Technical Report

Valuation of Ecological Goods & Services in Canada's Natural Resources Sectors

Submitted to
Ecosystems and Biodiversity Priorities Division,
Environment Canada

Prepared by
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EXECUTIVE SUMMARY

This project is part of a larger initiative by Environment Canada to determine the value of Canada's biodiversity. This technical report is designed for those with basic training in economics and who wish to understand the technical underpinnings of the modified production function (PF) method developed for this project. An accompanying communications report provides a less technical description of the method developed to estimate the "natural subsidy" value of ecological goods and services (EGS) in the production of various nature-related economic products.

The term "ecological goods and services" includes a wide range of goods and services that are produced by ecosystems and that benefit humans. One source of benefit is through their contribution to the production of nature-related products (e.g., agriculture, forestry and fisheries). The valuation of these EGS inputs is undertaken by applying economic theory and principles in combination with ecological understanding of the relationship between EGS supplies and economic production.

This report demonstrates how conventional economic methods can be modified to derive reasonable measures of value and presents the results of applying a modified PF method for estimating natural subsidy values. These results are consistent with the requirements of cost-benefit analysis and public welfare accounting, two primary public policy analysis techniques. An innovative modified version of the production function method developed by other researchers has been produced as part of this project. The application of this economic valuation method shows how the method can be applied, provides initial estimates of the magnitude of the value of EGS inputs in Canada, and outlines how the method should be applied for future policy analyses.

The results presented in this report are indicative of how the method can be applied. Specific recommendations for refining and applying the valuation method more broadly are presented. The results are not comprehensive; not all forms of EGS inputs are included, nor are all economic sectors and their associated nature-related products included.

Economic value estimates are estimated for products from three sectors and three EGS inputs. Table 1 summarises these results.

Economic Product	Loss of Economic Output	Implied EGS Price ($/% Change)[1]
Fruit Production	$(53,488,850)	$1,069,777
Harvested Wood	$(375,486,463)	$7,509,729
Marine Fish Harvest	$(5,885,854)	$117,717

Table 1 – Summary of Economic Value of EGS Inputs

These estimates are based on a 50% reduction in the supply of each EGS input for each product. The EGS input varies with each product (i.e., fruit – wild pollination, wood – natural water supply; fish – primary productivity).

A number of conclusions and recommendations follow from this analysis relating to:

- the application of the method and its results for policy analysis,
- priorities for refinement, and
- the need to publish the method and subject it to peer review.

[1] The value of EGS inputs are expressed as a percentage of the current supply. This unusual metric was used to overcome the absence of national EGS metrics and statistics that would allow an absolute, physical metric to be used.

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1.0 INTRODUCTION

This section sets out the context within which this report has been prepared and should be interpreted.

1.1 BACKGROUND

DSS Management Consultants Inc. (DSS) was retained to by Environment Canada to develop and apply an economic method to estimate the "natural subsidy" value of ecological goods and services (EGS) in the production of various nature-related economic products. This technical report documents in detail the method and data used to derive estimates of the value of these natural subsidies. A separate "communications" report provides a less technical description of the application and results of the economic valuation method used in this analysis. Both documents are stand-alone reports designed for different audiences but nonetheless are complementary.

This report is part of a larger initiative by Environment Canada to determine the value of Canada's biodiversity. *The Value of Nature to Canadians Study*[2] is one of six priority initiatives being advanced through a Federal-Provincial-Territorial partnership, as part of Canada's participation in the *2010 International Year of Biodiversity*. The study's purpose is to identify the social, cultural, and economic values of biodiversity and ecosystem services to Canada, in support of government policy and decision making, and public awareness initiatives.

The term "ecological goods and services" (EGS) includes a wide range of goods and services that are produced by ecosystems and that benefit humans. Section 1.4.3 discusses in greater detail the specific types of goods and services provided by ecosystems and different EGS classification schemes.

Environment Canada stipulated that this project would focus on ecological "input services" that enable the production of nature-related goods and services that are conventionally measured. These nature-related goods and services are those included in Canada's System of National Accounts. Statistics Canada regularly collects economic statistics relating to the production of these goods and services and maintains the national accounts to inform decision-makers and the public about the state of the economy. The valuation of these nature-related goods and services is part of the routine statistical method employed by Statistics Canada; namely market prices are used as the basis for valuation. Summaries of the supporting statistics on which the national accounts are based are routinely reported.

Deriving reliable quantitative estimates of the contribution of supporting EGS to the production of these conventional goods and services is a major challenge. The reason is that these EGS inputs are not traded and priced through markets and so comprehensive EGS statistics are not routinely collected as is the case with conventional goods and services. Barbier (2000, p. 50)[3] states that when valuing EGS "… it is extremely important that the relationship between any environmental regulatory function and the economic activity it protects or supports is well understood." In other words, for quantitative economic valuation methods to be used to estimate reliably the value of natural subsidies, the connections between the level of economic output and the type and quantity of EGS inputs must be well understood and adequately described statistically. As discussed in this report, both statistics and understanding are severely restricted when it comes to estimating at a national level, "natural subsidies".

This report describes the economic valuation method selected to derive estimates of EGS natural subsidies for nature-related goods. More specifically, the production function (PF) method has been selected for this analysis. The underlying economic theory on which the PF method is based is consistent with the economic basis for valuing conventionally measured, nature-related goods. Of particular note is the consistency of the PF valuation method with the underlying economic principles on which the National Accounts are based. This consistency means that the results of this analysis are directly comparable and compatible with conventional

[2] See http://www.cbin.ec.gc.ca/nature/valeur-value.cfm?lang=eng

[3] Barbier, E. B. 2000. Valuing the environment as input: review of applications to mangrove-fishery linkages. Ecological Economics 35(1): 47-61

economic measures; such consistency and compatibility are not common to many of the other methods used to value EGS. Given their compatibility with conventional economic measures, the modified PF method and the associated results can be directly incorporated in future policy analyses.

1.2 OBJECTIVES

This analysis is designed to achieve the following objectives:

1. To demonstrate how rigourous estimates of the value of natural subsidies can be practically derived by combining conventional economic statistics with appropriate ecological data;
2. To produce estimates of the economic value of these natural subsidies;
3. To discuss the economic significance of nature-related goods in the Canadian economy and the contribution of natural subsidies to this economic output;
4. To show how these results can be used for policy analysis; and
5. To communicate to decision-makers and the public the importance in giving due consideration to these natural subsidies when making economic and environmental policy decisions.

1.3 TARGET AUDIENCE

This report is written for those having a good understanding of economic theory and principles. As well, some sections require a basic understanding of ecological theory and principles. Those wishing a less technical explanation of this analysis should consult the companion communications report.

1.4 SCOPE OF THE ANALYSIS

This analysis is restricted to natural subsidies associated with nature-related economic goods (i.e., goods that are produced and traded within the market and are termed market goods). The objective is to value the contribution of EGS to the production of these conventional forms of economic output.

In principle, our entire economy can be said to be nature-related; without any EGS inputs, all economic activity would cease. Indeed in the extreme, without essential EGS inputs, humans could not survive. Raw material inputs are the foundation ultimately on which all human economies are based. Accordingly, it can be said that all economic products are tied to EGS inputs. These secondary connections throughout the economy are not included in this analysis; only the direct contribution to primary nature-related economic goods is included.

This analysis largely focuses on marginal (i.e., relatively small) changes in the supply of EGS and the impact of these marginal changes in supply are expected to have on the production of nature-related economic goods. Economics is most useful for dealing with this type of marginal change. However as the scale of change increases, the underlying *paribus ceterus* assumptions on which most economic valuation methods are based no longer hold. Wholesale shifts in social priorities and market prices can be expected when major perturbations occur (e.g., as is the case with climate change forecasts). These types of large-scale economic effects are beyond the scope of this analysis.

1.4.1 Scoping of Economic Sectors

The economic sectors that produce nature-related goods include various primary sectors (e.g., renewable energy, fisheries, forestry, and agriculture) plus nature-based sectors (i.e., outdoor tourism). These sectors were scoped down as explained below.

Fossil fuels are ultimately the result of nature-related biological and geological processes. Similarly, mineral deposits are the result of natural geological processes. However in the case of fossil fuels, the great time lag between the biological processes that produced the original organic material and the intermediate subsurface processes that ultimately produced oil, natural gas and coal makes the connection to biodiversity and EGS obscure at best. A similar situation exists with minerals except that the time lags are often much greater and many of the supporting processes are physical and chemical, not biological. Both of these types of goods were excluded from further analysis for this reason.

The relationship between the production of nature-related goods and EGS inputs is more direct with some sectors than it is with others. For example, agriculture, fisheries and forestry all involve the harvest of the "bounties of nature" (i.e., ecological goods). The quantity and quality of the supply of these "bounties" is a major determinant of the economic output of these sectors. As well, the available quantities and quality of these "bounties" is closely tied to EGS. These sectors are included in this analysis for these reasons.

In the case of nature-based tourism the connection is not nearly so direct. Some nature-based tourism involves the direct consumption of these "bounties" (e.g., fishing and hunting lodges) but other types of nature-based tourism (e.g., ecotourism, adventure tourism) are much more loosely tied to the quantity and quality of the supply of these "bounties". Instead, the economic output is not measured by the quantity harvested but rather by a multitude of other factors; some of which are nature-based (e.g., scenery, isolation) and others that are not (e.g., quality of service and infrastructure). For these reasons, application of the production function method is much more complicated since the connection between EGS supplies (both quantity and quality) is non-linear and much more complex than is the case with, say, the fish population productivity and fish harvests. As a result, no attempt was made at this time to apply the modified PF method to the nature-based tourism sector. Future applications of the modified PF method to the nature-based tourism sector are possible but the estimation of the supply and demand functions will be more complicated as will be the connections between the quantity and quality of the supply of different EGS and the level of economic output.

Another major nature-related economic output is power generation (e.g., hydro, solar, wind). Hydro-power comes directly from the solar energy that drives the hydrological cycle. The value of water to the output of this sector is readily calculated using engineering principles; the electricity generation potential of each cubic metre of water that passes through a generation facility is readily derived. The marginal value of an increase/decrease in water flow can be accurately and rapidly estimated. Furthermore with electricity production, small changes in water flow are not expected to affect market prices given the interconnected nature of the electricity transmission grid and the variety of generation sources. Certainly if all hydro power was to be eliminated, supply and demand would be affected but given the complexity of the generation substitutes, estimating new supply cost functions would be quite complex and well beyond the scope of this analysis. For these reasons, the hydro-electric power generation sector was not analysed using the modified PF method

1.4.2 Scoping of Economic Goods

Each of the three economic sectors included in this analysis (i.e., agriculture, fisheries and forestry) produces a variety of goods (i.e., products). For example, the agriculture sector produces crops, livestock, dairy products, fruits, vegetables, etc. Each of these broad product categories can be further subdivided (e.g., different types and varieties of crops). Some scoping of the list of goods to be included for each sector was necessary to arrive at a manageable number. The list of potential goods was scoped down as explained below.

This analysis adopted the product classification scheme used by Statistics Canada (i.e., Annual Survey of Manufactures List of Goods[4]. The products in this scheme are organized by product groups that correspond to different economic sectors. Each product is denoted by a seven digit code (e.g., the code for wheat is 1111400). These individual products are grouped into similar products (e.g., Level 1 and Level 2). Table 2 shows the product groups that have been selected for this analysis for each economic sector.

This grouping of the products is coherent with the types of EGS inputs that might affect output and yet involves a manageable number of product types. The modified PF method used in this analysis however can be readily applied to a much more disaggregated set of products as required.

[4] See http://stds.statcan.ca/english/asm/asm_intro.asp

Level 1			Level 2	
Code	Name	Examples	Code	Name
1110003-1119989	Crops	Cereal grains, fruit, vegetables and other crops	1113310	Fresh apples
			1113390	Apricots, peaches, pears, and other fruits (excluding berries, grapes and apples)
11321000-1133101	Forestry products	Logs, pulpwood, other logging products		
1141110-1142100	Fishing and trapping products	Fresh fish, raw fur skins	1141110	Fish, whole or dressed, excluding shellfish
			1141120	Shellfish, in shell

Table 2 – Product Categories Used for PF Analysis

1.4.3 Scoping of EGS

Various EGS classification schemes have been proposed (e.g., Costanza et al, 1997; deGroot et al, 2002; Millennium Ecosystem Assessment, 2005; Tallis et al, 2008; Fisher et al, 2009); generally, these schemes have been developed for other purposes and correspond poorly with the analytical focus of this work. None of the existing EGS classification systems satisfied the requirements associated with the PF method.

The typology of EGS used by the Millennium Ecosystem Assessment (2005) is commonly referenced (Figure 1). Four broad classes of services are identified, namely, provisioning, regulating, supporting and cultural services. The following discussion of this typology illustrates the problems that arise when it is used for this type of analysis.

Provisioning services produce specific goods. Some of these goods are traded in markets and others are not. For the purposes of this analysis, these provisioning services are largely represented by the nature-related goods that are conventionally measured and included in the national accounts.

The most direct source of “natural subsidy” comes from the regulating services. These services regulate ecosystem processes such that the yield of products from ecosystems is enhanced/diminished. Given that these regulating services are most closely tied to the production of nature-related goods, they are likely to have the greatest impact on production rates and the greatest “subsidy” value.

Cultural services deal largely with ecosystem services that are not closely tied to conventionally measured, nature-related goods; the exception being recreation and tourism. These outdoor activities differ from other nature-related economic sectors which produce physical goods that are exchanged through markets. The analytical approach to the treatment of nature-related recreation and tourism subsidies is conceptually somewhat different than the case with the other economic sectors being considered as discussed in Section 1.4.1 above.

The final type of ecosystem service is supporting services. Supporting services are the foundation for all ecosystem functions. These supporting services provide “natural subsidies” to all of the other ecosystem services as well as all nature-related goods. The challenge is the connections between these supporting services and the level of output for specific nature-related goods; these connections are commonly indirect, subtle and complex making the estimation of their “natural subsidy” contribution much more difficult. As well, considerable potential exists for double counting since the "products" of these supporting services are other types of EGS inputs that in turn are counted as natural subsidies.

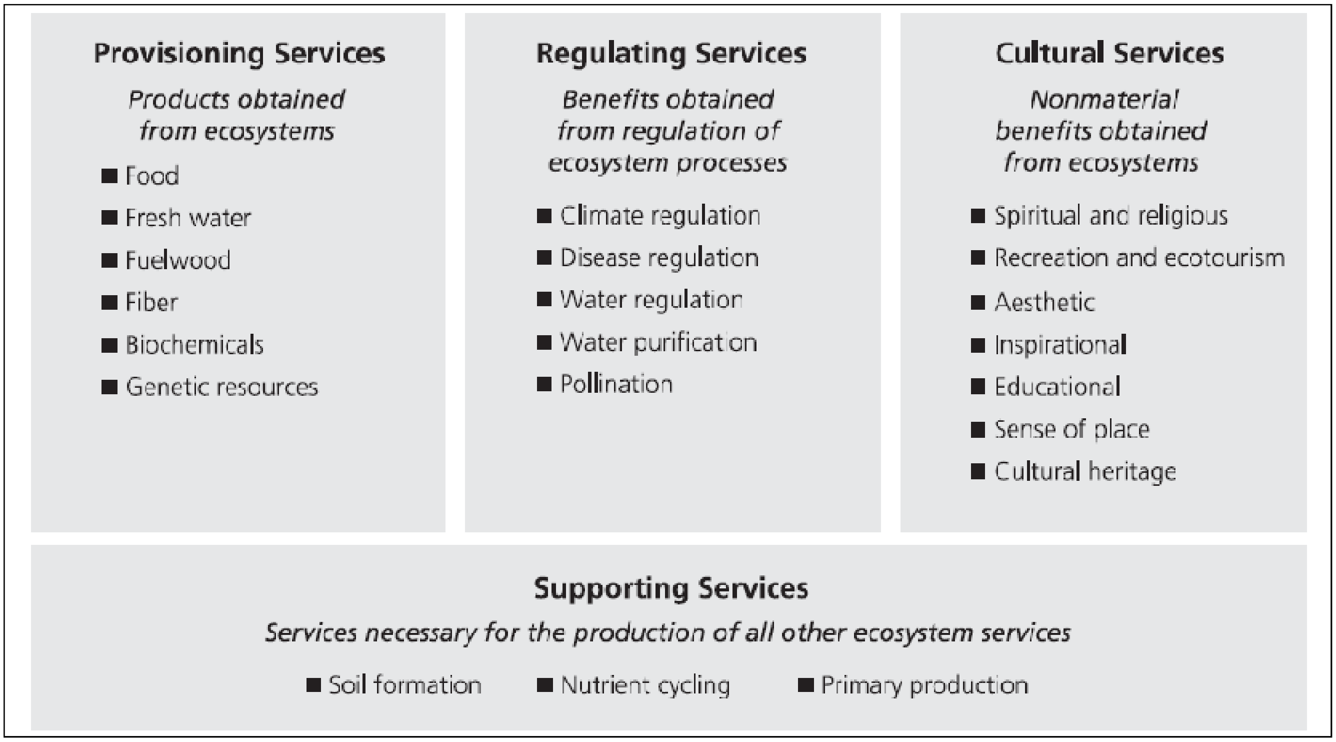

Figure 1 – Typology of Ecosystem Services (*from Millennium Assessment Report, 2005***)**

The problems with conventional ecosystem service classification schemes for welfare accounting is discussed by Boyd and Banzhaf (2006) wherein they conclude that "… consistently defined units of account to measure the contributions of nature to human welfare … have to date not been defined by environmental accounting advocates and that the term "ecosystem services" is too ad hoc to be of practical use in welfare accounting." (Abstract). They state that "[t]he development and acceptance of welfare accounting and environmental performance assessment are hobbled by the lack of standardized ecosystem service units" (p.1); a finding supported by this analysis. These authors lay out the requirements for defining useful units of account; specifically, they state "…an operationally useful definition of services will be clear and precise, consistent with the principles of the underlying ecology, and with the economic accounting system to which it relates." (p.2) They propose an ecosystem services index (ESI) that is designed to provide a consistent measure of ecosystem services to human wellbeing. They define ecosystem services as "…components of nature, *directly* enjoyed, consumed, or used to yield human well-being." (p.8) [emphasis added] The purpose of this definition is to differentiate between end-products and intermediate products. Doing so reduces the potential for double counting and confusion about the aggregate contribution by ecosystems to human wellbeing. A similar distinction is used in conventional welfare accounting for similar reasons.

An important aspect of this definition is that ecosystem services are confined to "things" and not functions or processes. Functions and processes are important intermediate products that contribute to the supply of ecosystem service end products but their value is embodied in the value of the end product and should not be double counted.

Boyd and Banzhaf go on to identify broad classes of ecosystem service end products; namely "…aesthetic enjoyment, various forms of recreation, maintenance of human health, physical damage avoidance and subsistence or foraged consumption of food and fiber." (p.12) The authors lay out an initial inventory/classification of ecosystem services associated with certain classes of benefits. (see p.19, Table 1) Their first grouping of services under the heading "Harvests" corresponds most closely to the natural subsidy inputs which are the focus of this study. The authors draw a distinction between managed and wild harvests which is not necessary for this analysis.

Table 3 shows the EGS inputs considered for each economic product[5]. Following is the rationale for including these EGS/product combinations in this analysis.

Economic Product		EGS Input						
		Pollination	Soil Quality	Nutrient Supply	Water Supply	Primary Productivity	Water Quality	Critical Habitat
Agriculture	Apples							
	Fruit							
Forestry	Wood							
Fisheries	Marine Fish							
	Marine Shellfish							

Table 3 – Economic Product/EGS Input Combinations

1. Pollination

Pollination by wild pollinators (i.e., largely insect pollinators like honey bees) is known to influence crop production (Dedej and. Delaplane, 2003; Gallaia et al., 2008); but only for some crops and not for others. For example, cereal grains are wind pollinated and their yield is insensitive to wild pollinator abundance. Only agricultural crop types impacted by wild pollinators were included in this analysis.

Researchers have estimated the relationship between pollinator abundance and crop yield. This information is critical to apply the modified PF method and is largely absent for most EGS inputs to production. For this reason, pollination services were included as an EGS input in this analysis.

Insect pollination services are not a major input to commercial forestry output in Canada. The dominant commercial tree species (e.g., conifer and softwood species) are primarily wind pollinated and are not impacted by wild pollinator abundance. As a result, the corresponding cell in Table 3 is left blank, indicating that this combination of product type and EGS input is not relevant.

2. Soil Quality

Soil quality comprises many soil characteristics; some of which vary with agricultural practices (e.g., pH, organic content, nutrients) and others which are largely unalterable (e.g., topography, internal drainage, soil texture). These features of soil quality create several challenges. First, because soil quality is a multi-factor attribute and a great number of different combinations of attributes are possible, no simple measure of soil quality exists. Instead, agronomists tend to focus on specific attributes when determining crop yield potential. As a result what constitutes say a 10% reduction in soil quality is highly ambiguous and difficult to quantify.

In the case of commercial forests, site classification schemes and site indices have been developed that tie soil/site quality to projected tree growth. These site classes however are broad and do not relate well to the types of subtle changes that might be expected to occur at a landscape level that would be relevant for estimating natural subsidies.

[5] Not all EGS/product combinations are appropriate. For example, pollination has limited relevance to marine fisheries output. The green shaded cells in Table 3 indicate the EGS/product combinations considered in this analysis.

These issues create serious measurement problems that greatly complicate tying the broad attribute of soil quality to economic output. Nonetheless, soil quality is recognized as being a significant ecological determinant for agriculture and forestry products. This EGS input can be valued using the modified PF method once a suitable aggregate metric for soil quality is produced that is relevant to policy issues. Alternatively, individual soil quality characteristics (e.g., nutrient availability, pH, organic content) can be individually valued using this method.

3. Nutrient Supply

Plants depend on a variety of nutrients; nitrogen is often the nutrient in limiting supply. As a result, most agricultural fertilizer mixes include a significant proportion of nitrogen compounds. However, other nutrients can be limiting when nitrogen compounds are in excess. The complex interactions of different types of nutrients with different crops and tree species make the valuation of the general EGS category "nutrient supply" challenging. For analytical purposes, the natural subsidy value of nutrient supply needs to be narrowed down to a single nutrient; nitrogen compound supply is the preferred type of nutrient for representing this EGS input.

Natural sources of nitrogen compounds include nitrogen fixation primarily by leguminous plants and atmospheric fixation by lightning. As well, anthropogenic nitrogen emissions (largely from internal combustion processes) contribute a significant portion of the annual nitrogen compound supply for agriculture and forestry.

The impact of changes in nitrogen supply varies greatly by plant species, growth stage, soil type and the supplies of other nutrients, water availability and solar radiation; not to mention the extent to which producers intervene by adding artificial nitrogen compounds to offset any changes in natural supplies. As a result, the EGS impact factor coefficient for nitrogen supply is highly variable. The nutrient supply category has been included in the valuation framework given the extensive information base regarding the impact of nitrogen compounds (and other nutrients) on plant growth. However, average impact coefficients for all of Canada have not been estimated for different crop types and different tree species. Site-specific impact coefficients are feasible should the modified PF method be applied for analysing a specific set of policy alternatives.

A further caution with this EGS input category is warranted. As discussed with soil quality, nutrient availability is often a direct or indirect characteristic defining soil quality. If an aggregate measure of soil quality and a specific measure of soil nutrients were both included, double counting would be highly likely; either directly or indirectly (e.g., through measures of soil chemistry and origin).

4. Water Supply

Water stress can inhibit plant growth and in extreme cases (i.e., drought conditions), can cause death. Likewise, an overabundance of water can negatively affect plant growth and lead to death. As a result, water supply cannot be simply measured by quantity. Instead, the impact of water supply on output depends on multiple attributes that vary from site to site and plants species to plant species. Ideally an index of water demand and water supply measured over a growth cycle would provide a useful measure of water availability. If such an index existed, it would need to tie back quantitatively to EGS functions and their role in water supply regulation.

The marginal increase in crop yield from an increase in water supply under conditions of water scarcity is reasonably well known for different crop types, soil conditions and growth stage. As a result, site-specific impact coefficients are feasible should the modified PF method be applied for analysing a specific set of policy alternatives in terms of changes in water supply and the impact on agricultural output. Note however that the use of irrigation is becoming increasingly prevalent in Canadian agricultural operations. The option to offset changes in natural water supply through substitution with irrigation complicates the EGS valuation process.

The situation is slightly different for commercial forestry operations. Water scarcity does affect tree growth but an even greater impact during periods of water scarcity is the resulting change in the frequency and extent of forest fires. During periods of low water supply, large losses of wood to fire are common. The cycle of forest fires is complex and includes dynamic feedbacks and time lags driven by factors such as daily water supply, temperature, forest age and species structure, landscape patterns of forest stands, etc. No simple relationship exists between changes in daily water supply and changes in wood yield. However given the large influence of forest fires on wood yields in Canada, this EGS supply category has been included for the forest sector.

5. Primary Productivity

Primary production is the driving force supporting all higher trophic levels in an ecosystem. As primary production is consumed and transferred through succeeding trophic levels, the amount of energy and material dissipates. Accordingly, changes in primary production affect all higher trophic levels.

The trophic transfer rate (i.e., a measure of the energy and material transfer efficiency from one trophic level to another) is dependent on ecosystem structure and diversity. These trophic transfer rates have been extensively researched and average values have been estimated for aquatic ecosystems. An average trophic transfer rate has been used in this analysis to forecast how changes in primary productivity are expected to alter the abundance of higher trophic level fish species.

6. Water Quality

Water quality is another multi-attribute EGS. Water quality is a function of the types and concentrations of specific chemicals and materials in water. No single composite measure of water quality exists that is connected to the economic output of fishery operations. Indeed, water quality can affect both the quantity and quality of harvested fish. The modified PF method could be refined to include changes in quantity and quality[6] but the method developed for this analysis is largely based on changes in total output, not changes in the quality of that output.

Nonetheless, regulation of water pollution is a major focus of environmental policy. The value of natural subsidies from high quality water areas is an important consideration in making water pollution policy decisions. For this reason, water quality has been included as a source of EGS natural subsidy but considerable ambiguity remains as to the appropriate metric for this EGS input.

As with the case of nutrient and soil quality, a similar situation exists between primary productivity and water quality. Nutrient availability is one of the determining factors for primary productivity. At the same time, nutrient concentration/load is a common water quality parameter. Accordingly, considerable potential exists for double counting if care is not taken in defining the units of measure for water quality.

7. Critical Habitat

The provision of habitat to support fish populations is an important EGS input to fishery operations. As with other EGS inputs, habitat is a multi-attribute input that involves complex site-specific interactions. A key concept when developing impact coefficients for changes in habitat is that of limiting factors. For example the Fisheries Act identifies a number of critical fish habitats (e.g., migratory, spawning, nursery, foraging). However, a local reduction in say, nursery habitat may have no impact on fish yields if spawning habitat is limiting and there is an excess of nursery habitat.

A further complication relates to connecting changes in critical habitat supply to fish yields. The habitat requirements of each species differ. As a result, the valuation of changes in critical habitat is largely meaningless across a broad assemblage of fish species. Further, the impacts of changes in critical habitat supply are dependent on the population dynamics of each fish species and the extent to which changes in critical habitat supply can be compensated by reliance on secondary habitat types or through changes in population factors (e.g., higher growth rates of the fish that are produced from the remaining habitat, lower

[6] With conventional economic products, quality is an attribute used to define different products (e.g., different grades of agricultural produce). The same principle could in concept be used to define different types of EGS inputs; however given current data constraints, this finer level of resolution (i.e., different quality levels) is not practical at a broad scale.

mortality rates for juvenile fish). Despite these complications, provision of critical habitat is an important EGS input to fisheries and has been included for this reason.

8. Summary Observations

This discussion of these seven EGS inputs illustrates clearly the relevance of the Barbier (2000) quote in Section 1.1 and the accounting challenges discussed by Boyd and Banzhaf (2006). The primary challenges with the valuation of EGS inputs to economic output involve ecology and not economics. Economic theory and analytical tools are available to value EGS inputs; the major gaps relate to the characterization of EGS inputs, units of measure, basic statistics for each and their functional relationship with economic products (i.e., their impact coefficients). This project cannot overcome these challenges. Instead, this study relies on a proven economic valuation method and conforms as best as possible to accepted welfare accounting principles. Resolving the gaping holes in the underlying ecological connections should be a major priority and this valuation method provides a good foundation around which to address these ecological issues.

1.4.4 Spatial Resolution

A key distinguishing feature of EGS is the spatial distribution of their supply. With many economic inputs, they are exchanged through the market and are transported to production sites where they are used. For this reason, much economic analysis is aspatial since location is implicitly reflected in transportation costs of inputs. Non-market EGS by definition are not traded within markets and are largely non-transportable; as a result, their value for economic production is closely tied to where they are found. Large supplies of EGS far removed from economic activity have less value than those in close proximity, at least from a natural subsidy perspective. The value of natural subsidies is therefore closely linked to the location of specific EGS relative to the location of specific types of economic production.

However, the objective of this analysis is to produce national estimates of the value of natural subsidies. Ideally, these estimates of the value of natural subsidies should be derived by conducting local analyses of the value of EGS inputs so that the spatial setting where the EGS are found can be reflected in their implied prices. If this type of analysis was conducted, national estimates of the value of natural subsidies could be derived by aggregating local results across Canada. This level of spatially detailed analysis far exceeded the resources of this project. Instead, a much coarser level of spatial resolution (i.e., a national level of resolution) was used in this analysis which unavoidably introduces much imprecision. Nonetheless, the analytical method developed for this project is readily applicable at a national, regional or local scale as appropriate.

1.4.5 Temporal Resolution

As discussed above, the relationships between EGS inputs and economic output are complex. One source of complexity is time lags between changes in EGS supplies and when the associated impact on economic output occurs. Nowhere is this more important than in the forestry sector.

For example, changes in nutrient supply may affect the growth of trees of all ages. As a result the full impact of the change is only apparent after at least a full cycle through all ages of the affected trees; a full cycle may be 100 years or longer. For this reason, the valuation of nutrient supplies for wood production ideally should be based on at least one full rotation of the forest.

This level of complexity is beyond the scope of this analysis. As a result, this analysis is based on the impact of changes in EGS supplies over a single year. Ignoring the cumulative impacts of changes in EGS supplies over an extended timeframe underestimates their economic value.

2.0 THEORETICAL FOUNDATION

This section discusses the economic theory associated with production functions and how the conventional PF method has been modified to fulfill the requirements of this project.

2.1 PRINCIPLE OF NATURAL SUBSIDIES

Conventional economic accounting of production tracks inputs of labour, capital, materials and energy. The quantity of each input used plus its cost allows the costs of production to be calculated. The derivation of supply costs functions (i.e., the relationship between inputs, the amount of output and the cost of production) is a critical component for forecasting future product prices and level of supply. Each conventional input to production is valued through market transactions (i.e., market prices). This conventional accounting framework does not include many EGS inputs to production since these inputs are not privately owned or traded through markets. As a result, these EGS inputs are treated as free (i.e., worthless) from a strict accounting perspective.

The term “natural subsidies” has been coined to describe the value of these free EGS inputs to economic production. Because the public who own these EGS provides them to private producers at zero cost, they can be viewed as a form of public subsidy to private production. The question that arises is what is the value of these subsidies in terms of economic output (i.e., what would be their expected price if these EGS inputs had to be purchased by private producers from the public?). A closely related question is how would economic output change if supplies of these free EGS were to diminish? Together these questions lead to the question of how significant are these free EGS inputs to economic output? Or in economic terms what is the implied value of these EGS inputs with respect to the economic products that rely on them? The objective of this analysis is to provide a method for answering these questions and to provide some preliminary estimates of the economic value of EGS inputs to economic production.

2.2 THEORETICAL FOUNDATION FOR PF METHOD

Economists have developed methods to describe economic production. The most common formulation of economic production is the Cobb-Douglas production function (PF). These production functions are commonly used by economists for forecasting how changes in inputs will affect the cost and quantity of output. Following is the generic form of the basic Cobb-Douglas production function.

2.2.1 Cobb-Douglas Production Function

Equation 1 shows a generic Cobb-Douglas production function. The left-hand side represents the amount of output; the right-hand side, the inputs to productions (i.e., factors of production).

$$Q = A\, L^{\alpha} K^{b} e^{\mu}, \qquad \text{Equation (1)}$$

where:

Q = total production (the amount/value of output)
L = labour input
K = capital input (i.e., stock of capital used for production)
A = total factor productivity (i.e., a measure of technological efficiency)
e = a random error factor[7]
α = the elasticity of labour ($0<\alpha<1$)
b = the elasticity of capital ($0< \beta <1$)
μ = the random error coefficient

[7] *This random error coefficient is not shown for the sake of simplicity in versions of the CD function discussed later in this report.*

This equation indicates that different combinations of labour and capital including new technology can be used to produce economic output of a given type. In other words, substitution among different inputs to production (e.g., labour and capital) is possible to produce a given product; the amount of substitution that occurs is largely driven by the relative prices of the inputs and the technology available to combine the inputs into desired outputs (i.e., products). Both the labour and capital variables can be broken down into specific types of inputs (e.g., general, skilled and managerial labour). As well, other factor inputs can be added to the equation (e.g., land, energy). The conventional PF form however does not include any EGS inputs.

2.2.2 Basic Production Function Method

More recently, economists have been adapting the basic PF method to estimate the value of EGS inputs to production. This valuation method is based on the principle that diminished supplies of EGS will result in reduced economic output or will require increased inputs of other factors of production to offset the reduced EGS supplies or some combination of the two. Technically, the result is that the supply cost function shifts as supplies of essential EGS diminish (Figure 2).

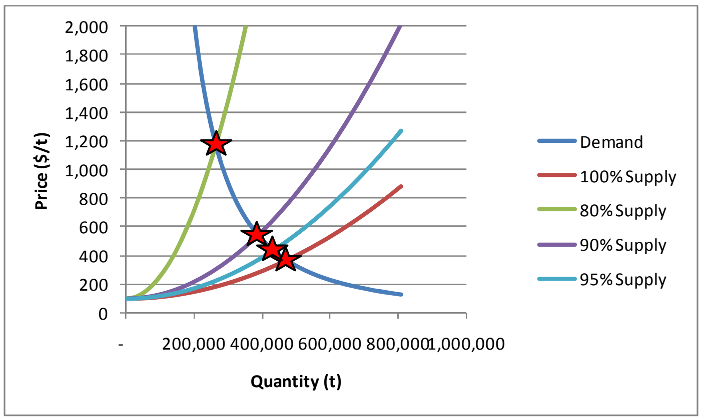

Figure 2 – Derived Supply Curves with Change in EGS Input[8]

This shift in the supply curve will affect the equilibrium price (red stars on Figure 2) at which the costs of supply equal the willingness to pay of buyers (i.e., at the intersection of the supply and demand functions); more specifically, reduced EGS supplies are expected to decrease output and increase the market prices of those nature-related products that depend on these inputs. This production cost increase leads to a reduction in economic surplus (i.e., economic benefit) which typically involves both producers (i.e., producer surplus/profit) and consumers (i.e., consumer surplus) as shown in Figure 3.

Figure 3 shows how a shift in the supply cost function resulting from a reduction in the supply of an EGS input results in a change in producer and consumer surplus. Several features of the shift are notable. First the shift in the supply cost function is postulated not to affect the intercept. This differs with the theoretical discussion developed by Freeman (2003, see Chapter 9). The intercept of the supply cost function represents the price at which all production would cease; this minimum price is dependent on the input costs that even the most efficient producer faces. When the price falls below these input costs, output can only be produced at a loss.[9]

The second notable feature is that the shift in the supply cost functions is proportionally constant (see note in Figure 3). The supply cost functions are represented algebraically for the purposes of deriving estimates of producer and consumer surplus (see Section 2.2.6 for further explanation). The parameter coefficients for the supply cost functions are held constant except for those affected by the change in EGS supply. By doing

[8] Red stars indicate equilibrium price for each level of EGS input.
[9] This assumption has partly been imposed to facilitate the estimation and solution of alternate supply cost functions.

so, the derivation of the supply cost function equations and the derivation of the economic surplus estimates are somewhat simplified. Nonetheless, if information was available to suggest that the shape of the supply curves would vary significantly with changes in EGS supply and those changes were predictable and quantifiable, more complex supply cost function shapes could be accommodated by the PF method. More complex shapes would affect the basic derivation of producer and consumer surplus explained following.

The initial consumer surplus is represented by the sum of areas *a* + *b* + *e* + *f* (i.e., the area above the P_1 price line and below/to the left of the demand function). The new consumer surplus with a shift in the supply cost function is represented by area *a* (i.e., the area above the P_2 price line and below/to the left of the demand function). The loss in consumer surplus is therefore *b* + *e* + *f*.

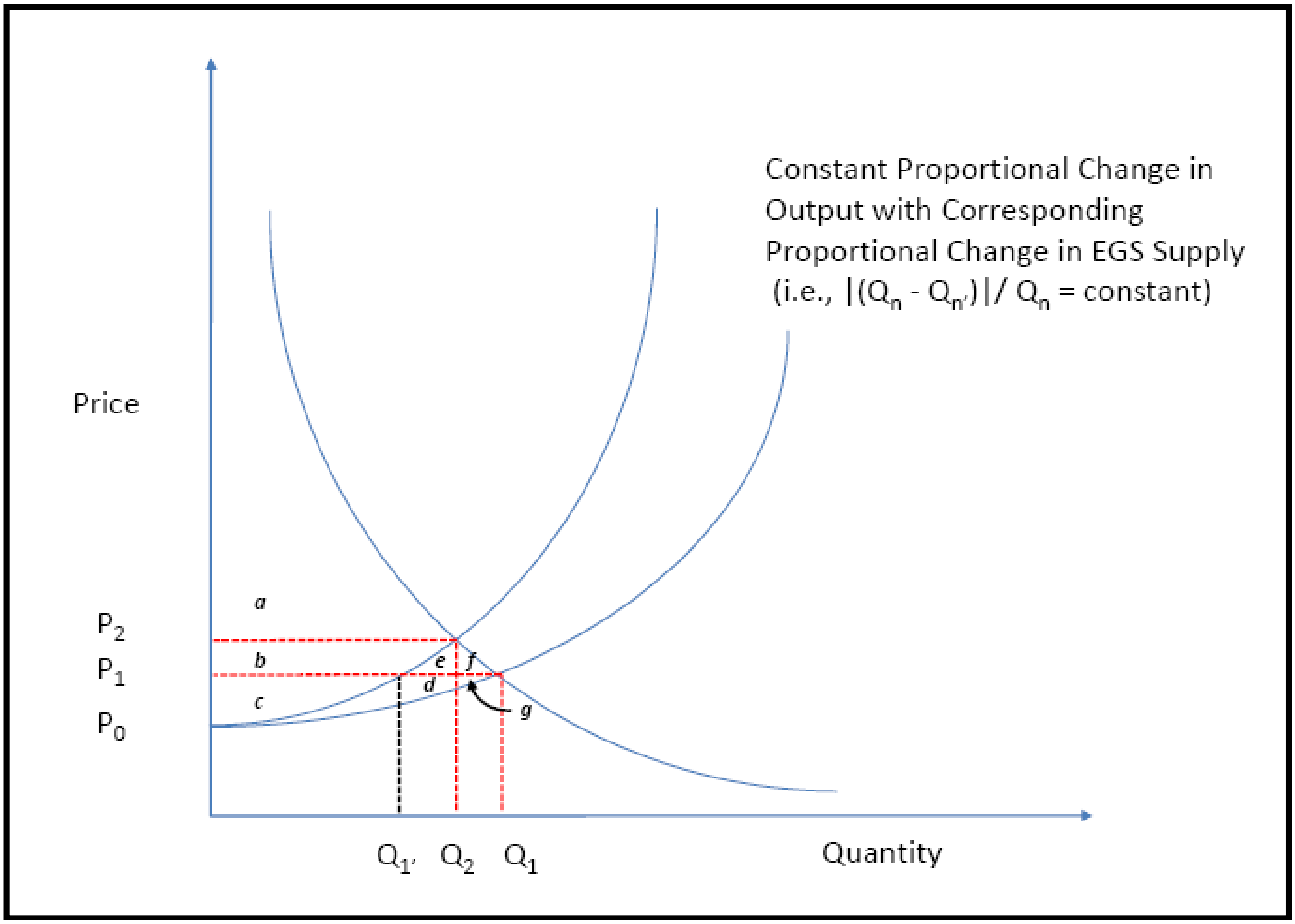

Figure 3 - Change in Producer and Consumer Surplus

The initial producer surplus is *c* + *d* + *g* (i.e., the area below the P_1 price line and above the initial supply cost function). The new producer surplus is *c* + *b* (i.e., the area below the P_2 price line and above the new supply cost function). The change in producer surplus is therefore is *b* - (*d* + *g*).

These relationships have been used to derive producer and consumer surplus estimates for each product for different levels of change in each EGS input.

2.2.3 Conventional Supply Cost Function Estimation Method[10]

The PF method is based on the premise that each producer balances inputs of capital and labour with the price of the product, the expected yield per unit of capital and labour expended and the cost of each. In other words, each producer strives to maximize the realized profit or net benefit (i.e., to maximize the difference between the costs of production and the revenue from the sale of output). This maximum occurs when the marginal cost of production is equal to the marginal revenue (i.e., the market price). In other words, at the point at which adding a unit more of output would cost more than the unit of output could be sold for.

The production of economic output with EGS inputs included is represented by a modified Cobb-Douglas production function as shown in Equation 1.

$$Q = A\, X^{a}\, E^{b} \qquad \textit{(Equation 1}^{11}\textit{)}$$

where:

Q = total production (the amount of output)
X = combined capital and labour input[12]
E = EGS factor input
A = total factor productivity (i.e., a measure of technological efficiency)
a = the elasticity of capital and labour ($0<\alpha<1$)
b = the elasticity of the EGS factor input ($0< b <1$)

Using the cost minimization principle, this function can be transformed to produce the supply cost function in Equation 2[13].

$$dC/dQ = W/\alpha\, A^{-1/\alpha}\, E^{-b/\alpha}\, Q^{(1-\alpha)/\alpha} \qquad \textit{(Equation 2)}$$

where:

W = unit cost of combined labour and capital factor inputs

The structure of this equation is consistent with the practical logic employed by producers; namely, the amount of EGS available affects the abundance of a nature-related good which results in effects on the quantity of output produced/harvested and the level of effort which producers choose to expend. In other words in times of abundance, output will increase both due to an increased allocation of labour and capital by producers and due to the increased productivity of that labour and capital.

The coefficients in Equation 2 are estimated using econometrics and trend-over-time datasets which include key economic and ecological variables (e.g., see Lynne et al, 1981; Ellis and Fisher, 1987). In effect, econometric techniques are used to derive both economic and ecological relationships associated with economic production. A critical requirement to apply this conventional approach to estimating a supply cost function including EGS inputs is a sufficiently robust integrated dataset for both economic and ecological variables. Such datasets are not readily available and require considerable effort to compile; in particular to derive the required ecological data that parallels the economic data over a sufficiently long time horizon to yield statistically significant coefficients.

2.2.4 Conventional Demand Function Estimation Method

The demand for economic output varies with the amount of product available and the price. A simple constant elasticity demand function is commonly assumed (Equation 3).

$$Q = k_d\, P^{-m} \qquad \textit{(Equation 3)}$$

[10] This explanation of the conventional PF method for estimating the supply cost function is based on the description provided by Barbier (2007).

[11] *This version of the CD function is a somewhat simplified version from that described in Section 2.1.*

[12] *This formulation combines capital and labour inputs for the sake of simplicity. This simplification eliminates the possibility of substitution between labour and capital but does not otherwise affect the estimation of the value of the EGS factor input.*

[13] *See Ellis and Fisher (1987) for the details of the algebraic transformation used to derive Equations 2 and 5.*

where:

P = equilibrium price
k_d = a statistically derived parameter
m = the elasticity of demand (assumed to be constant)

Equation 4 is transformed to yield a price equation (Equation 4).

$$P = k_d^{1/m} Q^{-1/m} \qquad \textit{(Equation 4)}$$

Equation 4 can be used to forecast the equilibrium price given a specific equilibrium output. Given the assumption of profit maximization, at equilibrium, this price will equal the marginal cost of supply.

2.2.5 Estimation of Equilibrium Price

Once the supply and demand functions have been estimated, the equilibrium price can be derived (i.e., the point at which the functions intersect). Combining Equations 2 and 4 and rearranging the terms yields Equation 5.

$$Q = [\alpha / W k_d^{1/m} A^{1/\alpha} E^{-\beta/\alpha}]^{m\alpha/[m + (1 - m)\alpha]} \qquad \textit{(Equation 5)}$$

Equation 5 can be used to estimate the economic output based on the unit cost of capital and labour and the EGS factor input. With Equation 5, the supply of EGS can be varied. The result is a change in output (i.e., Q) which can then be used with Equation 4 to derive a new equilibrium price. Combining these results, the marginal value of the EGS natural subsidy can be estimated. As noted above, the problem is that suitable economic and ecological data to derive these equations are not broadly available; in particular, suitable EGS datasets.

2.2.6 Modified Supply Cost Function Estimation Method

A modified method was adopted for this analysis given the absence of suitable long-term ecological datasets for estimating national EGS input relationships. The modified method uses to estimate the supply cost function a similar assumption as that used to derive the demand function with the conventional PF method. Specifically, the supply cost function can be estimated by assuming the coefficients are constant[14].

$$Q = k_s (P - i)^n \qquad \textit{(Equation 6)}$$

where:

P = equilibrium price
k_s = a statistically derived parameter
i = the supply cost function intercept (assumed to be constant)
n = the supply cost function coefficient (assumed to be constant)

Equation 6 is somewhat comparable to Equation 5 in terms of how it used in the modified PF method. The difference is that instead of EGS factor input variable being included directly in the production function, this relationship is captured independently.

$$Q_1' = Q_1 - e_s (E_1 - E_1') \qquad \textit{(Equation 7)}$$

where:

Q_1 = initial total production
Q_1' = adjusted total production with reduced EGS factor input
e_s = a derived parameter that relates the proportional change in production to a specific change in EGS factor input for EGS type *s*
E_1 = the initial supply of EGS type *s*
E_1' = the adjusted supply of EGS type *s*

[14] Note that with the supply cost function, the coefficient is positive whereas with the demand function the coefficient is negative and that an intercept parameter has been added.

Equation 7 can be used to forecast the impact of changes in EGS supplies on physical output. As well, Q_1'from Equation 7 can then be inserted in Equation 6 to yield an adjusted supply cost function.

2.2.7 Modified Estimation of Equilibrium Price

Once the adjusted supply cost function and demand function equations are estimated, the equilibrium price can be derived (i.e., the point at which the functions intersect). Combining Equations 4 and 6 and rearranging the terms yields Equation 7.

$$(k_d/k_s)^{1/n} * P^{m/n} - P + i = 0 \qquad \textit{(Equation 8)}$$

Equation 8 can be solved numerically to estimate the price at which Equation 8 is zero. Once the equilibrium price is derived, the corresponding equilibrium quantity of output can be estimated with either Equation 3 or 6.

2.3 APPLICATION OF MODIFIED PF METHOD

The modified PF method involves estimating new supply curves associated with reduced EGS inputs. For each supply curve, total economic surplus plus the producer and consumer surplus proportions are estimated. More specifically, the area above the supply curve and below the market price (i.e., producer surplus) and the area above the market price and below the demand curve (i.e., consumer surplus) are estimated numerically. The total loss in economic surplus is equal to the sum of the producer and consumer surplus. By calculating the difference in economic surplus between two supply cost functions, the economic benefit associated with the associated change in EGS inputs can be derived. This change in economic benefit is the value of the EGS input. By dividing the loss in economic surplus by the loss in EGS supply, the marginal value of a unit decrease in the EGS supply can be approximated.

This modified PF method has been used in this analysis to derive estimates of the economic value of EGS inputs to the production of nature-related products. The analytical steps for each product and for each EGS input are as follow:

1. Compile basic economic data (i.e., level of output, price; Appendix A),
2. Derive coefficients for demand function equation (Appendix A),
3. Derive coefficients for supply cost function equation (Appendix A),
4. Estimate impact of each key EGS input on economic output (Appendix B),
5. Vary supply of key EGS inputs,
6. Derive new level of output with revised EGS input based on initial supply cost function,
7. Estimate new supply cost function coefficient (i.e., k_s) associated with change in EGS input supply,
8. Derive numerically new equilibrium price, and
9. Calculate the change in producer, consumer and total economic surplus.

Further details are provided following.

2.3.1 Estimation of Demand Function Coefficients

The demand function coefficients are estimated using the same approach used with the conventional PF method (i.e., using Equation 3). The price and output values in Appendix A along with the assumed value of *m* are used to derive the value of k_d; this coefficient is held constant for all changes in EGS supply. Appendix A contains the estimated k_d coefficients for each nature-related product.

2.3.2 Estimation of Initial Supply Cost Function Coefficients

The same procedure that is used to estimate the demand function coefficients is used to estimate the initial supply cost function coefficients. The only differences are:

1. Equation 6 is used instead of Equation 3;
2. The value of n is assumed to be positive and equal to 0.5.

3. The intercept, i, is estimated roughly to be 33% of the price[15].

Appendix A contains the estimated initial k_s coefficients for each nature-related product.

2.3.3 Estimation of EGS Impact Factors

The contribution of EGS inputs to economic output is the critical link in the PF method, and for that matter, any other economic valuation method of EGS inputs to economic production. For example, how much does a marginal increase in pollinator abundance contribute to an increase in the yield of apples? This type of relationship between EGS factor inputs and economic products needs to be specified for all combinations of EGS inputs and nature-related economic products. These relationships are not the realm of economic research but rather are the realm of ecological research. These physical relationships must be understood and specified before economic valuation is possible[16].

The specification of the physical relationships between EGS inputs and economic output is a discrete step separate from the estimation of supply cost function coefficients. Appendix B presents the EGS impact coefficients used in this analysis. These coefficients represent first approximations and are based on the published literature where applicable research has been conducted. Linear coefficients have only been estimated at this time. However, more complex EGS impact functions can readily be accommodated as the scientific understanding required to derive more complex functions becomes available.

2.3.4 Estimation of Initial Economic Surplus

The economic surplus associated with the current level of production and prices is estimated for each product. The estimation of the area under the demand function and above the supply cost function is derived using numerical approximation of the integral (i.e., by calculating the area for a series of parallel slices running from the origin to the equilibrium price). These initial surplus estimates are used to derive the change in surplus for the different levels of EGS inputs. The same numerical approximation procedure is used to calculate the producer surplus. Consumer surplus is approximated by the difference between total economic surplus and producer surplus.

2.3.5 Initial Estimate of Change in Economic Output

Assumed changes in EGS supply are postulated. The magnitude of the assumed change in supply will affect how precise the marginal value of the EGS is estimated. The smaller the change, the more precise will be the approximation.

For each EGS, a standard set of percentage changes in EGS supply was used with the percentage change increasing with greater reductions in supply until a maximum 50% reduction (i.e., 50% of the original supply) is reached. These revised estimates of economic output assume no change in producer behaviour in response to these reductions.

2.3.6 Estimation of Revised Supply Cost Function Coefficients

These new levels of economic output represent new points on new supply cost functions. Figure 3 shows this procedure graphically. The new level of output is represented by Q_1'. The coordinates of this point are Q_1', P_1. The same procedure as that described in Section 3.3.3 is then used to estimate the k_s coefficient for the new supply cost function that passes through this point.

2.3.7 Estimation of New Equilibrium Price and Output

The equilibrium price for the new supply cost function is derived using Equation 8. The solution for Equation 8 is derived by numeric approximation.

[15] This intercept coefficient will vary from location to location and from economic product to economic product. Where detailed economic analyses of a sector have been conducted and intercepts derived empirically, these values should be used rather than a fixed percentage of the price.

[16] Barbier (2000) emphasizes this point on page 50 where he states "in order for this [PF] method to be applied, it is extremely important that the relationship between any environmental regulatory function and the economic activity it protects or supports is well understood."

2.3.8 Estimation of Change in Surplus

The new supply cost function and the estimated equilibrium price are used to derive estimates of the new economic surplus. The derivation is the same as that described in Section 2.3.5. The difference between the new economic surplus and the initial economic surplus is calculated. The marginal value of a unit change in EGS supply is calculated by dividing the change in surplus by the change in EGS supply.

3.0 VALUATION FRAMEWORK

This section examines the strengths and limitations of the analytical framework that has been developed specifically for this project.

3.1 METHODOLOGICAL STRENGTHS

The modified PF method used in this analysis has a number of strengths compared to the methodologies that have been used in other analyses. This section discusses some the major strengths of the modified PF method for estimating natural subsidies and for valuing EGS inputs to economic production for wealth accounting purposes.

3.1.1 Connection to Natural Sciences

The estimation of the physical impacts of changes in EGS supply on economic output is masked in the conventional PF method. With the conventional PF method, econometric techniques are used to derive the elasticity for each EGS factor input (see Equation 1). Further mathematical manipulations of this elasticity coefficient to arrive at an EGS impact coefficient that natural science specialists would understand.

The forecasting of the relationships between EGS inputs and physical output is the domain of ecologists and other natural science specialists. Economists are skilled at converting these physical relationships into economic relationships and deriving the value of the inputs. The econometric foundation for the conventional PF method effectively excludes natural science specialists from using their knowledge and understanding in deriving reasonable impact coefficients.

The modified PF method separates the estimation of the EGS impact coefficients from the forecasting of the economic consequences of changes in EGS supplies. Doping so increases the transparency of the method, particularly for non-economists. The EGS impact coefficients, which are the underlying ecological foundation of the analysis, can be easily reviewed by experts in ecology without them having to deal with the details associated with the economics of the modified PF method.

3.1.2 Ease of Updating

Economic and ecological data and understanding are constantly changing and often independently so. The modified PF method uses readily available economic statistics which can be updated from time to time as new statistics are published. These updates can be made independent of any updates to the ecological dataset and vice versa.

The EGS impact coefficients are clearly laid out in ecologically relevant units. Accordingly these coefficients can be readily changed from time to time through subsequent research and/or expert opinion elicitation methods. As well, the ecological coefficients can be updated without having to undertake extensive econometric re-analysis of large datasets to derive new supply equations.

While the basic data may change over time, the modified PF method itself is firmly based on well established economic principles and is not expected to change substantially over time.

3.1.3 Ease of Communication

The modified PF method is based on economic principles that may be somewhat foreign to non-economists. However, the basic method can be clearly communicated graphically to non-economists without the need to delve into the econometric complexities associated with deriving value estimates. As a result, non-economists will have greater comfort not only in the method but more importantly, in the resulting estimates of economic value of EGS inputs to production.

3.1.4 Economic Rigour

The modified PF method is derived from basic economic principles and theory. As a result, economic value estimates derived using this method are rigourous from a methodological perspective. Economic valuation in general has some serious weaknesses as discussed later in Section 3.2; but if the economic value of EGS inputs to production is to be estimated, the best and most rigourous estimates should be produced.
The modified PF method meets this challenge. The PF method is well established in the literature and has been fairly broadly applied. The modification made to the procedure for estimating the supply cost function does not materially change the method from an economic theory perspective. As a result, estimates of the economic value of EGS derived using the modified PF method can satisfy the strict economic theory requirements that are applicable to such analyses.

3.1.5 Compatibility with Conventional Economic Measures

The modified PF method produces estimates of the value of EGS that are directly comparable and compatible with conventional economic measures, in particular, the stringent accounting rules used for national wealth accounting. This compatibility is critical for policy analyses. For example with cost-benefit analyses, aggregate estimates of benefits and costs are combined to derive net benefit estimates for policy alternatives. These net benefit estimates involve combining conventional measures of value with derived measures of value for non-market goods like EGS. Given the sound economic basis for the modified PF method, no adjustments to EGS values derived using this method are required.

3.1.6 Scale Independent

This analysis of natural subsidies has been conducted at a national scale. The modified PF method however, can be applied at regional and local scales as well. As a result, the modified PF method can also be used to value EGS at regional and local scales as the need may be.

3.1.7 Diverse Applications

Economic values of EGS inputs have been estimated for three economic sectors. A much finer level of product resolution can be analysed using the modified PF method; albeit, data requirements and some further economic refinement of the supply and demand functions may be required. Similarly, the modified PF method could be combined with other economic analysis methods (e.g., input-output analysis) to derive estimates of the value of natural subsidies in subsequent processing stages of the economy. These diverse applications are facilitated by the sound economic foundations of the modified PF method.

3.1.8 Reduced Risk of Double Counting

A common problem with the valuation of EGS is the risk of double counting (see discussion in Section 1.4.3). Double counting arises in many and often subtle ways. Double counting is a common criticism raised by policy analysts when EGS values are proposed to be used to analyse policy alternatives. The modified PF method has the potential to eliminate this problem.

With the modified PF method, the value of EGS is based on actual market transactions and associated economic statistics. No “new” value is being assigned to EGS; instead, the modified PF method captures the proportion of the value of economic production attributable to EGS supplies. Criticisms that EGS values are inflated or hypothetical are not sustainable for this reason.

Further, if the selection of EGS input categories is based on the advice of Boyd and Banzhaf (2006), the risk of including both the value of intermediate and final inputs to production can be avoided. The EGS value estimates produced by this analysis for these reasons have largely avoided the risk of double counting through these means.

3.2 METHODOLOGICAL LIMITATIONS

The modified PF method used in this analysis has several important limitations that should be considered when applying the results for policy analysis. Notably, many of these limitations are not unique to the PF method but instead are common to other EGS valuation methodologies as well.

3.2.1 Generic Limitations of Economic Valuation

The underlying weaknesses of economic theory have been explored extensively in the economics literature. Market failures abound, leading to skewed prices and misleading economic signals. These same weaknesses persist when economic values are assigned to EGS. As a result deriving precise values for non-market goods, including natural subsidies, does not ensure the accuracy of the economic signals that they are intended to communicate. Skewed market prices will result in skewed prices for EGS. Furthermore, this effect may result in EGS prices being over or under-estimated.

A further complexity is the critical underlying assumption with the economic valuation of EGS. That assumption is that the current price structure would be stable if the value of EGS were included in market prices (e.g., payments were made for EGS) or at least, the shift in prices would be so minimal that the current price structure is reasonably representative of what would occur if EGS payments were collected. This assumption is difficult to defend given the myriad of EGS inputs to our economy with potentially large economic significance. However, the alternative is even more daunting; that is re-estimating new equilibrium market prices with the addition of EGS as economic factors within the market.

In addition to these generic economic valuation issues, some weaknesses of economic valuation are particular to EGS. Many EGS valuation studies attempt to derive the “total value” of EGS; in other words, the total economic value of the stock of “natural capital”. The objective often is to generate “big numbers” so that EGS can claim a prominent seat at the “public policy table”. These estimates of total value generally are unreliable from an economic perspective and ultimately for several reasons, are not helpful for making many policy decisions.

As noted above, as the supply of EGS becomes scarcer, the value increases substantially (which is true with most goods in the economy). This trend will continue until a substitute for the input becomes more competitive. For example, the price of wheat will climb as supplies diminish but at the same time, alternate types of grain or vegetable inputs will be used to replace wheat where it is economical to do so. These substitutes create a price ceiling for the good.

The same holds true with EGS supplies. For example, as the amount of untreated fresh water suitable for human consumption declines, water treatment systems may be constructed to replace the water purification services provided by an ecosystem. This relationship has led to using replacement costs as a means to value EGS inputs. However, as the water supply needed to sustain human life drops to critical levels, investing in water treatment plants is useless; water treatment plants have no value if there is no water to treat. Other substitutes may be possible (e.g., importing clean water from elsewhere) but when the total demand for water to sustain humans is exceeded, there is no substitute for this critical requirement to sustain human life. If an estimate of the total natural capital value of water assets was to be derived, the total value would include the value of the last drop of water under conditions of extreme scarcity. The value in this case would be virtually infinite since no substitute exists for the product.

This extreme example illustrates why efforts to estimate the total capital value of EGS have limited use and why some argue that economics should not be used at all to value EGS; at least under conditions of extreme scarcity. Economic valuation becomes largely irrelevant when critical levels of EGS supply occur. Methodologically, many natural capital assessments overcome this problem by valuing the total stock of a given type of EGS by multiplying the stock times the average or marginal price; but current prices do not capture well the exceptional characteristics of some forms of EGS under conditions of critical scarcity, in particular the lack of substitutes. On the contrary, these assessments are based on the underlying assumption that natural capital has comparable economic properties as conventional capital which clearly is not the case.

Fortunately, few public policy decisions involve such extreme conditions and instead, largely deal with small (i.e., marginal) changes to the supply of EGS. Under these conditions, economic valuation can play a useful role but the total value of natural capital is of little relevance to these decisions. The relevant measure is the marginal change in supply associated with each policy alternative and the associated economic value of this change. The modified PF method is designed top produce estimates of the marginal value of natural subsidies.

Finally, economic valuation involves a number of implicit normative assumptions (e.g., current wealth distribution, the interests of future generations, and our relationship with nature). By using economic valuation methodologies unquestioningly, these normative assumptions are in effect endorsed. The challenge is that no other comparable means are available to value the great diversity of goods and services that are important to humans. As a result, when economic valuation results are being used for policy analysis, these implicit normative assumptions need to be considered carefully.

For all of the above reasons, economic valuation should be but one of several measures for making important public policy decisions. When economic methods are used, the underlying normative assumptions should be kept clearly in mind. Finally, economic valuation methods should not be given great weight where public policy decisions involve non-marginal changes that could lead to large scale restructuring of prices (e.g., as is potentially the case with environmental issues like climate change) or where critical levels of non-substitutable EGS are at risk (e.g., endangered species).

3.2.2 Valuation of EGS

Considerable attention has been devoted over the last 15 to 20 years to developing accurate estimates of the economic value of EGS (e.g., Peters et al, 1989; Costanza et al, 1997; Pimental et al, 1997; Olewiler, 2004; Anielski and Wilson, 2006; Wilson, 2008). A large literature dealing with different methods and reporting the results of various studies has been produced. Many innovative valuation methods have been devised and used to estimate the economic value of EGS.

Several common weaknesses in many of these studies are evident. These weaknesses include double counting, weak theoretical foundation and lack of methodological consistency. These weaknesses lead to valid questions by conventional economists and policy analysts as to the applicability and reliability of the results of these studies for guiding major public policy decisions. For example, various critical reviews of the limitations of these valuation methods have been written from various perspectives (e.g., Abson and Termansen, 2009; Spash, 2008). The conclusions of these critical reviews can be summarised as follow:

- no method is perfect;
- the best method depends on the purpose to which the results are intended to be applied and the nature of the ecosystem service being valued;
- economic valuation methods need to be complemented by other decision support analyses in a multi-criteria evaluation framework when policy decisions are being made, and
- economic value estimates can vary greatly from one method to another and from one application/location to another.

This study is an attempt to overcome some of these methodological weaknesses and to produce economic value estimates that are methodologically consistent with conventional measures of economic value and welfare accounting and that are suitable for informing public policy decisions.

3.2.3 Economic Data Demands

The modified PF method has quite modest economic data requirements as a result of a key feature of the method. The estimation of both the supply and demand functions involves a key assumption; namely the shape of both functions has a consistent form. This assumption allows both functions to be estimated based on one point on each curve.

For this reason, the supply and demand functions used in this analysis should be viewed as first approximations. Economists have spent lifetimes deriving complex supply and demand functions for diverse products. Future refinement of the functions developed in this analysis for nature-related products will improve estimates of the value of EGS supplies. While the supply and demand functions used in this analysis are approximate, the modified PF method is fully capable of incorporating more refined and complex functions should they come available. Efforts to refine these functions should be tempered by the significance of the policy question(s) being considered and the importance of the EGS values to the final determination of the best policy alternative.

3.2.4 Ecological Data Demands

The modified PF method is strongly dependent on a good understanding of the impact of changes in EGS supplies on economic output for various nature-related products. The understanding of these relationships largely involve applied science disciplines (e.g., agriculture, forestry, fisheries, hydrology, atmospheric science). In most cases, understanding of these critical relationships is limited to broad generalities and principles. Improving this understanding requires primary research that takes time. However, no matter what economic valuation method is used this understanding is critical.

A further limitation is the absence of a comprehensive national statistical database for EGS comparable to what is available for conventional economic goods and services. National estimates of natural subsidies must use any scattered local statistics that may be available to extrapolate national values. The result is that estimates of the value of EGS are imprecise. This imprecision however, is not a result of the modified PF method but is common to any method that attempts to rigourously quantify the value of EGS. An attractive feature of the modified PF method is that it provides a concise and coherent framework for identifying data needs and for incorporating new understanding and data as they come available.

3.2.5 Assumed Partial Equilibrium

The modified PF method provides estimates of the new equilibrium between supply and demand when EGS supplies are altered. The result is shits in the equilibrium price and the quantity of product produced/consumed. The modified PF method however, does not consider how this shift in the equilibrium price for a single product will ripple through the economy. Depending on the magnitude of the price shift, many market prices could be affected and the resulting feedback may alter the partial equilibrium derived for a single product in isolation. Economists have developed complex general equilibrium models for the entire economy to deal with these types of large scale shifts in the economy. In principle, these models could be used in combination with the modified PF method. Practically however, a more extended analysis of this nature is likely warranted only where large-scale changes in the price of key products are being contemplated.

A closely related issue is the assumption that Canadian prices for nature-related products are largely driven by domestic consumption. The modified PF method uses only Canadian economic statistics and analyses only changes in Canadian EGS supplies. If Canadian production declines but significant competition from foreign producers is present and these producers are not faced with comparable changes in EGS supplies, prices may not vary as much as predicted. Instead, consumers will switch to purchasing the same goods imported from elsewhere. These types of international trade issues are important to a country like Canada that is a large exporter of nature-related products. The modified PF method is amenable to the analysis of these types of trade issues but refinement of the demand functions to account for such relationships is beyond the scope of this project.

3.2.6 Impact of EGS Substitutes

As discussed, a common response of producers and consumers to rising prices/scarcity is to seek substitutes. In the case of fruit producers, for example, as wild pollinator populations have declined greater reliance has been placed on importing domesticated bees to provide this service. The initial supply cost functions developed as part of this project only capture the impact of EGS substitutes to a limited extent. Competitive substitutes will dampen the shift in the supply cost functions with reductions in EGS supplies, the result being reduced derived values for EGS supplies. The impact of substitutes for EGS inputs on prices is similar in concept to the impact of competing products on the sensitivity of supply cost functions for nature-related goods.

3.2.7 Economic Impacts beyond the Primary Production Stage

The results presented in this report account only for the direct impact of changes in EGS supplies on the production of nature-related products. Estimating the full economic impact of changes in EGS supplies would require tracking the primary nature-related production through the entire supply chain and accounting for the impact on the value added at each stage.

No accounting of these impacts has been included in this analysis. Nonetheless, the modified PF method could be readily expanded to track the impact of changes in EGS supplies throughout the supply chain. The results of this type of analysis would be additive to the direct impacts included in this analysis.

4.0 VALUATION RESULTS

The section discusses the data compiled for, and the results produced by, applying the modified PF method.

4.1 SUPPORTING DATA

4.1.1 Economic Data

The economic data for agricultural output that were used for this analysis are presented in Appendix A. These data are for 2008. Prices for agricultural products vary by region. Provincial price data were combined with the corresponding production levels to yield national weighted prices for apples and other fruit products.

The same method was used for fishery products. Different types of fish products were aggregated across different regions to arrive at estimates of the physical output. National weighted prices were calculated by weighting the price of each product type by the weight of the harvest.

Timber harvest data were aggregated for all types of wood across the provinces. Gross government revenues from forestry operations (e.g., land rental, stumpage, other fees and charges) were used to represent the value of the harvested wood. The average price of harvested wood was calculated by dividing the gross revenues by the annual harvest. This method for deriving a proxy for the market price is imperfect and approximate and underestimates the full value of harvested wood. However, this approach is necessary given that the majority of the Canadian timber harvest occurs on Crown land and operates under licence agreements whereby harvested wood is not sold at the roadside by the licencee but is largely consumed by the licencee's integrated harvesting and processing operation with the processed products being what is sold through the market. Deriving proxies for what the competitive market price for harvested wood at the roadside would be in an open market is difficult and imprecise. As a result, the wood price used in this analysis is not as reliable and precise as that used for other sectors. Nonetheless, the proxy price estimated for wood at the roadside is surely an underestimate of its full value. Therefore, estimates of the value of EGS supplies for wood production will also be underestimated.

4.1.2 Ecological Data

The ecological data used for this analysis are presented in Appendix B. In principle, each of the EGS impact factors operates largely independently of one another and can be analysed separately or together. Which combination of EGS factors to include will vary with the policy question being addressed. For the purposes of this demonstration of the PF method, only one EGS impact factor has been applied to each sector; namely, pollination for agriculture, water supply for wood and primary productivity for fisheries. Adding additional EGS inputs would further impact economic output and would be equivalent to higher levels of reduction in the supplies of the EGS types presented in this analysis. As well, if multiple EGS inputs are varied simultaneously, the potential for interactions among the EGS inputs would also need to be considered. These types of complexities are beyond the scope of this analysis.

4.2 AGRICULTURE

Total agriculture production prior to processing in Canada in 2008 was valued at $8.8 billion[17]. For the purposes of this analysis, a small subset of agricultural products has been selected, namely fruit crops. The annual harvest of these crops comprised over 530,000 tonnes and was valued at over $250 million. The fruit harvest from all provinces reported in the national statistics has been included in this analysis. The following results are based on these fruit harvest statistics.

Fruit crops are one of the most sensitive product types to variations in wild pollination services; albeit, other agricultural products are dependent on other EGS supplies. The following results are representative of the scale of economic impact that variations in EGS supplies might have on the value of Canadian agricultural production.

Table 4 presents the estimates of the annual value of wild pollination services for the production of apples and other fruit in Canada. Discussion of these results is presented below.

Reduction in EGS Supply	Change in Economic Surplus[18]			EGS Unit Value ($/% Change)
	Consumer[19]	Producer[20]	Total	
50%	$(84,107,007)	$30,618,157	$(53,488,850)	$(1,069,777)
40%	$(63,592,451)	$23,641,499	$(39,950,953)	$(998,774)
30%	$(45,197,655)	$17,092,656	$(28,104,999)	$(936,833)
20%	$(28,618,401)	$10,970,895	$(17,647,506)	$(882,375)
10%	$(13,623,407)	$5,283,279	$(8,340,128)	$(834,013)
5%	$(6,653,780)	$2,595,180	$(4,058,600)	$(811,720)

Table 4 – Change in Agriculture Economic Surplus: Wild Pollination

4.2.1 Change in Economic Production

A 50% reduction in wild pollination services would result in an annual loss in the value of fruit production of about $53 million. The reduction in output (e.g., the annual production of domestic fruit would decline from about 531,000 tonnes to 457,000 tonnes) would result in the price of fruit increasing significantly (e.g., the price of apples would climb from $365/tonne to $491/tonne).

This price increase would mean that not only would consumers consume less domestic fruit, but that they would have to pay more per fruit. The net result would be a loss in consumer surplus of approximately $84 million. On the other hand, increasing prices would more than offset the reduction in output for producers; as a result, producer surplus would increase by about $31 million. In other words, the loss in wild pollination services would be borne exclusively by consumers.

With less reduction in wild pollination services, the loss in economic surplus becomes less as well. This decrease is not linear due to the non-linear shape of the supply and demand functions.

4.2.2 Value of Wild Pollination Services

The annual value of a one percent decline in wild pollination services varies with the overall amount of decline being considered. The value ranges from a low of about $812,000 to a high of about $1,070,000 per year.

[17] The value of agricultural output is equated to the aggregate net cash farm income.
[18] Economic surplus is a technical term that generally equates to net value.
[19] Consumer surplus is the portion of the change in net value realized by consumers.
[20] Producer surplus is the portion of the change in net value realized by producers.

4.3 FORESTRY

The wood harvest in Canada in 2008 comprised more than 237 million cubic meters and generated more than $730 million in direct gross government revenue[21]. These totals include pulpwood and saw wood with the great majority harvested from Crown land. All harvested wood included in the national statistics has been included in this analysis. The following results are based on these harvested wood statistics.

One of the challenges in analyzing EGS impacts on wood production is the long lag between the time an impact occurs and the time that the wood is harvested; many commercial tree species require 80 years or more to reach a harvestable age. Changes in water supply services have been analysed to reduce the complexity of time lags associated with the impact of other EGS inputs on wood harvest. Reduced water supply is expected to result in increased losses to wild fire, immediately reducing the volume of wood available for harvest.

Even in this case, the impact of a reduction in water supply is only partly captured. Forest fires burn all ages of wood. As a result, a forest fire has not only an impact on the wood immediately available for harvest but also on the wood available for harvest in the future. These future impacts are not captured in these results. Likewise, changes in water supply are anticipated to affect the growth rate of trees; these impacts would accumulate over time. No allowance for cumulative changes in tree growth rates is included in these results. Accordingly, these results underestimate the full impact of changes in water supply services on wood harvest.

Table 5 presents the estimates of the annual value of a change in water supply services for the production of wood in Canada. Discussion of these results is presented below.

Reduction in EGS Supply	Change in Economic Surplus			EGS Unit Value ($/% Change)
	Consumer	Producer	Total	
50%	$(505,255,767)	$129,769,304	$(375,486,463)	$(7,509,729)
40%	$(351,965,150)	$86,852,771	$(265,112,379)	$(6,627,809)
30%	$(234,265,261)	$55,484,894	$(178,780,367)	$(5,959,346)
20%	$(140,593,938)	$31,936,917	$(108,657,021)	$(5,432,851)
10%	$(63,975,826)	$13,911,959	$(50,063,867)	$(5,006,387)
5%	$(30,648,069)	$6,544,564	$(24,103,505)	$(4,820,701)

Table 5 – Change in Value of Harvested Wood: Water Supply

4.3.1 Change in Economic Production

A 50% reduction in water supply services would result in an annual loss in the value of wood harvest of about $375 million. The reduction in output (i.e., a loss of over 60 million cubic metres of wood) would result in the price of wood increasing significantly (e.g., the price would climb from $3.08/m^3 to $5.58/m^3).

With this price increase, the loss in consumer surplus would be approximately $500 million. On the other hand, producer surplus would increase by about $130 million.

4.3.2 Value of Water Supply Services

The annual value of a one percent decline in water supply services for the forestry sector varies with the overall amount of decline being considered. The value ranges from a low of about $4.8 million to a high of about $7.5 million per year.

[21] No measure comparable to net farm income is available for forestry operations. Gross government revenues provide only a partial measure of the value of this sector.

4.4 FISHERIES

The marine fish harvest in Canada in 2008 comprised a total of 475,500 tonnes and generated almost $400 million in gross revenue. These totals include finfish and shellfish. All types of marine fish products included in the national statistics for 2008 have been included in this analysis. The great majority of the annual fish harvest is included in these statistics; the Canadian freshwater fish harvest is a small percentage of the marine harvest. The following results are for harvested marine fish in Canada.

A similar lag, as is present with wood products, is present between changes in some types of EGS supplies and fish harvest but the length of the lag is much less; most fish species reach harvestable age within 5 to 10 years at most. This analysis does not account for these lags and assumes that changes in EGS supplies affect fish harvest in the same year. Failure to account for cumulative impacts of changes in EGS supplies will underestimate the value of these supplies.

These results are based on changes in the primary production rates of marine ecosystems that support Canadian fish harvest. Reductions in primary production result in less food to support populations of higher trophic level species; most commercially harvested marine fish are higher trophic level species. A 10% trophic transfer coefficient between trophic levels and three levels of trophic transfer are assumed between primary producers and harvested fish.

Changes in primary production rates would likely not be exhibited for several years in terms of fish harvest. This analysis assumes that the impacts would be evident immediately. Conversely, secondary impacts associated with declining fish stocks are not captured. As a result, these results may underestimate or overestimate the full impact of changes in primary productivity services on fish harvest.

Table 6 presents the estimates of the annual value of a change in primary productivity services for the fish harvest in Canada. Discussion of these results is presented below.

Reduction in EGS Supply	Change in Economic Surplus			EGS Unit Value ($/% Change)
	Consumer	Producer	Total	
50%	$(7,423,128)	$1,537,273	$(5,885,854)	$(117,717)
40%	$(5,933,621)	$1,228,216	$(4,705,405)	$(117,635)
30%	$(4,446,557)	$919,957	$(3,526,600)	$(117,553)
20%	$(2,961,953)	$612,523	$(2,349,430)	$(117,472)
10%	$(1,479,769)	$305,871	$(1,173,898)	$(117,390)
5%	$(739,583)	$152,838	$(586,745)	$(117,349)

Table 6 - Change in Value of Fish Harvest: Primary Productivity

4.4.1 Change in Economic Production

A 50% reduction in primary productivity services would result in an annual loss in the economic surplus associated with the fish harvest of about $5.8 million. The reduction in output (i.e., a loss of about 2,000 tonnes of harvest) would result in the price of fish products increasing (e.g., the price for shellfish would climb from around $3,280/tonne to $3,290/tonne).

With this price increase, the loss in consumer surplus would be approximately $7.5 million. On the other hand, producer surplus would increase by about $1.5 million.

4.4.2 Value of Primary Productivity Services

The annual value of a one percent decline in primary productivity services for the fishing sector varies with the overall scale of decline being considered. The value ranges from a low of about $117,350 to a high of about $117,720 per year.

4.5 SENSITIVITY ANALYSIS

This section presents the results of a basic sensitivity analysis conducted for these results. These results provide some initial insights into the variability of the EGS value estimates associated with the values assigned to certain key parameters. More extensive sensitivity analysis should be conducted if the compounded impact of multiple parameters is of interest.

4.5.1 Sensitivity Analysis Method

A comprehensive sensitivity analysis would involve varying multiple parameters over a broad range of values. The best method to cope with the uncertainty associated with multiple parameters over large uncertainty ranges would be to incorporate a Monte Carlo analysis routine in the valuation model. Doing so would allow analysts to produce central value and probability range estimates for key parameters. This type of uncertainty analysis would allow EGS values to be expressed with confidence ranges. The sensitivity analysis discussed following is much more limited in scope and does not yield quantitative uncertainty measures.

These sensitivity analysis results are derived for one product, namely apples and by varying one input parameter at a time. Given the common value estimation method for all products, the following results are reasonably representative of the sensitivity of the EGS economic value estimates for all of the products included in this analysis. Only one EGS input has been analysed, namely pollination. The general sensitivity pattern for pollination is also representative of what can be expected for other EGS inputs. However where interdependencies among EGS inputs are present, the sensitivity of the results may differ significantly.

4.5.2 Results

All results are expressed in terms of the percent change in the estimated unit value of the EGS relative to a unit change in the parameter value. The sensitivity measure is the percentage change in the unit marginal value of the wild pollination service. All sensitivity parameters were increased and decreased by 10% and a constant 20% reduction in wild pollination services was used.

The average of the high and low change was used to calculate the sensitivity measure for each parameter. Table 7 shows the base values that were used as the starting point for this sensitivity analysis, the range of values for each sensitivity parameter and the resulting sensitivity measures.

Sensitivity Parameter	Base Value	High Value	Low Value	Sensitivity ($/%)
Demand Function Coefficient	-0.5	-0.55	-0.45	$ 509
Supply Cost Function Coefficient	0.5	0.55	0.45	$ 1,294
Supply Cost Function Intercept	$120	$132	$108	$ 2,774
EGS Impact Factor Coefficient	0.6	0.66	0.54	$ 6,255

Table 7 – Sensitivity Analysis Results

The parameters included in the sensitivity analysis are the ones which involve the highest level of uncertainty. These results indicate that the lowest sensitivity is associated with the value assigned to the demand function coefficient and the highest sensitivity is associated with the value assigned to the wild pollination impact factor. These results should be considered when priorities for refining this analysis are being evaluated.

5.0 INTERPRETATION AND RECOMMENDATIONS

A modified valuation model based on the PF method has been developed specifically for this project and applied to derive estimates of the value of EGS inputs for the production of nature-related products. This section discusses the results of this analysis and the recommended follow-up actions.

5.1 ACHIEVEMENT OF OBJECTIVES

Section 1.2 sets out the objectives for this analysis. These objectives have been achieved. The achievement of each objective is discussed following.

The modified PF method developed through this project is based on conventional economic principles and has allowed reasonable preliminary estimates to be generated for the value of natural subsidies in the production of nature-related goods. These estimates have involved combining conventional economic statistics with appropriate ecological data.

The result of the analysis of these data is estimates of the economic value of a sample of natural subsidies associated with EGS inputs to nature-related products.

National economic statistics for the three economic sectors analysed are provided. The relative economic significance of these natural subsidies is evident by comparing the potential economic impact of reductions in EGS inputs to the total value of the output associated with each sector. These estimates of the value of natural subsidies are not comprehensive but rather are broadly indicative of the scale of these subsidies.

This analysis provides an indication as to how available supplies of EGS impact on the production of nature-related goods in the Canadian economy and their contribution to economic output.

The application of these results for policy analysis is discussed further below.

5.2 APPLICATION FOR POLICY ANALYSIS

Economic methods are useful for informing many, but not all, policy decisions. Where alternative courses of action are being considered that involve incremental change in EGS supplies, techniques like cost-benefit analysis (CBA) and economic valuation methods are helpful. If the EGS valuation method presented in this report is to be used for policy analysis, the following recommendations should be heeded.

The value of EGS inputs to production varies according to local circumstances and the magnitude of the change in EGS supply associated with each policy alternative. Furthermore many, if not most, policy alternatives will affect the supplies of multiple EGS. The combined impact of policy alternatives on all relevant EGS supplies should be analysed and not each impact valued independently. For these reasons, the modified PF method developed through this project should be used to analyse specific policy alternatives based on data relevant to the specific circumstances under consideration. Simply transferring the economic value estimates presented in this report to a specific policy issue is not recommended.

5.3 PRIORITIES FOR REFINEMENT

The modified PF method developed through this project has broken new ground. Considerable progress has been made in refining and applying a technically sound and practical EGS valuation method. That being said, considerable potential remains to use this modified PF method to refine future estimates of the value of EGS supplies. Indeed, the number of potential refinements could be seen by some as being overwhelming; this need not be so.

Even in the absence of more reliable and precise input data, proper application of this modified PF method can inform policy decisions. At the same time, efforts to improve the supporting data should be prioritised based on the policy significance of key parameters and the likelihood that significant improvements in parameter estimates might be achieved through further research and analysis. The highest priority should be given to refining key data that have the greatest impact on those EGS of greatest economic significance and policy relevance. In this regard, the highest priority should be placed on improving the supporting EGS dataset and the associated EGS impact factors.

5.4 AGGREGATED PRODUCTS

These results are based on aggregated product types (e.g., all wood types are lumped into a single category). Ideally aggregate results should be produced by summing up the results for more detailed disaggregated analyses of more specific product types. Detailed disaggregated analysis of specific products would facilitate expert review of key data inputs and underlying assumptions.

For example, the impact of water supply on different tree species and the associated change in yield is much easier to discuss with experts than a generic relationship that covers all tree species and wood types (e.g., timber, pulpwood). For this reason, the modified PF method developed for this analysis should be refined over time by applying this method to more disaggregated product types. The results of these more disaggregated analyses should be combined to refine the aggregate EGS value estimates produced as part of this analysis.

5.5 EXCLUDED SECTORS AND PRODUCTS

The scope of sectors and products included in this analysis has been narrowed as explained in Section 1.4.2. By excluding sectors like nature-based tourism and products like other types of agricultural output (e.g., grain, livestock), the value of certain EGS inputs is underestimated.

For this reason, this modified PF method should be expanded over time to include all nature-related products in all sectors that depend directly on EGS supplies.

5.6 EXCLUDED EGS

The scope of EGS inputs included in this analysis has been narrowed as explained in Section 1.4.3. Excluding some types of EGS inputs underestimates the overall economic significance of natural subsidies.

For this reason, this modified PF method should be expanded over time to include all types of EGS inputs that contribute to economic output. In so doing, care must be exercised to include only final EGS inputs and not intermediate EGS inputs as discussed in Section 1.4.3.

5.7 EGS IMPACT FACTORS

The impact of each type of EGS on the output of individual products has been estimated. These impact coefficients play a critical role in the modified PF method. These coefficients involve a large measure of judgement and the supporting scientific literature is in many cases weak or non-existent. Improving the scientific foundation for these coefficients will require concerted and focussed research over an extended period of time. In the interim, a formal expert opinion elicitation process should be employed to review and refine these EGS impact coefficients.

This process will have many benefits, namely:

1. The estimated value for different EGS will be improved by having better EGS impact coefficients.
2. The results of the expert review will improve confidence in the scientific foundation for the results.
3. As part of the expert opinion elicitation process, participants should be asked to identify future research needs and priorities.
4. Many of the experts participating in the process will likely also be interested in undertaking future research. The elicitation process can be an effective means for communicating research needs and attracting skilled researchers to undertake this work in the future.

A repository of EGS impact factors and supporting research should be maintained. The results of the elicitation process should be used to assist in populating and keeping this repository up to date.

5.8 INTERACTIONS AMONG EGS

The impacts of multiple EGS inputs typically affect the supply function for any given product. For example, water availability and pollination together affect fruit production; these interactions may be synergistic, additive, compensating or some other form of interdependence. The EGS impact factors used in this analysis are strictly based on consideration of the impact of each EGS input in isolation. No allowance for interdependencies among EGS inputs has been included. Nonetheless, interactions among EGS inputs are likely and are also likely to vary with the scale of change in EGS supply and the type of product being considered. These types of interactions should be explored as part of the expert opinion elicitation process recommended in Section 5.7.

If this modified PF method is to be used for evaluating policy options, the interacting effects of changes in multiple EGS supplies should be carefully considered. The key interactions will depend on the nature of the policy options under consideration, the EGS impacts of importance and the local environment.

5.9 IMPACTS OVER TIME

The modified PF method developed through this project involves single point-in-time estimates of the value of EGS natural subsidies. However, most policy analyses involve forecasting impacts over multiple years. An expanded time horizon introduces the potential for additional feedbacks and interdependencies, both economic and ecological. These types of complexities are common to virtually all economic forecasts.

This modified PF method is capable of handling these types of inter-temporal relationships. To do so, these inter-temporal relationships need to be quantified and then applied recursively over the analysis time horizon. New prices and outputs plus EGS supply conditions would need to be forecast for each succeeding time period and the modified PF method repeatedly applied for each time interval based on the new conditions. If a present value of natural subsidies is needed, the economic value estimates for each time period could be discounted accordingly.

The key point is that this modified PF method is capable of dealing with inter-temporal relationships consistent with the techniques conventionally used to address changes over time. Practically, these types of inter-temporal relationships would probably be best managed by incorporating them in a dynamic simulation model in which this modified PF method was a core routine.

5.10 UNCERTAINTY ANALYSIS

Uncertainty is present whenever the future is being forecasted. Nowhere is this more so than with situations involving many factors and complex relationships, the hallmark of ecological and economic systems. The capability to undertake systematic uncertainty analysis should be added in the future to this modified PF method. The uncertainty dataset needed for such analyses should be derived as part of the expert opinion elicitation process recommended in Section 5.7.

5.11 AGGREGATION WITH OTHER ECONOMIC VALUE ESTIMATES

The estimates of the economic value of EGS supplies in this report deal with one specific source of value. These estimates do not represent the total value of each type of EGS or of the different types of EGS combined. These economic value estimates capture only the natural subsidy value of EGS inputs to nature-related products.

Some may wish to add these estimates of the economic value of EGS to other estimates of the economic value of EGS; the objective being to produce more comprehensive estimates of the value of a specific type of EGS. Aggregating these results with economic value estimates derived using other datasets and methods raises issues of methodological consistency, double counting and similar concerns. Any efforts to do so should proceed with considerable care and caution and should be based on a sound economic accounting framework.

5.12 PUBLICATION OF THE METHOD

A large and expanding literature exists involving methods for valuing EGS. That literature includes various applications of the PF method. However, none of the published applications are comparable to the modified PF method developed through this project. This modified PF method has the potential for wide application yet at the same time, it involves some significant deviations from the conventional PF method.

Preparing and submitting for peer review, a scholarly paper outlining this modified PF method is recommended. Doing so will provide further insights on the technical aspects of the method, will communicate the method to a broad audience and will encourage others to refine and apply the method over time; all of which will advance the goal in undertaking this work.

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A ECONOMIC STATISTICS AND COEFFICIENTS

The EGS value estimates presented in this report have been derived using the following national economic statistics obtained from the latest CANSIM datasets. These data correspond to 2008 Canadian output.

Sector	Product	Output[22]	Price[23]	Demand	Supply	
				Coefficient (k_d)	*Coefficient (k_s)*	*Intercept[24] (i)*
Agriculture[25]	Apples	470,531	$ 365	8,988,937	30,091	$ 120
	Fruit	60,390	$ 1,351	2,219,911	1,643	$ 446
	Oilseeds		$			$
Forestry[26]	Wood	237,114	$ 3.08[27]	416,372	135,031	$ 1.02
Fisheries[28]	Marine Fish	475,500	$ 825	13,654,673	16,558	$ 272
	Marine Shellfish	442,625	$ 3,277	25,338,673	7,732	$ 1,081

22 The physical units for output vary by product.
23 Prices are shown as 2008 Cdn dollars. Weighted prices have been calculated using regional data; prices are weighted by the physical amount of output associated with each region. Where multiple products are lumped under one product type, a composite weighted price has been calculated by weighting each product price by the corresponding physical output.
24 Supply curve intercepts are estimated at 33% of the current market price.
25 Agriculture output is reported in tons.
26 Wood production is reported as thousands of cubic metres.
27 The wood price is based on government revenues paid by forest companies to the Crown. These revenues largely represent fees and charges to cover government costs (e.g., protection, silviculture) and are not prices derived from a competitive market. As a result, these revenues are considerably less than the price that the wood would be expected to be worth if it was sold on the stump through a public auction. The great majority of wood harvested in Canada is not sold on the stump but is instead harvested by integrated forest product companies that retain harvesting rights and which sell the large majority of the wood harvested as processed wood products.
28 Fisheries output is reported in tonnes.

B EGS IMPACT COEFFICIENTS

The EGS value estimates presented in this report have been derived using the following impact coefficients for various EGS inputs to production. Blank cells indicate EGS/sector combinations for which there is not a strong connection.

EGS Input	Agriculture		Forestry		Fisheries	
	Impact Coefficient[29]	Effect Threshold[30]	Impact Coefficient	Effect Threshold	Impact Coefficient	Effect Threshold
Pollination[31]	0.6	110%		110%		
Soil Quality[32]	0.8	110%	0.8	110%		
Water Supply[33]	1.2	120%	1.4	120%		
Nutrient Supply[34]	0.5	130%	1.5	130%		

[29] The same impact coefficients and thresholds are used for all products associated a given EGS input. Developing specific coefficients for each product type is an important refinement that should be added to the valuation method. The coefficients are expressed in relative terms; coefficients greater than one mean that a unit change (i.e., percent change relative to current levels) in EGS supply results in more than a unit change in economic output (i.e., percent change relative to current levels). For example, a 1% loss in an EGS input with a coefficient of 1.1 would cause a 1.1% loss in output for the corresponding economic product. The converse holds for EGS impact coefficients less than 1.

[30] The focus of this report is the impact of declining EGS supplies. However the potential also exists to enhance EGS supplies through effective management. As the level of supply increases, at some point further increases in EGS supply will not enhance economic output. Thresholds reflect the declining effect of EGS supplies as they increase beyond current levels and are the point beyond which further increases will not enhance economic output.

[31] The pollination coefficients are based on estimates of the relationship between honey bee abundance and fruit crop yield.

[32] Soil quality includes texture, internal drainage, organic content, nutrient availability, etc. and is closely connected to such things as parent soil origin, climate and land use. In the case of forest products, soil quality is largely controlled by exogenous factors; extensive management of soil quality is uneconomical with most forests in Canada. Conversely farmers actively manage soil quality through chemical additions, cultivation, cropping practices and land management (e.g., drainage). As well, soil requirements vary with plant species. The soil quality coefficients are based assumed changes in organic content; organic content may change due to climate change. The other soil quality variables are more stable.

[33] Water supply relates to the amount of water available during the growing season and the distribution of that water over the season. The water supply coefficients relate to the impact of increased rates of water stress either due to reduced total precipitation or to an altered and less favourable pattern of precipitation.

[34] Nutrient supply relates to the availability of the most limiting nutrient. Typically with most terrestrial ecosystems, nitrogen is the most limiting nutrient; the nutrient supply coefficients are based reduced supply of nitrogen.

EGS Input	Agriculture		Forestry		Fisheries	
	Impact Coefficient	Effect Threshold	Impact Coefficient	Effect Threshold	Impact Coefficient	Effect Threshold
Primary Productivity[35]					1	115%
Water Quality[36]					1.5	110%
Critical Habitat[37]					2.5	110%

[35] Marine fishery products are higher trophic organisms supported ultimately by aquatic primary productivity. Primary productivity is converted into biomass through the aquatic food chain with a certain loss of energy from one trophic level to another. The primary productivity coefficients are based the trophic energy transfer rate remaining unchanged such that the change in fish productivity is directly proportional to the change in primary productivity. This assumption is likely valid provided that the magnitude of the changes to primary productivity are relatively minor and existing food chains remain largely intact (i.e., the trophic energy transfer rate remains constant).

[36] Water quality is a generic term that comprises a large number of chemical parameters that are relevant to some water uses and not others. The water quality coefficients are based changes in the concentrations of contaminants that concentrate in marine fish and reduce their marketability (e.g., mercury).

[37] Critical habitat refers to the habitat components that limit the size and productivity of a fish population. Critical habitat may include spawning, nursery, migratory and foraging habitats. The nature of these habitat components vary widely from one species to the next. Likewise, the specific limiting component will vary from one species to the next and often among populations of the same species. The critical habitat coefficients are based changes in the amount of the limiting habitat component.