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Economic value of Greater Montreal's non-market ecosystem services in a land use management and planning perspective

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The Greater Montreal (Quebec, Canada) area is currently re-evaluating the future of its land use planning and development sector. One of the approaches being considered is the monetization of non-market goods and services provided by biodiversity and ecosystems in this region. This is in the interest of providing decision makers and stakeholders a tool for quantification and comparison. Herein we analyzed land use cover in 2010 and applied benefit transfer using 103 monetary observations from 62 studies. The value measured for the 11 non-market ecosystem services monetized for the Greater Montreal area reached $2.2 billion/year. More than three-quarters of this total value is provided by the services of air quality regulation, recreation, and habitat for biodiversity. Ecosystems providing the highest non-market values are urban forests, woodlands, and wetlands. We believe that the results of this ecosystem services value mapping could lead to better resource allocation and enable policy-makers to design more effective land use policies in southern Quebec.

Keywords: ecosystem services valuation, benefit transfer, spatial analysis, environmental decision-making

La valeur économique des services écosystémiques non marchands de la grande région de Montréal dans une perspective de gestion et de planification de l'occupation du territoire

Une évaluation de l'aménagement et du développement futurs du territoire est en cours dans la grande région de Montréal (Québec, Canada). L'une des approches envisagées à cet effet est la monétisation des biens et services non marchands fournis par la biodiversité et les écosystèmes afin d'offrir aux décideurs et intervenants de nouveaux outils d'aide à la décision, à la fois quantitatifs et comparatifs. Nous avons en ce sens procédé à une étude par la méthode de transfert de bénéfices qui combine l'analyse de l'occupation du sol en 2010 et 103 observations monétaires tirées de 62 études. La valeur mesurée pour les 11 services écosystémiques non marchands monétisés atteint 2,2 milliards de dollars par année pour la grande région de Montréal. Plus des trois quarts de cette valeur globale sont fournis par les services relatifs au contrôle de la qualité de l'air, aux loisirs et aux habitats favorables à la biodiversité. Les forêts urbaines, les milieux boisés et les milieux humides forment les écosystèmes dont la valeur des services non marchands est la plus élevée. Nous sommes d'avis que cette cartographie de la valeur des services écosystémiques pourrait faciliter une meilleure distribution des ressources et aider les décideurs à concevoir des politiques d'occupation du territoire plus efficaces dans le sud du Québec.

Mots clés : évaluation des services écosystémiques, transfert de bénéfices, analyse spatiale, prise de decision en matière d'environnement

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Introduction

The Greater Montreal area (GMA) is home to more than half the population of Quebec, and bears its richest ecosystems and best farmland (CMM 2010). The coexistence of urban development, agricultural activities, and natural systems in recent decades has become a challenge (Cavayas and Baudouin 2008). Although protected since 1978, agricultural lands are continually subjected to real estate speculation and natural environmental processes that result in steady declines—towards the point of no return in many cases (Cavayas and Baudouin 2008). Southwestern Quebec contains the highest concentration of threatened and vulnerable species across the province while having the lowest ratio of land with protected status (FDS 2012).

To address the problems of urban sprawl and provide a balance between city, nature, and agriculture, several major cities around the world are taking new approaches to the management of urban areas, and protect natural and agricultural ecosystems with varying effectiveness (Bourne 2007). The new Metropolitan Plan for Planning and Development proposes the development of the Montreal Metropolitan Community (a political grouping of 82 municipalities) over the next 20 years, focusing on the development of public transportation, sustainable living, healthy environments, and green infrastructures (CMM 2011). This plan offers an opening for progress on environmental governance in the region. In this context, we suggest the analysis of the non-market economic value of the region's ecosystems services (ES) as a developmental tool for the creation of new policies and tactics for effective land management. This tool could be used as part of a plan to counter the loss of biodiversity, ensure ecological functionality of the territory, and maximize ES provisioning. This study seeks to fulfill this goal by providing additional information on how non-market benefits provided by ecosystems contribute to communities' well-being and how they are distributed throughout the region.

The framework of this study consists of five core steps that were adapted from the value transfer methodology proposed by Troy and Wilson (2006). These steps, presented in Figure 1 are organized as follows: the spatial designation of the study area (Step 1) and the classification and mapping of land use cover (Step 2) are detailed in the next section, which offers a general overview of the GMA and describes the current status of the regional natural environment by mapping the land use cover. In the following section, ecosystem valuation methodology (Step 3) is detailed. This section explains the benefit transfer method or how non-market ES values can be screened in the literature and transferred to our study site. The Results section presents the results of the ES valuation literature. The biophysical and land use cover indicators are linked to non-market based economic indicators and the value of 11 ES for nine types of different ecosystems is measured (Step 4). Then, with policy implications in mind, we present and analyze the results for the whole GMA through relevant management geographies (Step 5). Finally, before concluding, results are discussed.

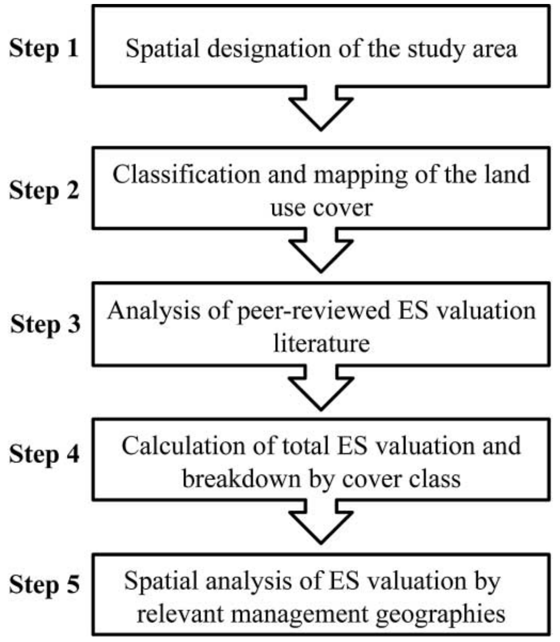

Figure 1
Methodological framework for mapping the Greater Montreal ecosystem service values (partially adapted from Troy and Wilson 2006).

Target area

The boundaries of the territory covered by this study are based on the natural region of the Upper St. Lawrence Plain of Quebec's ecological reference framework (MDDELCC 2014a). It includes two major bioclimatic regions, those of the maple–hickory and maple–basswood (FDS 2012). The 1.7 million hectares territory under study covers the GMA and adjacent territories, whose boundaries are based on persistent elements of the regional landscape (i.e., geology, surficial deposits, topography, climate, network drainage, vegetation, and wildlife). This territory is embedded in Quebec's ecological reference framework—a common, hierarchical ecosystem framework that in turn is embedded in similar Canadian and North American initiatives (Ducruc et al. 1995). Thus, this area does not correspond to an administrative entity but relies on a geographical approach where the territory is delineated according to an ecological logic included in a larger North American framework to allow coherence in land use planning and resources management mechanisms. The boundary of the area and its positioning within the province of Quebec is shown in Figure 2.

Biophysical and socio-economic characteristics

The location and altitude of the area gives it a mild and humid climate; it is home to rich and diverse vegetation. The area covers only 1% of the province, but is home to more than half its population, encompassing the entire metropolitan area of GMA (over 3.9 million people) (CMM 2010). The diverse economic activities, which vary from one region to another, include manufacturing, telecommunications, aerospace, information technology, and pharmaceuticals. The city of Montreal is also a well-known scientific and cultural centre. Agriculture and biotechnology are the main economic drivers in the South Shore region, while recreational tourism and forestry are more prevalent in the North Shore region (CMM 2010).

Provincial biodiversity is highest in southern Quebec where we find the GMA (Tardif et al. 2005). For this reason, anthropogenic pressures pose a serious threat to biodiversity for this region of Quebec. Nearly two-thirds of threatened or vulnerable species are limited to the extreme south of the province (Tardif et al. 2005). Urbanization, intensification of the exploitation of natural resources, agriculture, industrialization, environmental degradation, and the introduction of invasive alien species are some root causes for the loss in biodiversity (Bélanger and Grenier 2002; Jobin et al. 2010).

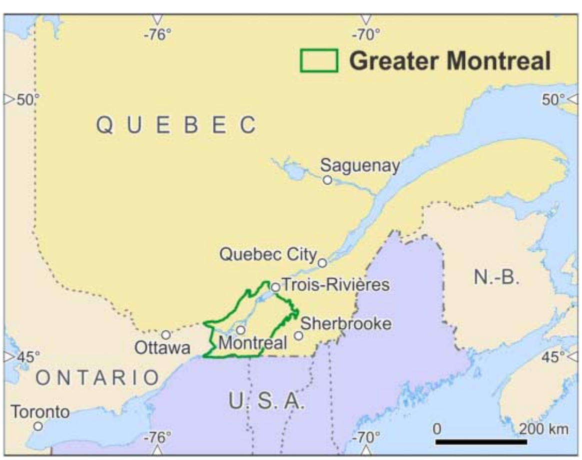

Figure 2
Location map of Greater Montreal Area in Quebec.

Land use cover

Over the decades, the lowlands of the St. Lawrence River have been cleared to make way for agriculture and logging practices that have nearly eliminated all the white pine forests that once characterized eastern Canada (Brisson and Bouchard 2003). Subsistence farming that prevailed until the late 1930s was abandoned to commercial agriculture, with specialty crops farmed over large areas. Since the 1940s, the expansion of the city by way of urban sprawl has led to the development of the northern and southern suburbs within the GMA (Pan et al. 1999; Jobin et al. 2010).

Cartographic analysis of the territory was used to categorize the different land types in the GMA. Using ArcGIS software, we combined six different geospatial databases, each of the databases having different levels of precision for each of the land use cover classes. Combining the databases allows for the best possible definition of land use practices over the GMA. Special care was paid to the harmonizing of databases: as several polygons presented different classifications we had to compare with several geospatial databases to avoid any misrepresentation of land use cover. In the end, the six main categories of land use are agricultural land (41.8%), forest areas (21.6%), urban and developed (21.5%), water bodies (8%), and wetlands (1.4%). The spatial resolution (pixel size) available was 30 metres.

Our distinction between urban and rural areas is based on Statistics Canada's classification. It is founded on a spatial dimension and refers to demographic characteristics such as population size and density and the proximity to important agglomerations (Statistics Canada 2011). An urban space refers to population centres and is defined as an area with a population of at least 1,000 (up to those over one million) and a density of 400 or more people per square kilometre. All spaces that do not fit this definition are considered as rural. The illustration of the land use cover is shown in Figure 3 and summarized in Table 1.

Ecosystem valuation methodology

Many elements of the natural capital do not refer to any existing economic market. Consequently, they are assigned a zero dollar value, which limits their inclusion in the economic system and leads to unsustainable use (Farber et al. 2006). Since in some instances natural resources are scarce and not internalized by economic markets, their importance for natural and human systems—and their undeniable relevance in the creation of wealth and well-being—leads to a misuse. This causes distortions in land use planning and development of urban and peri-urban areas where trade-offs between protection, exploitation, and processing of natural environments are important (Farber et al. 2006). The economic analysis of ES attempts to curb this problem by demonstrating the real contribution of natural capital to the well being of communities.

Further to this, an economic approach can be useful in cost-benefit analysis when comparing alternative options for ecosystem management, or the restoration of degraded ecosystems. For example, a time series analysis of net present values of coffee production in a business-as-usual scenario

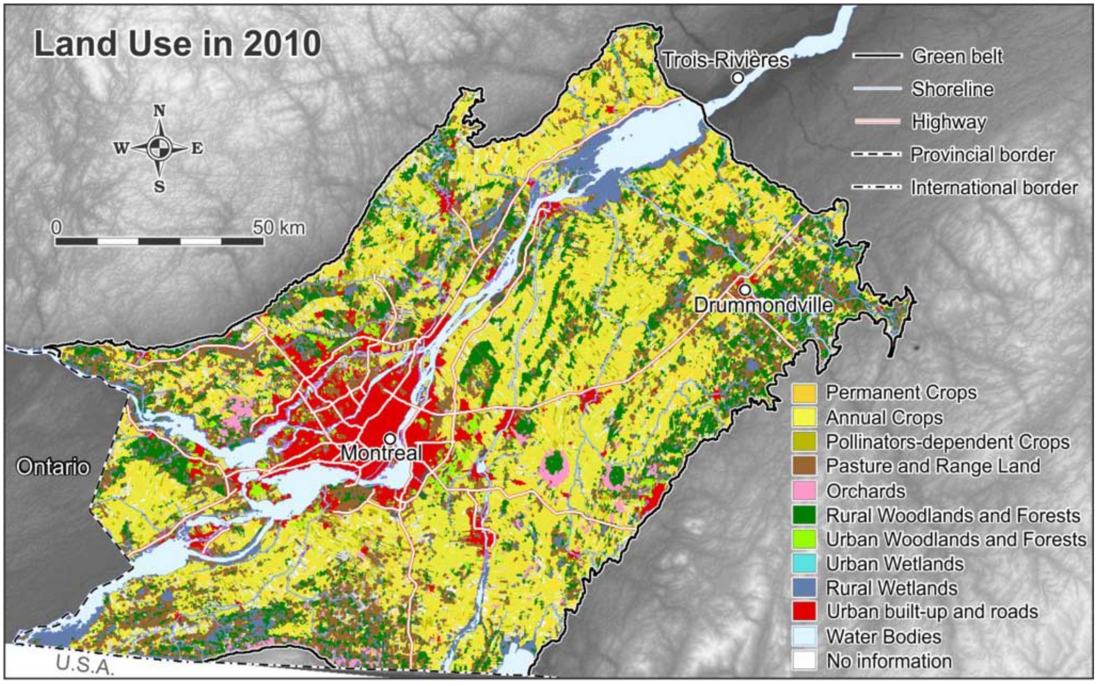

Figure 3

Characterization of the land use cover of Greater Montreal.

SOURCE: Base de données de cultures généralisées (BDCG) - Financière agricole ; Base de données topographiques du Québec (BDTQ) - MRNF ; Inventaire des terres du Canada - Productivité forestière des terres ; Produits du système d'information écoforestière (SIEF) ; Système d'information hydrogéologique (SIH) ; Cartographie des milieux humides de la Communauté métropolitaine de Montréal Canards Illimités Canada.

Table 1
Summary of the land use cover of the Greater Montreal area

Land Use Cover	Total Area (ha)	Total Area (%)
Total	1 726 872	100
Rural Woodlands and Forests	337 215	19.6
Urban Woodlands and Forests	33 477	2.0
Croplands (Annual Crops)	544 024	31.5
Croplands (Permanent Crops)	73 708	4.3
Croplands (Pollinator-dependent)	23 374	1.4
Pasture and Range Land	72 637	4.2
Rural Wetlands	23 194	1.3
Urban Wetlands	954	0.1
Orchards	6663	0.4
Water Bodies	132 561	7.7
Urban	371 459	21.5
Other	107 607	6.2

(i.e., declining pollination due to continued deforestation) *versus* sustainable ecosystem management (i.e., forest restoration) scenarios can be used in more informed policy decisions (Aplizar and Bovarnick 2013). The question, however, is how to internalize the pollination services in the cost–benefit equation? The market cannot recognize the economic consequences of pollination decline if there is no price for it. And since the conventional market does not provide any price information for such services, a simulated market can be constructed to find what the shadow price would be (Richmond et al. 2007).

While market pricing exists for most provisioning services, there are several ways to determine the shadow price for a given ES such as a regulating or cultural service using familiar non–market valuation tools. Some methods are, for example, based on the costs associated with the loss of services provided by ecosystems, or by analyzing the preferences and behaviours of individuals/consumers; these are "primary" methods based on on–site analysis (Rosenberger and Loomis 2001). The alternative approach, known as the benefit transfer method, is a "secondary" analysis that transfers existing results from one site to another (Rosenberger and Loomis 2001).

The benefit transfer method

This method of non–market environmental benefits transfer gives a monetary value to non–market goods when direct research on the selected site is not possible or feasible (Rosenberger and Loomis 2001; Pearce et al. 2006). This unfeasibility may be due to constraints in time or resources, or other reasons. However, it must be remembered that this is a "second–tier" method from an analysis of the target site. It is better to have an approximate value rather than an implicit zero value associated with an ES (Rosenberger and Loomis 2001; Pearce et al. 2006); there are, however, limits associated with this method and they will be explored in the Discussion section.

The development of GIS technologies and the public availability of high quality land cover data sets allowed the emergence of ES mapping studies (Troy and Wilson 2006). Bio–geographic entities can now be more easily linked with the ES they deliver on the ground and result in the facilitation of ES value estimates (Troy and Wilson 2006; Schägner et al. 2013). Over the past 15 years, it emerged as an important research topic as a total of 72 studies using this approach were documented in the scientific literature (69 of them, from 1995 to 2011, are reviewed in Schägner et al. 2013). Benefit transfer of ES has been applied at different scales, from small areas such as a 550ha forest in Scotland (Moons et al. 2008) to the whole biosphere (Costanza et al. 1997; De Groot et al. 2012). Studies have been conducted on urban areas (e.g., Los Angeles by McPherson et al. 2011), administrative regions (e.g., New Jersey by Liu et al. 2010), countries (e.g., Bhutan by Kubiszewski et al. 2013), and natural areas (e.g., the Elbe river by De Kok and Grossmann 2010).

Several methodological classifications of benefit transfer exist, but generally there is a distinction between the transfer unit or fixed value and the transfer of functions (Rosenberger and Loomis 2001; Johnston and Rosenberger 2010). The function corresponds to the relationship between willingness to pay (WTP) and the characteristics of the analyzed site. While the transfer of value uses the result of the relationship between population and environmental change in the site analyzed, the transfer of function applies this function to the target site by adjusting the explanatory or independent variables to their value at the target site (Navrud and Ready 2007). In general, the function transfer is considered to give more robust results by capturing the heterogeneity across different sites through their ecological, socio–economic, or demographic specificity, but the validity of each of the transfer methods depends largely on the context of its use (Johnston and

Rosenberger 2010). Moreover, some studies have found that fixed transfer values perform better than value functions (Brouwer and Bateman 2005; Brouwer 2006).

For ES mapping, the approach can be based on biophysical data, modelling, representative data, or implicit modelling (Schägner et al. 2013). To perform this study, we chose a fixed value transfer approach in which the values were calibrated with gross domestic product (GDP) deflators and purchasing power parity (PPP) conversion factors to fit into our study context. Consequently, using the land use cover data that was measured in the first part of the study, the valuation mapping approach combined adjusted values and biophysical variables to map variations of ES supply across space.

Selected literature

We reviewed the scientific literature on the economic valuation of ES. This review of original articles from peer-reviewed literature led to the acquisition of data that could be transferred to the GMA context. To maximize similarities between sites and minimize bias due to the transfer of values, we used socio-economic and ecological transfer filters.

The socio-economic filter refers to the living conditions of people in the countries where the studies were conducted and was based on the comparison of demographic indicators such as standard of living and education. As the validity and reliability of the transfer of environmental benefits depends largely on the degree of socio-economic similarity between sites, only studies from countries with high income, according to the Gross National Income per capita classification of countries by the World Bank, were considered (Wilson and Hoehn 2006). This filter is particularly relevant when comparing willingness to pay for individuals or households with respect to ES since it tends to be highly dependent on socio-economic characteristics (Johnston and Rosenberger 2010).

For benefit transfer, the characteristics of the biophysical environment must be comparable to allow consistency in ecosystem goods and services production (Wilson and Hoehn 2006). The ecological filter allows comparability between services and ecosystems: they should present the same level of quality and present similar ecological characteristics. If the requirement for these similarities largely constrains the use of this method and questions its credibility, funnelling the literature through these filters limits the potential of bias. We should also mention that so far no agreement regarding the similarity of criteria has been reached in the literature (Johnston and Rosenberger 2010).

Consequently, the ecological filter that we used represents the comparability between services and ecosystems in the studies found in the literature and our site, based on the similarity of the site type (e.g., urban temperate forest), of its quality (e.g., quality of the forests, its size and facilities), and the existence of available substitutes (e.g., number of surrounding urban forests in the area). Only studies produced on sites with similar characteristics to southern Quebec were selected. In general, the ecosystems of Western Europe and North America had the most commonalities.

In the end, the selected studies shared two main characteristics: they estimate values of ES that are also provided by southern Quebec natural and semi-natural's environments, and they refer to temperate regions, largely from North America and Europe.

The relatively low number of studies selected for this research—103 observations (number of $ estimates) from 62 peer-reviewed studies—compared to those available in the Environmental Valuation Reference Inventory database is attributed to the following reasons. First, we considered the valuation of 11 ES to ensure that the services evaluated were actually produced by ecosystems of the target territory. Depending on the classification of ES sources, the number of services may vary, but are still higher than the number we evaluated (e.g., number of ES varied from 17 to 24 in Daily 1997; De Groot et al. 2002; MEA 2005; De Groot et al. 2012). In the studies that mapped ES, value assessments vary from 1 to 22 services while the average is 7 (Schägner et al. 2013). We chose to focus only on non-market services and in a relatively small study area. These parameters explain the number of services and ecosystems evaluated here compared to studies on a global scale. Second, the transfer filters limited the number of primary studies that could apply to our study. Third, the mapping tool and GIS database combination led to the standardization of results in order to enable evaluation of the territory by land cover and allow subsequent aggregation. Thus, we translated the results into value per hectare whenever possible. In other words, WTP per person or household could be converted to per hectare per year value when the relevant information on the case study area and the relevant population size were given. However, many studies provided results that were not transferable units of ground cover. The application of standardized results limited the number of studies we could use for value transfer.

Similarly, it is important to be careful when transferring values from one country to another. In addition to using the exchange rate that maintains constant purchasing power to convert the WTP in another currency (Pearce et al. 2006), several other factors must also be considered—for example, the characteristics of the population, cultural differences or common experience, measures of wealth and income, as well as the scope of the contract. Several additional challenges such as heterogeneity of the studies, the possibility of combining studies, and differences in selection bias may also be encountered (Johnston and Rosenberger 2010).

Adjustment and standardization of values

In analyzing the literature on the economics of ES, we noted that values can be expressed in several units (e.g., $/household, $/hectare, $/year) and are also dependent on currency and the year in which the value was given. This variability in monetary units makes it difficult to compare and makes it necessary to standardize the values to allow the expression of average values and perform aggregations. Consequently, to ensure their contextualization, the economic values for ES were standardized and expressed in 2013 Canadian dollars per hectare per year. This unit is more easily inferable to cartographic tools and land cover data expressed in hectares. From the raw data, the values were adjusted using the GDP deflators of each country and PPP conversion factors relative to the year 2013. Based on the World Development Indicators (World Bank 2013), we consequently used the exchange rates, GDP deflators, and PPP conversion factors to harmonize the units.

Results

The results of the literature review show the value per hectare per year for the ES provided by the different types of ecosystems of the GMA. Table 2 displays the values provided by the urban and rural forests while Tables 3 and 4 focus on wetland and agricultural ecosystems respectively.

The method of benefit transfer has allowed us to obtain an average value for each of the services provided by the nine ecosystems studied. Knowing the location and area of each of the land use cover types (Table 1) and the dollar values per hectare per year (Tables 2, 3, and 4), it became possible to overlay the values and the land use cover types to estimate the total values of the GMA. The tables show that the difference between the values varies greatly, from as low as $4/ha/year for pollination in rural forests and woodlands to as high as $6,773/ha/year for air quality regulation in urban forests and woodlands.

Table 5 presents the value for each of the nine analyzed ecosystems. Those providing the highest non-market values per hectare are urban forests and woodlands and rural and urban wetlands (respectively 11,170, 5,463, and $5,284/ha/year), while the highest total value is clearly provided by rural forest and woodlands ($1,430.1 M/year). The urban forests, annual crops, and rural wetlands all present significant total values (respectively $373.9, $137.1, and $126.7 M/year). The total estimated value for the GMA's non market ES is approximately $2.2 billion/year. Using minimum and maximum values for each ES, this estimate is in a range between $0.8 and $6.0 billion/year.

Table 6 shows the aggregated values presented in Tables 2, 3, and 4 according to the type of ES. We find that the services with the most important total value are air quality regulation ($366.4 M/year), recreation and tourism ($382.4 M/year), and habitat for biodiversity ($910.5 M/year). With total values over $100 M/year, the other services of significant economic value are waste treatment and water provisioning.

Sub-regional spatial analysis

The results show that forested ecosystems found in urban areas present higher values than those in rural zones. This can be explained by their ecological functions and human dependence on ES. In this case proximity translates to a higher impact on the quality of life of communities living close to these forested ecosystems. In urban areas where air quality is poor due to human activity, the additional depolluting treatment provided by urban trees holds higher value, compared to the same ES in rural areas where air quality is generally better (Nowak et al. 2006). From this perspective, Bateman et al. (2006) showed that empirical assessments often confirm

Table 2
Non-market values provided by the forests and woodlands of the Greater Montreal area

Ecosystem Services	Nb. of $ Estimates	Total Area (ha)	Min. Value ($/ha/y)	Max. Value ($/ha/y)	Mean ($/ha/y)	St. Deviation ($/ha/y)	Total Value ($M/y)
Urban Forests and Woodlands	**23**	**33 477**	**7 950**	**20 094**	**11 170**		**373.9**
Global Climate Regulation	4		2	116	48	53	1.6
Air Quality	1		–	–	6 776	nd	226.8
Water Provisioning	1		–	–	594	nd	19.9
Waste Treatment	1		–	–	137	nd	4.6
Erosion Control	–		–	–	–	–	–
Pollination	2		4	224	114	156	3.8
Biodiversity Habitat	3		433	6 987	2 623	3 779	87.8
Disturbance Prevention	–		–	–	–	–	–
Nutrient Cycling	–		–	–	–	–	–
Aesthetics	–		–	–	–	–	–
Recreation	11		4	5 260	878	1 575	29.4
Rural Forests and Woodlands	**39**	**337 215**	**1 157**	**13 513**	**4 241**		**1 430.1**
Global Climate Regulation	4		2	116	48	53	16.2
Air Quality	1		–	–	414	nd	139.6
Water Provisioning	1		–	–	594	nd	200.3
Waste Treatment	1		–	–	137	nd	46.2
Erosion Control	–		–	–	–	–	–
Pollination	1		–	–	4	nd	1.3
Biodiversity Habitat	8		2	6 987	2 344	3 025	790.4
Disturbance Prevention	–		–	–	–	–	–
Nutrient Cycling	–		–	–	–	–	–
Aesthetics	–		–	–	–	–	–
Recreation	23		4	5 261	700	1 170	236.1

declining marginal values and distance decay in direct use values.

Furthermore, there is a close relationship between the scarcity of natural environments and their values as attributed by users and non-users. In urban areas, the competitiveness and trade-offs that characterize land use tend to erode the total amount of natural capital. This scarcity leads to a diminution of available substitute sites and can lead to differences in valuation (Brander et al. 2012). Different criteria can be used to determine relevant alternatives for a specific natural environment: the existence of similar ecosystems in the study area (or within a certain range); similar ecosystems known or visited by the population; all natural sites in the study area or the total possible recreation areas (including non-natural ones) (Brander et al. 2012). The absence of relevant substitute sites for recreation, biodiversity habitat, or other services reveals the appreciation and valuation of that site by the surrounding communities (Brander et al. 2012). To spatially underline the different values between urban and rural ecosystems, we looked at the results in sub-regions embedded in the Montreal ecological area.

Based on the legal frontiers of administrative sub-regions of the Greater Montreal area, Figure 4a shows the average value of all natural and agricultural ecosystems studied in each of these areas. The sub-regions with lower values mean that their ecosystems generally have a smaller per hectare non-market value, as found in agricultural ecosystems in general. Therefore, it tells us about the average value of ecosystems in the sub-regions, but does not reflect their abundance. Figure 4b shows the total value of ecosystems, the value per hectare of each ecosystem multiplied by the total area. Some sub-regions are included in the Greater Montreal area but only in a small percentage of their total area. In consequence, evaluating the total value would not be relevant, and hence we did not include them in the analysis.

Drawn from these figures is the conclusion that terrestrial ecosystems with a high value per hectare can have a low overall value since their total area is low. Breaking down urban ES values serves to enrich the understanding of their contribution to communities, offering added incentive for policymakers to further protect the natural environment. In contrast,

Table 3
Non-market values provided by the wetlands of the Greater Montreal area

Ecosystem Services	Nb. of $ Estimates	Total Area (ha)	Min. Value ($/ha/y)	Max. Value ($/ha/y)	Mean ($/ha/y)	St. Deviation ($/ha/y)	Total Value ($M/y)
Urban Wetlands	**30**	**954**	**143**	**18 691**	**5 284**		**5.0**
Global Climate Regulation	–		–	–	–	–	–
Air Quality	–		–	–	–	–	–
Water Provisioning	2		8	53	30	32	0.03
Waste Treatment	6		0.3	6 224	1 412	2 377	1.3
Erosion Control	–		–	–	–	–	–
Pollination	–		–	–	–	–	–
Biodiversity Habitat	6		22	4 148	1 556	1 946	1.5
Disturbance Prevention	4		75	5 823	1 781	2 732	1.7
Nutrient Cycling	–		–	–	–	–	–
Aesthetics	–		–	–	–	–	–
Recreation	12		38	2 443	505	682	0.5
Rural Wetlands	**42**	**23 194**	**93**	**18 691**	**5 463**		**126.7**
Global Climate Regulation	–		–	–	–	–	–
Air Quality	–		–	–	–	–	–
Water Provisioning	2		8	53	30	32	0.7
Waste Treatment	8		35	6 224	2 252	2 488	52.2
Erosion Control	–		–	–	–	–	–
Pollination	–		–	–	–	–	–
Biodiversity Habitat	8		2	4 148	1 172	1 792	27.2
Disturbance Prevention	5		30	5 823	1 430	2 492	33.2
Nutrient Cycling	–		–	–	–	–	–
Aesthetics	–		–	–	–	–	–
Recreation	19		18	2 443	579	658	13.4

sub-regions where ecosystem values are low but total value is high generally represent areas with a high concentration of agricultural land. For the decision maker, this information calls for the protection, restoration, and enhancement of non-agricultural ecosystems that could increase the global value and diversify the supply of ES on their territory, and for modifying management practices on agricultural lands. As demonstrated by Raudsepp-Hearne et al. (2010), Holland et al. (2011), and Pan et al. (2013), interventions in natural or human-driven ecosystems such as land consolidation, afforestation, fertilization, and conservation tillage lead to a higher supply of multiple ES.

Discussion

Policy implications

In the context of public decision making with respect to land use, the economic valuation of ES should be considered a tool that garners increased respect for ES and biodiversity. Recognizing the economic valuation of ES in this way will allow access to a range of economic indicators that are quantifiable and comparable. The principal policy applications of ES valuation mapping studies are, in order of their occurrence in literature: (1) land use policy evaluation, (2) resource allocation, (3) green accounting, and (4) payments for ES (Schägner et al. 2013).

In the Montreal region, a bundle of existing tools, laws, and regulations support land use planning and management, but the valuation and measure of ES is only used by the Canadian Minister of Agriculture for the development of fiscal incentives to encourage the implementation of agro-environmental practices, as shown by Tamini et al. (2011). The need for new environmental policies is also stressed by the low percentage of protected areas in the region (MDDELCC 2014b). Table 1 presents an area of 370,692 ha of forests, for 19.6% of the total land use coverage of the region and 24,148ha of wetlands accounting for 1.4%. The majority of these ecosystems are subjected to urban development pressures since they are not protected: the region of Montreal is one of the areas with the lowest percentage of protected areas in Quebec (under 5%) (MDDELCC 2014b). Low levels of protected areas, due to private

Table 4
Non-market values provided by agriculture lands of the Greater Montreal area

Ecosystem Services	Nb. of $ Estimates	Total Area (ha)	Min. Value ($/ha/y)	Max. Value ($/ha/y)	Mean ($/ha/y)	St. Deviation ($/ha/y)	Total Value ($M/y)
Croplands (Annual Crops)	**8**	**544 024**	**187**	**374**	**252**		**137.1**
Croplands (Pollination Dependent)		**23 374**	**187**	**374**	**252**		**5.9**
Global Climate Regulation	–		–	–	–	–	–
Air Quality	–		–	–	–	–	–
Water Provisioning	–		–	–	–	–	–
Waste Treatment	–		–	–	–	–	–
Erosion Control	–		–	–	–	–	–
Pollination	2		18	39	29	15	16.5
Biodiversity Habitat	1		–	–	5	nd	2.8
Disturbance Prevention	–		–	–	–	–	–
Nutrient Cycling	–		–	–	–	–	–
Aesthetics	6		21	187	75	68	42.6
Recreation	1		–	–	143	nd	81.1
Croplands (Permanent Crops)	**16**	**73 708**	**489**	**841**	**618**		**45.6**
Pasture and Range Land		**72 637**	**489**	**841**	**618**		**44.9**
Orchards		**6 663**	**489**	**841**	**618**		**4.1**
Global Climate Regulation	–		–	–	–	–	–
Air Quality	–		–	–	–	–	–
Water Provisioning	–		–	–	–	–	–
Waste Treatment	2		100	135	117	25	17.9
Erosion Control	3		59	189	106	71	16.2
Pollination	2		18	39	29	15	4.4
Biodiversity Habitat	1		–	–	5	nd	0.8
Disturbance Prevention	–		–	–	–	–	–
Nutrient Cycling	1		–	–	143	nd	21.9
Aesthetics	6		21	187	75	68	11.5
Recreation	1		–	–	143	nd	21.9

Table 5
Summary of the non-market values provided by ecosystems of the Greater Montreal area

Land Use Cover	Total Area (ha)	Min. Value ($)/ha/y	Max. Value ($)/ha/y	Mean Value ($)/ha/y	Min. Total Value ($M)/y	Max. Total Value ($M)/y	Total Value ($M)/y
Total	**1 726 872**				**839.5**	**6 021.7**	**2 173.3**
Rural Woodlands and Forests	337 215	1 157	13 513	4 241	390.2	4 556.8	1 430.1
Urban Woodlands and Forests	33 477	7 950	20 094	11 170	266.1	672.7	373.9
Croplands (Annual Crops)	544 024	187	374	252	101.7	203.5	137.1
Croplands (Perm. Crops)	73 708	489	841	618	36.0	62.0	45.6
Croplands (Pol.-dependent)	23 374	187	374	252	4.4	8.7	5.9
Pasture and Range Land	72 637	489	841	618	35.5	61.1	44.9
Rural Wetlands	23 194	93	18 691	5 463	2.2	433.5	126.7
Urban Wetlands	954	143	18 691	5 284	0.1	17.8	5.0
Orchards	6 663	489	841	618	3.3	5.6	4.1
Water Bodies	132 561	–	–	–	–	–	–
Urban	371 459	–	–	–	–	–	–
No Information	107 607	–	–	–	–	–	–

Table 6
Summary of the non-market values per ecosystem service

Ecosystem Service	Nb. of $ Estimates	Occurrence in Ecosystems	Total Value ($M)/y
	103		2173.3
Global Climate Regulation	4	2	17.8
Air Quality	2	2	366.4
Water Provisioning	4	4	220.9
Waste Treatment	14	7	122.2
Erosion Control	3	3	16.2
Pollination	4	5	26.0
Biodiversity Habitat	17	9	910.5
Disturbance Prevention	5	2	34.9
Nutrient Cycling	1	3	21.9
Aesthetics	6	5	54.1
Recreation	43	9	382.4

land tenure in the area, increases the need to develop policies that increase the protection of natural heritage. In urban or peri-urban areas where the economic value associated with ES is the highest, policies encouraging private owners to participate in voluntary conservation or donation through fiscal incentives, payment for ES (e.g., for farmers and foresters) could be particularly effective.

Assessing the limits of the benefit transfer approach

The main advantage of the benefit transfer approach is that it reduces the time and cost required to conduct a valuation study. Within a planning context, this may allow a decision maker to evaluate and implement a policy more quickly while requiring less human and financial resources than for a primary study. In this way, a preliminary study can be carried out to better identify where research efforts (through primary study) should be invested. In this study it made sense to do the transfer given the size of the study area and the large number of valued services and socio-economic contexts. Therefore, the results herein can provide a first estimate of the value of GMA ecosystems while highlighting specific areas for primary study with the goal of policy development.

In addition to the limitations mentioned above, two types of errors can introduce further bias in benefit transfer: those affecting primary or measurement error, and generalization errors (Johnston and Rosenberg 2010). The quality of the transfer largely depends on the quality of primary research. In data-poor regions, studies are often conducted with limited resources resulting in low confidence in conclusions. Measurement errors can also occur due

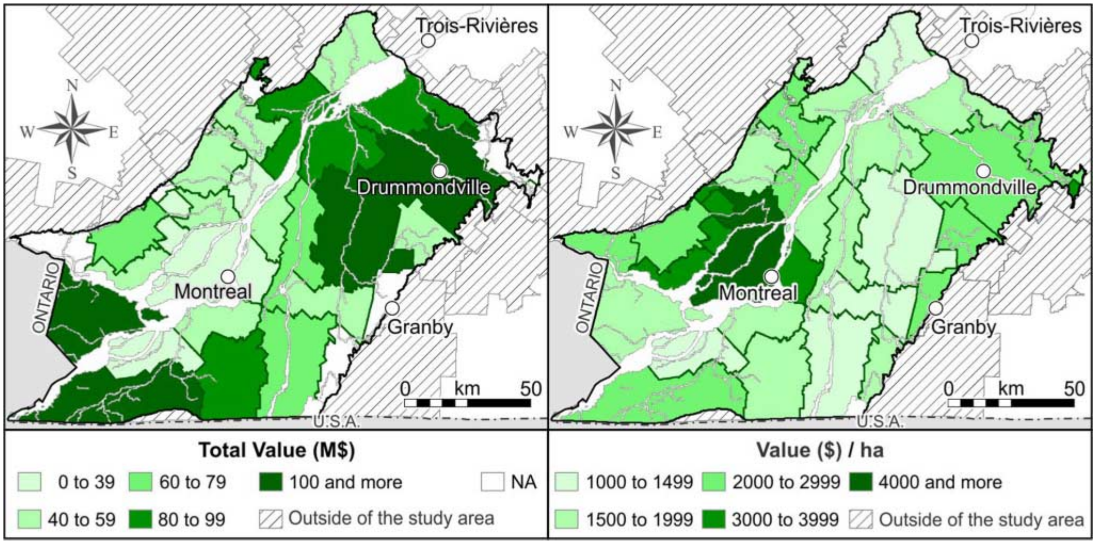

Figure 4
Total non-market value and value per hectare of the ecosystems of sub-regions of the Greater Montreal Area.

to random error or because of judgment and technical assumptions made by researchers (Rosenberg and Stanley 2006). Such results in the primary study are often reported with cautions and limitations, which are often ignored when transferring the results to other studies. In this way, errors of primary research can be transmitted through the transfer and can even be amplified by the transfer method. The error due to the transfer may be due to the mismatch between assets and sites assessed, and is called a generalization error (Johnston and Rosenberg 2010). The magnitude of error is inversely related to the correspondence (e.g., affected markets, ecological and spatial characteristics, time) between the study and target sites. By focusing our transfer on land use cover, ES, and socio-economic factors, we did not take into account factors such as the methodology and marginal changes of the primary studies that are significant in explaining the variance of the results (Liu et al. 2010). Moreover, we used only a limited number of original studies, which limited our capacity to explain the variance in results. The use of meta-analysis, where more variables are taken into account in the transfer, would theoretically have given more robust results. Moreover, as discussed earlier, there is also a potential bias due to the "distance-decay" issue in differential ES value (Bateman et al. 2006).

In short, analysts should look at the trade-offs between the costs of achieving a primary study and the potential losses from a poor decision derived from transferred values (Navrud and Ready 2007). The magnitude of the transfer error that policymakers and analysts are willing to accept should be determined beforehand (Pearce et al. 2006). A good application of transfer methods requires advanced analytical skills, which suggests that practitioners should explicitly observe the limitations raised by the proposed transfer (Pearce et al. 2006).

Future prospects of Montreal's ES valuation

Functional natural processes have several dynamic dimensions that reflect the complexity of ecosystems. However, in spatial analysis and mapping methods, the perspective is static and does not capture the interrelationships that characterize ecosystems. Their dynamics and phenomena, like those related to tipping points for example, cannot be measured in primary studies. As highlighted in Liu et al. (2010) and Dupras and Alam (2014), spatial analysis of a large territory leads to an assumption of homogeneity of services provided by different types of ecosystems. If each ecosystem has a functional uniqueness, it becomes clear that spatial analysis inferring a general value for each ecosystem is reductive. If we do not fully understand how changes in landscape connectivity can affect the provision of ES, both theory and field studies suggest that connectivity is an important factor for both qualitative and quantitative services production (Mitchell et al. 2013).

Considering all the limitations and uncertainties in the methodology, it becomes difficult to determine whether our results reflect the "true" economic value of non-market services provided by ecosystems of the GMA. However, some parameters allow us to say that they constitute a bottom line, which might tend towards higher amounts. Indeed, because of limitations associated with the spatial data layers, we were not able to identify all the natural areas of the territory. For example, we note in Figure 2 that the heart of the study area (i.e., Metropolitan Montreal) is exclusively classified as an urban area. While Montreal and its surroundings are largely built-up areas, there are also many green spaces, lakes, and rivers as important sources of ES delivered to urban people. These unmapped blue and green spaces are not included in the study, but contribute to the provision of important ES, including micro climate regulation through reduction of the effects of urban heat islands, the provision of habitat for biodiversity, the control of water runoff, or the diversification of recreational outdoor activities offered. In addition, these unmapped spaces are located in urban areas, which probably confer a high value despite their small area. Moreover, considering that we evaluated a sub-set of 11 ES from a larger set of potential services, we think that higher economic values could be found through a more exhaustive analysis.

Conclusion

The GMA area covers over 1.7 million hectares—its rich natural diversity distributed over a dynamic set of forests, wetlands, agricultural lands, and riparian areas that provide a set of natural benefits both to communities and on a global scale. ES have a significant economic value for the entire population, businesses, and institutions, even if it has not been taken into account to date by traditional economic markets. This study estimates that these services are worth $2.2 billion annually.

At the political level, poor recognition of natural capital and ES has led to decisions that contribute to the degradation of the environment and threaten the future capacity of ecosystems to offer the same level of welfare (MEA 2005). Recognizing the value of ES provides new information for decision-making that can have a positive impact on achieving economic goals and social objectives. This approach consequently contributes to the development of new economic indicators in the region of Montreal. The characterization of its biophysical land use cover and the evaluation of the ecosystems' non-market values are interesting foundations on which to build further land use and management policies for the sustainable development of the Montreal area and surroundings.

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