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Assigning Unit Values in Ecosystem Services Valuation: A Comparative Analysis of Global, Regional, and Local Unit Values for Three Ecosystem Services in the Grand River Watershed, Ontario, Canada

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Abstract: Economic valuations of ecosystem services often transfer previously estimated global unit values to the geographical setting of interest. While this approach produces quick results, its reliability depends on how representative the large-scale average unit values are for the given local context. Here, we estimate the values of three ecosystem services (ES) – water filtration, nutrient cycling and carbon sequestration – in the Grand River watershed (GRW) of southern Ontario, Canada. The watershed covers nearly 7000 km^2, has a humid continental climate and a population of close to one million people. Land cover is dominated by agriculture. We compare ES valuations using locally derived (i.e., GRW-specific) unit values to valuations based on unit values from a regional database and those compiled in the global Ecosystem Services Valuation Database (ESVD). The regional database includes mean unit values from three case studies within southern Ontario and one boreal watershed in British Columbia. As expected, the regional database yields average monetary values for the three ES that are close to those obtained with the local unit values but with larger associated uncertainties. Using the ESVD, however, results in significantly higher monetary values for the ES. For water filtration, the ESVD value is more than five times higher than the regional and local estimates. We further illustrate the effect of the extent of aggregation of forested and agricultural land categories on the ES values. For example, by subdividing the forest category into three sub-categories (deciduous, coniferous, and mixed forest), the estimated value of the carbon sequestration ES of forested areas within the GRW increases by 15%. Overall, our results emphasize the importance of critically assessing the origin of unit values and the land cover resolution in ES valuation, especially when the latter is used as a policy-guiding tool.

Keywords: ecosystem services, value transfer method, replacement cost method, unit value database, land cover resolution, grand river watershed

1. Introduction

The importance of ecosystem services (ES) is now well established, as well as the need to protect ES against degradation and loss [1]. In almost all cases, humans are directly or indirectly causing the loss of ES through, among others, land use and land cover changes, climate warming, introduction of invasive species, changing lifestyles, and conflicts [2–7]. To highlight the contributions of ES to decision-makers attuned to economic thinking, the concept of assigning economic values to ES was introduced [8]. While the number of studies on economic valuation of ES rapidly grew over the past few decades, many challenges still face its practical uptake in environmental policy and management [9,10]. The value transfer method—a straightforward and popular method for estimating monetary values of ES—uses secondary data from pre-existing valuation studies and applies them to the region of interest. That is, the data originate from other geographical settings and were generated employing a variety of economic valuation methods, e.g., cost-based and survey-based methods [11]. Despite the associated uncertainties, many valuation studies from around the world transfer unit values compiled in global databases to their study area (Table 1).

Table 1. Studies from around the world that have used unit values from Costanza et al. (1997) and the Ecosystem Services Valuation Database (ESVD, 2012) to value ecosystem services.

Study Area	Reference	Dataset used
Texas, USA	[12]	**Costanza et al. (1997)**
Chongming Island, China	[13]	**Costanza et al. (1997)**
Sanjiang Plain, Northeast China	[14]	**Costanza et al. (1997)**
Wenzhou, China	[15]	**Costanza et al. (1997)**
Changsha, China	[16]	**Costanza et al. (1997)**
Shenzhen, China	[17]	**Costanza et al. (1997)**
Bhutan	[18]	**ESVD (2012)**
Czech Republic	[19]	**ESVD (2012)**
Asia	[20]	**ESVD (2012)**
Okanagan, Canada	[21]	**ESVD (2012)**
Portugal	[22]	**ESVD (2012)**
China	[23]	**ESVD (2012)**
Central highlands, Ethiopia	[24]	**Costanza et al. (1997)**
Taiwan	[25]	**ESVD (2012)**
Iran	[26]	**ESVD (2012)**
Iceland	[27]	**ESVD (2012)**

The value transfer method can yield rough first estimates of the economic value of ES in a given geographical unit, for example, a country, province, river watershed or coastal zone. The method is particularly favored in regions where little or no prior ES economic valuation work has been done [28]. Here, we focus on ES in a moderately large watershed in southern Ontario, Canada. River watersheds are the fundamental landscape units of the freshwater cycle. Watersheds are mosaics of surface and subsurface ecosystems and the comprehensive value assessment of all their ES requires a combination of methods and metrics [29]. Because of the diversity of ecosystems and ecosystem functions within watersheds, a full valuation of ES based on primary data may become prohibitive in terms of costs and human resources [30]. Thus, the transfer of part, or all, of the required unit values from existing global and regional databases may be inevitable.

The ranges associated with transferred unit values are typically very large, hence, yielding monetary estimates of ES with equally large uncertainties that, in turn, cast doubt on the reliability and relevance of the ES values. Kennedy for example, compared the value transfer method against cost-based approaches for ES in a region of the Netherlands [31]. This author showed that the value transfer method imparted systematically higher (up to three times higher) values to the ES compared to the other methods. This raises the question as to how meaningful and effective unit values transferred from existing datasets are for informing decision-making at the local level [32–34].

The valuation of (land-based) ecosystem services is often performed by considering two variables [8]: 1) the unit value of a given ES delivered by a particular land-use category (expressed, e.g., in units of dollars per hectare per year), and 2) the area of the land use category in the region of interest. The unit values determine to a large extent the accuracy and reliability of the monetary estimates of ES [35]. There is thus a need to investigate how regional and global unit values compare against primary valuation studies specific to the watershed under consideration. Furthermore, in many studies, diverse land cover types are aggregated into a single land use

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category to match the available unit values. However, the aggregation process itself can significantly affect the outcomes of economic valuation studies [36–41].

With advances in remote sensing, high spatial resolution land cover datasets are becoming available worldwide [42]. This may cause a growing mismatch between the level of detail in local land use data and the coarseness of the unit values in existing databases that only account for major land use categories (for an example of this mismatch, see [24]). To apply the (coarse) unit values it then becomes necessary to aggregate land use sub-categories (e.g., deciduous, mixed plus coniferous forest) into the larger category (e.g., forest). Hence, there is a need to explore the effect of the aggregation of land use categories on the estimated values of ES.

In this paper, we assess the effects of using different unit value and land use datasets on the economic values of three ES, water filtration, nutrient cycling and carbon sequestration. The valuations are carried out for the Grand River watershed (GRW) in southern Ontario. Specifically, we compare watershed-scale monetary values of the ES using local, that is specific to the GRW, unit values against those derived from regional and global compilations of unit values. We further compare the results obtained with the local unit values for two different land use resolutions. Our case study illustrates the danger of using unit values that are not grounded in the local reality, as well as the importance of considering the variable impacts of land use resolution on the valuation of ES.

2. Materials and Methods

2.1 Study Area

The Grand River watershed (GRW) in southern Ontario, Canada covers an area of 680,000 hectares and flows into Lake Erie ([43], Figure 1). It is a multi-use watershed with land cover dominated by agriculture (66%). It has a rapidly growing population of just under 1 million, mostly concentrated in the urban areas. Olewiler previously valued the total natural capital and ES of the GRW at $195/ha/year [44]. Increasing pressures from ongoing population growth, urban expansion and agricultural intensification, however, are negatively impacting the provision of many ES in the watershed [44,45]. Most importantly for our study, primary (i.e, local, GRW-specific) unit values have been estimated for the selected ES (see next section). In addition, detailed land cover data are available (Table 2).

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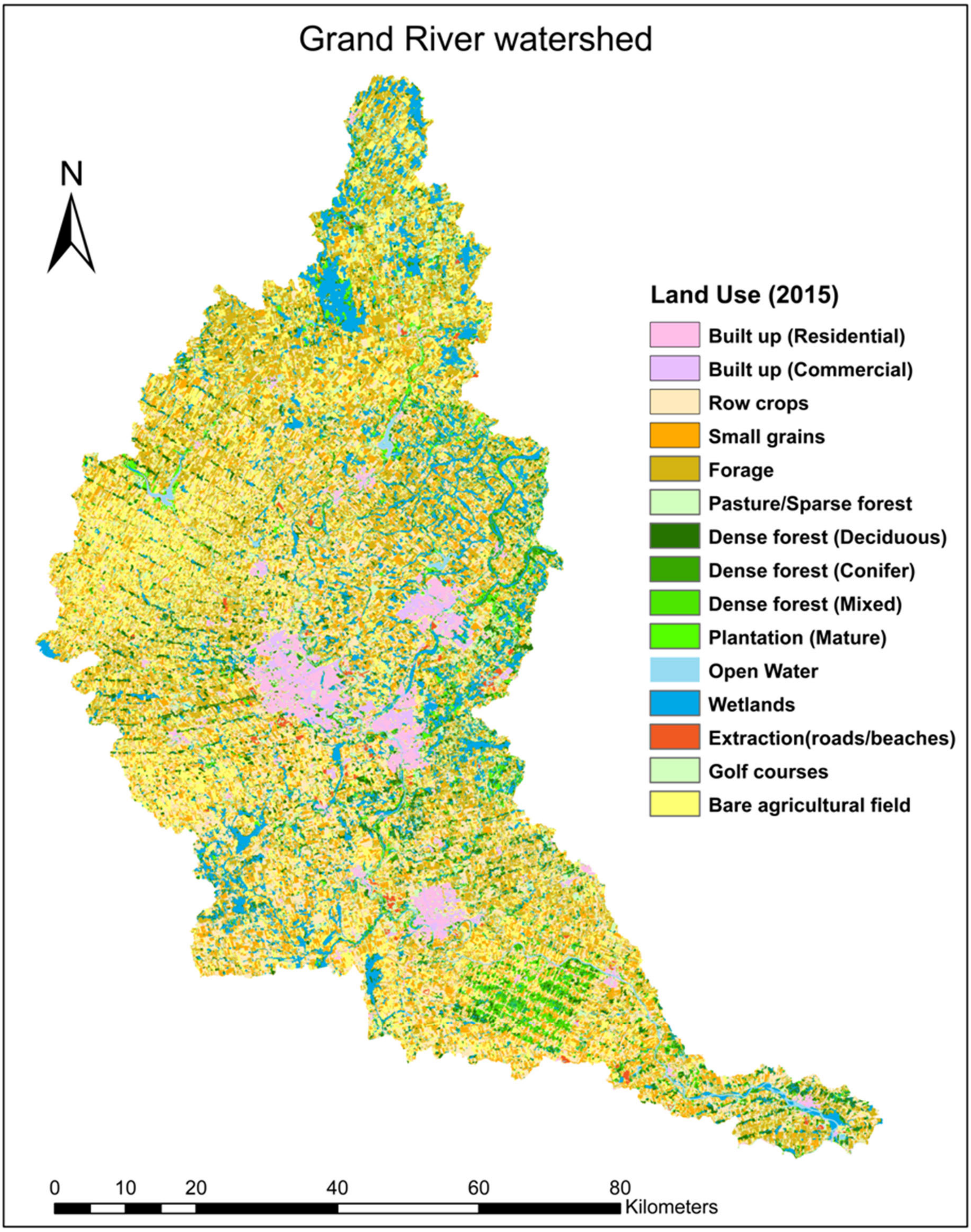

Figure 1. Land cover in the Grand River Watershed, Ontario, Canada (data taken from the Grand River Conservation Authority, or GRCA, website: https://data.grandriver.ca/downloads-geospatial.html).

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Table 2. Areas of land cover categories in the Grand River watershed [43]. Note that the categories shown in Italic are not valuated for ecosystem services. The numbers in bold represent the total area and percentage of the major land-use categories.

Major Categories	Subcategories	Area (hectares)	Area (%)
Agriculture		**446,162**	**66**
	Row crops	133,082	19
	Small grains	79,662	12
	Forage	127,389	19
	Fallow fields	106,029	16
Pasture/sparse forest		**55,660**	**8**
Forest		**72,305**	**11**
	Dense forest (Deciduous)	35,722	5
	Dense forest (Conifer)	11,731	2
	Dense forest (Mixed)	19,497	3
	Plantation (Mature)	5,305	1
Wetlands		**64,278**	**9.5**
Open Water		**8,475**	**1**
Urban		**29,442**	**4**
Extraction	*(roads/beach/bedrock)*	***3,256***	***0.5***
Total		**679,820**	**100**

2.2. Economic Valuation of Three Ecosystem Services

The annual monetary value of a given ES integrated over the entire watershed was calculated as follows [12]:

$$ESV = \sum_{k=1}^{n} (A_k \times UV_k) \quad (1)$$

where ESV is the total ES value for the watershed ($/year), A_k is the area (ha) of land cover category k, UV_k is the unit value ($/ha/year) of the selected ES provided by land cover category k, and n is the total number of land cover (or land cover) categories considered. All unit values used here were recalculated to 2017 Canadian dollars (CAD) using the Bank of Canada's inflation calculator.

Equation (1) was applied to three ES: water filtration (or purification), nutrient cycling and carbon sequestration. These ES were selected because they are key to, respectively, drinking water source protection and supply, soil fertility, and climate regulation. Furthermore, their values are closely linked to the performance of local ecosystem functions, as well as regional socio-economic and, particularly in the case of climate change mitigation, political factors. Nutrient cycling reflects the nature and management practices of agroecosystems, including fertilizer usage, crop rotation and nutrient abatement strategies [46]. Carbon pricing politics across various levels of government affect the value of carbon sequestration, while the loss of natural water filtration capacity in turn may require additional investment in conventional (engineering) water treatment infrastructure.

The use of equation (1) requires that the unit values and land cover categories coincide. Thus, when unit values are only available for major land cover categories (e.g., forest, agriculture, open water) the areas of land cover sub-categories must be aggregated to generate the total area of the corresponding major category. Alternatively, when unit values are available for multiple land cover sub-categories but the land cover data only covers the major land cover categories, then the unit values of the land-cover sub-categories must somehow be averaged to produce a single value for the major land cover category.

2.3 Unit Values

2.3.1. Local Unit Values

Local unit values for the three ES based on primary biophysical and economic data specific to the GRW have been estimated by Aziz (2018) and Belcher et al. (2001). Both studies used cost-based

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approaches, including the replacement cost, and avoided cost methods, to derive the unit values. Cost-based approaches are appropriate to valuate a single or a limited number of ES, given that technological solutions cannot replace all the services provided by an ecosystem [47]. The resulting unit values, expressed in 2017 CAD, are listed in Table 3. Because these values are specific to the GRW they are henceforward assumed to yield the best (i.e., most accurate) baseline valuations for the watershed.

Table 3. Local, regional, and global unit values of three ecosystem services for land cover categories in the Grand River watershed. Where no unit value is shown, the ES provided by the given land cover was not valuated in the source study or, for the global unit values, in the ESVD dataset.

Ecosystem Service	Providing Land Covers	Value (2017 CAD/hectare/year)		
		Local	Regional	Global
Carbon Sequestration	Forest	485±30[a,b]	430±540	680±1570
	Pasture/sparse forest	110±75[a]	35	585±580
	Wetlands	100±10[a,b]	16	215±340
	Open water	-	16	-
	Cropland	35±5[a]	-	-
	Fallow fields	35±5[a]	36	-
Water Purification	Forest	105±28[a,b]	420±230	10±20
	Pasture/sparse forest	175±75[a]	-	115±140
	Wetlands	105±10[a,b]	850±750	4690±6910
	Open Water	20±15[a]	260	290±370
	Cropland	115±5[a]	-	466
	Fallow fields	115±5[a]	-	-
Nutrient cycling	Forest	135±35[a]	300±420	145
	Pasture/sparse forest	545±2[a]	30±1	-
	Wetlands	240±13[a]	1170±1800	2665±3730
	Open water	930±105[a]	30±45	-
	Cropland	15±45[a]	-	-
	Fallow fields	15±45[a]	30	-

[a]Aziz (2018); [b]Belcher et al. (2001); [a,b] average of the values in Aziz (2018) and Belcher et al. (2001).

2.3.2 Regional Unit Values

To build a regional dataset of unit values for the three ES, we reviewed existing valuation studies conducted for Canadian watersheds or areas. The studies were screened using web-based search engines/databases (Google scholar and Web of Science), and the Environmental Valuation Reference Inventory (EVRI; https://www.evri.ca/), which was developed by Environment and Climate Change Canada to help analysts interested in assessing environmental services. EVRI allows users to scan and select studies of interest [48]. For the regional unit values dataset in the present study, we only selected valuation studies that entirely or partially used local data to generate unit values and, hence, can be assumed to best reflect the local socio-ecological context.

Three of the four studies extracted from EVRI are in southern Ontario, that is, the region where the GRW is located. As shown in Figure A1, the studies correspond to (1) the Greenbelt [49], which surrounds the Greater Toronto Area and overlaps with the GRW in places, (2) all of southern Ontario [50], which includes the GRW, and (3) the Lake Simcoe watershed [51], a watershed neighboring the GRW. The fourth study area is the portion of the Peace River watershed within British Columbia, Canada, which is located in the boreal climate zone [52]. We included this watershed to align with the ESVD database which aggregates temperate and boreal forests into one category. For each of the three ES and each land cover, we computed the arithmetic average unit value and the standard deviation from the corresponding unit values reported in the four selected studies. In some cases, however, the same unit value was assigned in all four studies, in which case

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no standard deviation was computed. Henceforth, the average unit values derived from the four studies are referred to as the regional dataset (Table 3).

2.3.3. Global Unit Values

To derive global unit values of the three ES, we based ourselves primarily on the ESVD [53]. ESVD considers 10 biomes, each with 22 ES. The unit values for each biome are based on a review of over 300 local case studies across the world. The 22 ES are further divided into 90 sub-services. In total, the database contains more than 1350 individual unit values and 665 standardized values. Unit values are expressed in 2007 international dollars per hectare. Because it includes a larger number of case studies, recent ES valuation studies tend to prefer ESVD over the earlier global dataset of Costanza et al. (1997) (Table 1). As can be seen in Table 3, the ESVD does not provide unit values for all the land cover categories covered by the local dataset, for example, pastures and forests have no unit values assigned for the nutrient cycling ES.

2.4 Land Cover Resolution

Aggregation of land cover data or unit values, or both, becomes inevitable in some situations depending on the availability of unit values and the resolution of land cover data. To assess the effect of aggregation, we used high- and low-resolution land cover areas for forests and agriculture in the GRW (Figure 1). The forest category was subdivided into three sub-categories: deciduous, coniferous and mixed forest. The agriculture category was similarly subdivided into three sub-categories: row crops, small grains and forage. Aziz (2018) estimated the local unit values of the three ES (water filtration, carbon sequestration, nutrient cycling) for each land cover sub-category in the GRW [54]. These values are given in Table 4 and were used directly in the high-resolution land cover calculations. In the low-resolution calculations, for each land cover category we imposed the arithmetic average of the unit values of the corresponding sub-categories.

Table 4. Local unit values ($/ha/year) of three ecosystem services for sub- and major- landcover types (in bold; arithmetic average of landcover subcategories). The total values (million $/year) for high and low resolutions of agricultural and forest land cover types are obtained by applying Eq.(1), using the unit values and land cover data given in Table 2. The "*Total*" value represents the combined value of each ecosystem service for agricultural plus forest land cover types.

Parameter	**Land cover**	**Sub-categories**	**Ecosystem services**		
			Carbon sequestration	Nutrient cycling	Water filtration
Unit values of ecosystem services ($/ha/year)	**Agriculture**		**35±5**	**15±45**	**115±15**
		Row crop	52±13	70±115	102±100
		Small grains	28±8	18±18	98±98
		Forage	24±2	-42±80	125±90
	Forest		**910±55**	**135±35**	**178±80**
		Deciduous	1330±160	145±20	178±80
		Coniferous	540±60	110±22	178±80
		Mixed	855±110	130±15	178±80

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	Plantation	910±70	130±10	178±80
Value of ES (million $/year) for high resolution	Agriculture	12.2±1.9	7.7±18.5	37.3±19.2
	Forest	70.5±6.1	9.0±0.8	11.9±3.4
	Total	*82.72±6.4*	*16.7±18.5*	*49.2±19.5*
Value of ES (million $/year) for low resolution	Agriculture	11.8±1.7	5.2±15.9	36.8±18.9
	Forest	60.8±5.6	8.6±0.7	11.9±5.4
	Total	*72.6±5.9*	*13.8±16.0*	*48.8±19.6*

3. Results

3.1. Whole-Watershed Valuation of the Three Ecosystem Services

Combined, the annual values of the three ES (water filtration, carbon sequestration, nutrient cycling) in the GRW are estimated at CAD 209±18, 227±136 and 746±518 million CAD (2017) with the local, regional, and global unit values, respectively. The single highest value is for the water filtration service estimated using the global unit values (Figure 2). For water filtration and nutrient cycling the values decrease in the order of global > regional > local. For carbon sequestration, the regional unit values yield a lower value than the local unit values. Overall, however, local and regional values are in reasonable agreement, although the regional unit values impart much larger standard deviations to the estimated ES values.

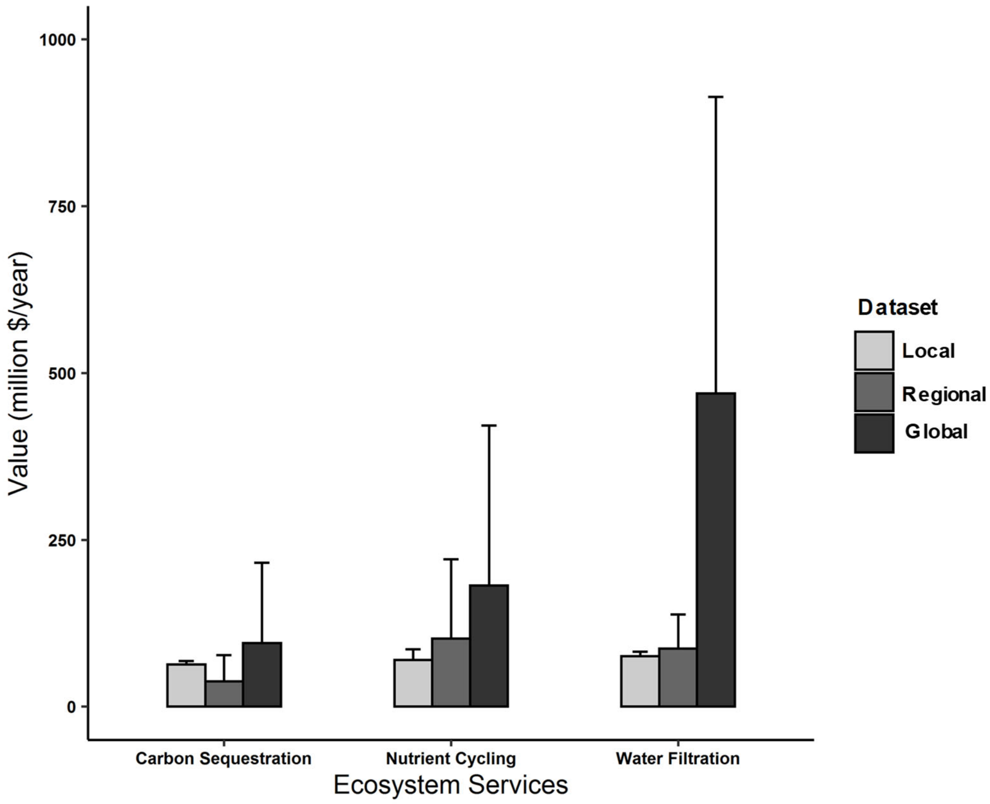

Figure 2. Total value of three ecosystem services in the Grand River watershed based on three datasets (i.e., local, regional, global). (See section 2.2.1 for details on datasets). Error bars show standard deviations. All values are in CAD 2017.

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The global unit values result in the highest monetary values for the three ES. The estimate for water filtration is more than five times greater than the local and regional estimates. This is a result of the order-of-magnitude higher global unit values for water filtration and nutrient cycling by wetlands, compared to the corresponding local and regional unit values (Table 3).

3.2. Impact of land cover resolution

The results of combining the forest and agricultural sub-categories into major categories are summarized in Table 5. The forest land cover contributes most to carbon sequestration despite only representing 11% of the area of the watershed, compared to 66% for agricultural land. The importance of forests reflects their very high unit value for carbon sequestration. By aggregating the different forest subcategories, the value of carbon sequestration by forests drops by 14%, that by agriculture by 3%. The larger drop for forests is a consequence of the higher variability in the unit values assigned to the forest sub-categories. Water filtration is the least impacted when aggregating the land cover sub-categories because differences in the unit values among the subcategories are small.

Table 5. Total values of forest and agriculture for low- and high-resolution land cover data (inferred by aggregating the value of three ecosystem services given in Table 4). The P values are from t-Test (given in Tables S3–S5).

Land cover data	**Value (million $/year) of land cover**		
	Forest	Agriculture	Total
High resolution	91±7.0	57±27	149±28
Low resolution	81±8.0	54±25	135±26
Percent change, Ci (%)	**12**	**6**	**10**
P (T<=t) two-tail*	**1.64E-06**	**0.32**	**1.24E-05**

* For P ≤ 0.05, there is a significant difference between the means. The details of t-Tests are provided in the Appendix A (Tables A4–A6).

4. Discussion

Global datasets of unit values offer a ready solution for estimating the economic value of ES in data-poor regions (Table 1). Prior to the ESVD, many valuation studies used the Costanza et al. (1997) dataset of unit values together with the value transfer method. The dataset was originally assembled to raise awareness about the need to recognize and value ES. In that respect, it has very successfully served its purpose, with the resulting global monetary estimates clearly showing the critical importance of ES to human wellbeing [55]. The Costanza et al. (1997) dataset includes the values of 17 ES in 16 biomes synthesized from more than 100 studies that, in turn, were based on a wide variety of methods and underlying assumptions, with only a few unit values derived from primary data.

Costanza et al. (2014) re-estimated the total monetary value of global ES based on the 2012 ESVD unit values. For the same land area distribution of terrestrial biomes this yielded an approximately 6 times higher value than that estimated based on the 1997 dataset (both converted to 2007 international dollars). There are numerous reasons for the differences in unit values between the two global datasets, including the availability of new data, evolving functionality of ecosystems, and changes in human or built capital [55]. The unit values for wetlands (swamps/floodplains) and open water (lakes/river) showed minimal differences, which can be explained by the fact that these ecosystems were already well-studied when the Costanza et al. (1997) dataset was established [55]. It should be noted, however, that the Costanza et al. (1997) estimates have been criticized for overestimating the unit values for wetlands and underestimating those for croplands [35]. Nonetheless, because it is more comprehensive database, we use ESVD as the reference global dataset of unit values.

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As expected, the global unit values are also characterized by much broader ranges compared to those in the regional and local datasets. According to de Groot et al. (2012) the following five reasons explain the high variability of the unit values in ESVD: (1) the inclusion of a very large number of valuation studies from around the world, (2) the variety of valuation methods used, (3) the variety of subservices considered, (4) the possibility of double counting, and (5) the variability of unit values across geographies, as well as over time [53]. Other factors may interfere with the transferability of unit values across geographies, such as differences in income and income inequality [56].

In the study here, we compared the values of three non-market ES obtained by transferring global unit values to those based on unit values derived from local biophysical and cost data in a moderate size watershed (GRW, ~7000 km^2) using the replacement cost method [57]. As representative ES where the replacement cost method can be readily applied, we considered water filtration, carbon sequestration and nutrient cycling. In principle, these ES can be replaced or compensated by water treatment, carbon pricing and fertilizer applications [54,58]. The unit values can therefore be derived from contemporaneous local market prices and costs, that is, market values serve as proxies for the valuation of the ES. These local unit values help overcome the assumption that the supply of ES by a particular land cover is constant from one location to another [59]. Overall, more efforts should go toward generating locally relevant unit values. Although this requires more work than simply transferring unit values from a global dataset, it will confer credibility to the estimated ES values and help restore confidence in the practicality of ES valuation.

Our results show that the value estimates are markedly higher for the nutrient cycling and water filtration ES when applying the global ESVD than local unit values (Figure 2). The values from the regional dataset agree much more closely, which is not surprising given that the four case studies included in the regional dataset are in Canada, with three of them in the same region as the GRW. In addition, these studies and the associated estimations of the unit values were conducted over a relatively short time span (six years). That is, the general agreement between the local and regional values reflects the closeness in biophysical and socio-economic characteristics, as well as the current state of knowledge in ES valuation, underlying the two datasets [60]. The standard deviations of the values estimated with the regional dataset, however, are significantly higher than those of the local dataset.

The GRW is dominated by the human-managed ecosystems that cover a growing fraction of the continents [61]. Global datasets of unit values, such as ESVD, tend to focus on natural ecosystems and their services, however. In agriculture-dominated watersheds, the transfer of unit values from global datasets may therefore be unreliable because it fails to capture the relevant local environmental and socio-economic context [62]. For instance, for the three ES considered here, ESVD does not valuate ES provided by agroecosystems but assigns very high unit values to other land covers, most notably to wetlands (Table 3). The high ESVD wetland unit values are one of the main reasons for the large deviations between the global and local value estimates, even though wetlands make up less than 10% of the GRW area (Table 2). The local unit value for water filtration by wetlands was derived using local water treatment replacement cost estimates, while many unit values in the literature rely on contingent valuation methods. The latter methods typically valuate a broader set of welfare benefits and preferences associated with clean water and therefore tend to yield higher unit values.

Land cover resolution can substantially alter estimated values of ES [63]. Konarska et al. (2002), for example, report an increase by 200% of the total value of ES in the United States when switching from a 1-km satellite land cover resolution to a 30-m one [64]. Such a dramatic effect of land cover resolution is not seen for the ES in the GRW (Table 5), although the lower (coarser) resolution decreases the values of carbon sequestration and nutrient cycling by forests and agricultural landscapes by 14-17%. The much larger effect seen by Konarska et al. (2002) is due to the detection of ES-rich land covers (e.g., wetlands) in the 30-m resolution satellite data that were not recognized in the 1-km resolution data. By contrast, in our study, the total spatial coverages of forest and agricultural lands remain constant at the high and low resolution; the only factor influencing the ES values is aggregation of sub-categories into the corresponding major category. The observed changes therefore reflect the variability in unit values of sub-categories within the major land cover categories. In other words, at the regional to local scales, increasing land cover resolution can only improve ES valuation if it can be paired with a reliable assignment of unit values to newly emerging land cover sub-categories.

When valuating ES, it is crucial to identify the methods and underlying assumptions that are used. Although the use of global datasets may be inevitable in regions with no primary or local unit values, the caveats of transferring global unit values to a specific watershed or area should be clearly delineated to avoid undermining the credibility of the estimated ES values. This is especially important when ES valuation is included into decision-making processes, as these should be based on reliable and locally relevant monetary values. In that respect, the transfer of global unit values to areas where land cover, climate, biodiversity and socio-economic conditions deviate significantly from their global average counterparts may be risky, and potentially counter-productive. To enhance the relevance of ES valuation for policy, establishing, documenting, and regularly updating national and regional datasets of ES unit values would seem to be the most logical step forward.

5. Conclusions

The value transfer method offers a simple method to monetize ES, especially when limited information and quantitative data are available on the local supporting ecosystem functions and economic context. As shown here, however, the transfer of unit values from global databases such as ESVD can introduce a high degree of uncertainty in ES values. For the GRW, the large differences in the values of water filtration and nutrient cycling estimated with global versus regional and local unit values reflect both the specific biophysical characteristics of the watershed, largely dominated by agricultural land cover, and the methods underpinning the derivation of the unit values (e.g., replacement cost & contingent valuation methods). In the case study presented here, the comparative analysis underpins the credibility of the local unit values for the three ES considered, precisely because they are valuated in one of the most densely populated and agriculturally intensive watersheds in Canada. By contrast, the very large, often by orders of magnitude, ranges in valuation estimates that are obtained using global unit values, such as ESVD, limits their practical acceptance and even undermines their uptake in decision making processes. The valuation of broad land cover and land cover categories (e.g., forest, wetlands, agriculture) represents a further source of uncertainty that brings into question the relevance of the estimated ES values. Research should therefore focus on refining ES unit values to match the increasingly high-resolution earth-surface mapping capabilities. While valuating ES has shown potential to inform land planning, environmental policy, and infrastructure investments, further advances will need to clearly identify, quantify, and reduce the sources of uncertainty in ES unit values.

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Appendix A

A1 Regional Values

Four studies on valuation of ES conducted across Canada (Figure A1) are used to establish the regional dataset. The values of three ES (carbon sequestration, water purification and nutrient cycling) are extracted from the regional dataset (Table A1). Some of the studies did not assign any value to these ES and some few assigned zero values. If there is only one value available for an ecosystem service, we refer that as the best estimate.

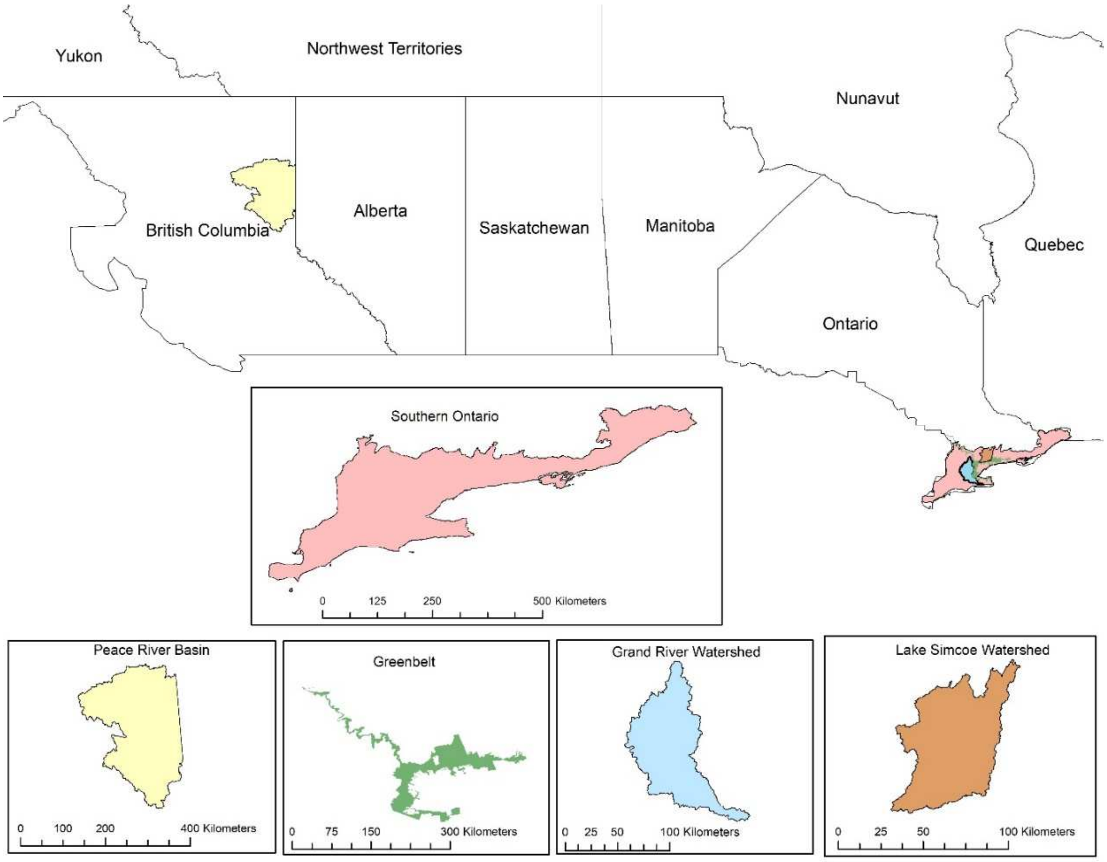

Figure A1. The location of areas/watersheds across Canada used to derive regional unit-value dataset of ecosystem services (top). The areas are magnified for their shape and size in the panels below.

Table A1. Unit values of ecosystem services for major biomes taken from regional studies

Ecosystem Services	Providing Land Covers	Value ($/hectare/year)		
		Low	Best	High
Carbon Sequestration	Forest		48[a]	815[b]
	Pasture		35[a]	
	Wetlands		16[a]	
	Open water		16[a]	
	Cropland	0[a]	-	
	Fallow fields		36[a]	
Water Purification	Forest	258[c]	583[a]	
	Pasture	0[c]		

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	Wetlands	258[c]	583[a]	1701[b]
	Open Water	258[c]		
	Cropland	0[c]		
	Fallow fields	0[c]		
Nutrient cycling	Forest	0[c]		596[e]
	Pasture/sparse forest	29[c]		28.5[e]
	Wetlands	0[c]	275[d]	3225[e]
	Open water	0[c]		63[e]
	Cropland	0[c]		-
	Fallow fields			30[a]

[a][49];[b][44]; [c][51]; [d][52]; [e][50].

Table A2. Different features of the selected studies for regional database.

Parameters	Study Area	Studies used for regional database			
	(Grand River)	Southern Ontario	Greenbelt	Lake Simcoe	Peace River basin
Area (ha)	679,820	12,449,039	760,420	330,741	5,611,799
Dominant land use	Agriculture	Agriculture	Agriculture	Agriculture	Forest
Population density (people/ha)	1.50	0.90	1-3.65*	1.20	0.01

*population density at inner and outer rings of the greenbelt.

Results of t-Tests

We conducted the following t-Tests to assess the significant differences between the two mean values based on low and high resolution data:

Table A3. t-Test: Two-Sample Assuming Unequal Variances for forest.

	Variable 1	*Variable 2*
Mean	91	81
Variance	20	25.5
Observations	15	17
Hypothesized Mean Difference	0	
df	30	
t Stat	5.940885258	
P(T<=t) one-tail	8.22489E-07	
t Critical one-tail	1.697260887	
P(T<=t) two-tail	1.64498E-06	
t Critical two-tail	2.042272456	

As P <0.05, there is a significant difference between the two means.

Table A4. t-Test: Two-Sample Assuming Unequal Variances for Agriculture.

	Variable 1	Variable 2
Mean	57	54
Variance	256.6666667	221
Observations	55	51
Hypothesized Mean Difference	0	
df	104	
t Stat	1	
P(T<=t) one-tail	0.159815774	
t Critical one-tail	1.659637437	
P(T<=t) two-tail	0.319631548	
t Critical two-tail	1.983037526	

As P <0.05, there is a significant difference between the two means.

Table A5. t-Test: Two-Sample Assuming Unequal Variances for total value of forest and agriculture

	Variable 1	Variable 2
Mean	149	135
Variance	275.5	238.5
Observations	57	53
Hypothesized Mean Difference	0	
df	108	
t Stat	4.582575695	
P(T<=t) one-tail	6.19494E-06	
t Critical one-tail	1.659085144	
P(T<=t) two-tail	1.23899E-05	
t Critical two-tail	1.982173483	

As P <0.05, there is a significant difference between the two means.

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