.44**	**366.51**	**487.68**	**488.95**

Table E.2: Total Value of Stored Carbon in Provincial Parks of Canada

Ecozone	Park	Case 1 ($17.50)	Case 2 ($16.25)	Case 3 ($2.30 - $3.00)	Case 4 ($500)
		Total C (Mill. $)	Total C (Mill. $)	Total C (Mill. $)	Total C (Mill. $)
Boreal Plain	Anglin Lake	4.44	4.12	0.76	126.75
	Bronson Forest	119.73	111.18	20.53	3,420.85
	Candle Lake	10.03	9.31	1.72	286.55
	Chitek Lake	4.95	4.60	0.85	141.40
	Clearence-Steepbank Lakes	173.51	161.12	29.74	4,957.45
	Clearwater River	1,838.84	1,707.49	315.23	52,538.25
	Duck Mountain	155.53	144.42	26.66	4,443.60
	Emma Lake	0.38	0.35	0.07	10.90
	Greenwater Lake	170.92	158.71	29.30	4,883.35
	Makwa Lake	20.65	19.18	3.54	590.00
	Meadow Lake	132.11	122.68	22.65	3,774.70
	Narrow Hills	524.20	486.76	89.86	14,977.20
	Wilcat	179.17	166.38	30.72	5,119.25
Boreal Shield	Athabasca Sand Dunes	2,089.18	1,939.95	358.14	59,690.80
	Clearwater River	1,225.89	1,138.33	210.15	35,025.50
	Lac La Ronge	1,791.44	1,663.48	307.10	51,184.05
Prairie	Blackstrap	0.45	0.42	0.08	12.95
	Buffalo Pound	2.51	2.34	0.43	71.85
	Crooked Lake	0.27	0.25	0.05	7.60
	Cypress Hills	14.49	13.46	2.48	414.00
	Danielson	0.86	0.80	0.15	24.65
	Douglas	9.64	8.95	1.65	275.40
	Echo Valley	0.86	0.80	0.15	24.65
	Good Spirit Lake	2.58	2.40	0.44	73.70
	Katepwa Point	0.01	0.01	0.00	0.30
	Moose Mountain	52.73	48.96	9.04	1,506.60
	Pike Lake	0.33	0.30	0.06	9.35
	Regina Beach	0.26	0.24	0.05	7.50
	Rowan's Ravine	0.36	0.33	0.06	10.25
	Saskatchewan Landing	7.26	6.75	1.25	207.55
	The Battlefords	0.80	0.74	0.14	22.75
Saskatchewan		**8,533.94**	**7,924.79**	**1,463.04**	**243,839.70**

Table E.3: Economic Value of Stored Carbon in Provincial Parks of Saskatchewan under Alternative Prices (Dollars per Hectare)

Ecozone	**Park**	**Area (ha)**	**Total C Stored (Mt)**	**Case 1 ($17.50)**	**Case 2 ($16.25)**	**Case 3 ($2.30 - $3.00)**	**Case 4 ($500)**
				Value/ha ($/ha)	**Value/ha ($/ha)**	**Value/ha ($/ha)**	**Value/ha ($/ha)**
Boreal Plain	Anglin Lake	1,360.0	0.25	3,261.95	3,028.95	559.19	93,198.53
	Bronson Forest	14,500.0	6.84	8,257.22	7,667.42	1,415.52	235,920.69
	Candle Lake	1,214.0	0.57	8,261.33	7,671.23	1,416.23	236,037.89
	Chitek Lake	599.0	0.28	8,262.10	7,671.95	1,416.36	236,060.10
	Clearence-Steepbank Lakes	17,549.0	9.91	9,887.22	9,180.99	1,694.95	282,491.88
	Clearwater River	13,440.0	105.08	13,681.84	12,704.56	2,345.46	390,909.60
	Duck Mountain	16,250.0	8.89	9,570.83	8,887.20	1,640.71	273,452.31
	Emma Lake	35.0	0.02	10,900.00	10,121.43	1,868.57	311,428.57
	Greenwater Lake	20,700.0	9.77	8,256.87	7,667.10	1,415.46	235,910.63
	Makwa Lake	2,500.0	1.18	8,260.00	7,670.00	1,416.00	236,000.00
	Meadow Lake	16,000.0	7.55	8,257.16	7,667.36	1,415.51	235,918.75
	Narrow Hills	53,613.0	29.95	9,777.52	9,079.12	1,676.15	279,357.62
	Wilcat	21,700.0	10.24	8,256.85	7,667.08	1,415.46	235,910.14
Boreal Shield	Athabasca Sand Dunes	192,500.0	119.38	10,852.87	10,077.67	1,860.49	310,082.08
	Clearwater River	8,960.0	70.05	13,681.84	12,704.56	2,345.46	390,909.60
	Lac La Ronge	336,197.0	102.37	5,328.55	4,947.94	913.47	152,244.22
Prairie	Blackstrap	656.0	0.03	690.93	641.58	118.45	19,740.85
	Buffalo Pound	1,900.0	0.14	1,323.55	1,229.01	226.89	37,815.79
	Crooked Lake	200.0	0.02	1,330.00	1,235.00	228.00	38,000.00

Ecozone	Park	Area (ha)	Total C Stored (Mt)	Case 1 ($17.50)	Case 2 ($16.25)	Case 3 ($2.30 - $3.00)	Case 4 ($500)
				Value/ha ($/ha)	Value/ha ($/ha)	Value/ha ($/ha)	Value/ha ($/ha)
	Cypress Hills	18,524.0	0.83	782.23	726.35	134.10	22,349.38
	Danielson	650.0	0.05	1,327.31	1,232.50	227.54	37,923.08
	Douglas	7,300.0	0.55	1,320.41	1,226.10	226.36	37,726.03
	Echo Valley	650.0	0.05	1,327.31	1,232.50	227.54	37,923.08
	Good Spirit Lake	1,950.0	0.15	1,322.82	1,228.33	226.77	37,794.87
	Katepwa Point	8.0	0.00	1,312.50	1,218.75	225.00	37,500.00
	Moose Mountain	40,000.0	3.01	1,318.28	1,224.11	225.99	37,665.00
	Pike Lake	449.8	0.02	727.55	675.58	124.72	20,787.02
	Regina Beach	20.0	0.02	13,125.00	12,187.50	2,250.00	375,000.00
	Rowan's Ravine	270.0	0.02	1,328.70	1,233.80	227.78	37,962.96
	Saskatchewan Landing	5,500.0	0.42	1,320.77	1,226.43	226.42	37,736.36
	The Battlefords	600.0	0.05	1,327.08	1,232.29	227.50	37,916.67
Saskatchewan		**795,794.80**	**487.68**	**8,556.23**	**7,945.49**	**1,466.86**	**244,476.61**