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Comparative valuation of potential and realized ecosystem services in Southern Ontario, Canada

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ABSTRACT

The full production of a given ecosystem service is called the potential ecosystem service; the fraction of the potential ecosystem service that is actually used by society is referred to as the realized ecosystem service. Because they are directly contributing to human well-being, the realized ecosystem services are of particular socio-economic importance. A key challenge faced by the economic valuation of ecosystem services is how to differentiate between realized and potential ecosystem services. Here, we address this challenge for Southern Ontario, which is the most densely populated region of Canada. We apply the Co$ting Nature model to generate the combined spatial distribution and use intensity of a bundle of six ecosystem services: water provisioning and supply, water quality, carbon sequestration, carbon storage, flood regulation, and nature-based tourism. The relative distribution of the potential ecosystem services is then combined with region-specific unit values for the land covers supplying the ecosystem services. The unit values are expressed in 2017 Canadian dollars per hectare and per year. Our analysis yields a total potential value of the bundled ecosystem services of $19 billion per year for Southern Ontario. To estimate the value of the realized ecosystem services, the potential values are scaled by the corresponding relative use indices. The resulting value of the realized ecosystem services is $9.7 billion per year, that is, about 50% of the value of the potential ecosystem services. The importance of accounting for the use intensity of ecosystem services is illustrated for the Greenbelt, a protected area of about 7600 km^2 surrounding the Greater Toronto-Hamilton conurbation, which is home to more than nine million people. Within the Greenbelt, 61% of the value of potential ecosystem services is realized, significantly higher than the regional average. Of particular importance is flood regulation by the Greenbelt, given the growing threat of urban flooding in the Toronto area.

1. Introduction

The value of ecosystem services depends on their direct or indirect consumption by humans (François et al., 2005; Costanza et al., 2014; Goldenberg et al., 2017; Jones et al., 2016). Thus, it is important to determine what fraction of the full supply of an ecosystem service, or a bundle of ecosystem services, generated in a given area is actually consumed or used (Burkhard et al., 2012). However, valuation studies often consider the full supply of ecosystem services but not their actual consumption (that is, the demand side). There is, however, the increasing realization of the need to distinguish the supply and use of ecosystem services (Burkhard et al., 2012; Goldenberg et al., 2017; van Jaarsveld et al., 2005). For example, the use of payments for ecosystem services to upstream land owners in order to protect downstream water supplies (Chan et al., 2017) requires a knowledge of the spatial arrangement of service providing and service consuming areas. The ecosystem service supply in a given area is called the potential ecosystem services, while the fraction of the potential ecosystem services that is consumed is defined as the realized ecosystem services (Goldenberg et al., 2017). Although some studies distinguish potential and realized services (e.g., Fisher et al., 2008; Goldenberg et al., 2017; Syrbe and Walz, 2012), there is a paucity of studies which use this concept practically in mapping and valuating the services.

There is no single agreed upon definition of ecosystem services. This raises confusion about implementing the outcomes of ecosystem service assessments (Wainger and Mazzotta, 2011). Additionally, valuation studies of ecosystem services usually only provide monetary estimates for the potential ecosystem services (e.g., Camacho-Valdez et al., 2013; Costanza et al., 2014, Costanza et al., 1998, 2006; Dupras et al., 2016; Kennedy and Wilson, 2009; Kubiszewski et al., 2013; Parrott and Kyle, 2014; Tianhong et al., 2010; Tolessa et al., 2016; Zhao et al., 2004). However, information on the supply and use of ecosystem services

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would aid the decision-making process regarding land use planning and management. It is also helpful in identifying upstream provider areas for the payment of ecosystem services used by people living downstream (Fisher et al., 2008; Silvestri and Kershaw, 2010; Wei et al., 2017). Thus, the lack of clarity in accounting for realized ecosystem services limits the practical application of ecosystem services valuation in policy and management (Jones et al., 2016).

The relationships between potential and realized ecosystem services differ depending on the nature of the ecosystem services. For example, carbon storage and sequestration services help mitigate climate change globally and, therefore, most of the potential supply of these services is realized (Baró et al., 2015). By contrast, the water provisioning service by headwater streams may only be realized when the water is used by downstream communities, businesses and agriculture. Thus, in general, there is no reason to expect potential and realized ecosystem services to overlap in space and time (Mulligan and Clifford, 2015). Consequently, characterizing and comparing the distributions of potential and realized ecosystem services in a given geographical areas can guide investments and prioritization for restoration projects and other land-use activities (Allan et al., 2015).

Because realized ecosystem services are used by the people, their values have a concrete economic impact (Fei et al., 2018). Valuation of realized ecosystem services can thus strengthen the understanding of the geographical context and relative significance of different ecosystems to people’s well-being. For example, a forest located in the remote wilderness will provide less realized ecosystem services compared to a forest situated in the vicinity of a densely populated urban area. The valuation of realized ecosystem services may, in turn, justify efforts to protect natural ecosystems in peri-urban areas (Mulligan and Clifford, 2015).

Complementary information and data on ecosystem services can help policy makers meet the challenge of sustainability (Bennett and Chaplin-Kramer, 2016). The need for more specific information on ecosystem services is emphasized in many policy documents on sustainable development. However, the existing valuation studies tend to be biased towards the supply side of ecosystem services, while there is much less information on the demand and use of ecosystem services. The demand for, and use of, an ecosystem service varies with population density, socio-economic factors, location and time, and it also differs across different ecosystem services (Geijzendorffer et al., 2017). A clear distinction between potential and realized ecosystem services would go a long way in highlighting the impact of ecosystem services on human well-being (Wei et al., 2017) and assisting decision makers in aligning policy with sustainable development goals.

Realized ecosystem services depend not only on the distribution of the potential ecosystem services but also on the distribution of the beneficiaries. Capturing realized ecosystem services (i.e. the demand side) via spatially-explicit analyses is currently identified in the literature as a key challenge (Castro et al., 2014). We selected the region of Southern Ontario to implement a methodology differentiating the value of realized from the value of potential ecosystem services. Several studies have valuated ecosystem services in this region, or in watersheds located within the region (Kennedy and Wilson, 2009; Troy and Bagstad, 2010; Wilson, 2008a, 2008b; Aziz, 2018) but, to our knowledge, no study has made the distinction between potential and realized ecosystem services. In this paper, we consider a bundle of six ecosystems in Southern Ontario, and explicitly account for their use intensity to determine and compare the spatial distributions of both realized and potential ecosystem services and assess their respective economic values.

2. Materials and methods

2.1. Study area and land use data

With close to 13 million inhabitants, Southern Ontario (Fig. 1) is the most densely populated region of Canada. Not surprisingly, the majority of the natural ecosystems in this region have been converted to human uses, including urban settlement, managed forests and agriculture. The major cities in Southern Ontario include Toronto, Kitchener-Waterloo, London, Kingston, Ottawa, Hamilton and Windsor. Major river systems include the Grand, Thames, Credit and Humber Rivers (Crins et al., 2009).

Within Southern Ontario, we selected the watersheds that are managed by conservation authorities (https://conservationontario.ca) and for which up-to-date land use data are available. The Southern Ontario Land Resource Information System (SOLRIS) provides land use data updated to 2016 for ecoregions 6E and 7E. Several key initiatives in the province, such as source water and natural spaces protection, and biodiversity conservation, are based on the SOLRIS data (MNR, 2008). These land use data comprehensively cover most of the area managed by the conservation authorities in Southern Ontario, with the exception of watersheds managed by the Mississippi Valley, Rideau Valley, Quinte and Crowe Valley conservation authorities that are only partially covered by the land use data. Therefore, we selected those areas which fall under the jurisdiction of conservation authorities and are also covered by the SOLRIS data.

The SOLRIS data divide land use into 28 total categories (major and subcategories) for the selected region. For valuation purposes, we aggregated the subcategories into six major land use categories (Fig. 1): Forest (includes treed cliff and talus, mixed, deciduous, coniferous, hedgerows and plantations); grassland (includes open and treed alvar, tallgrass prairie, tallgrass savannahs and tall woodlands); wetlands (include treed swamps, thicket swamps, fens, bogs and marshes); open water (includes lakes, reservoirs and rivers); agriculture (includes tilled and undifferentiated agricultural features); and built-up plus extraction areas (includes roads, residential areas, industrial terrain and extractive industries). The total area of the region covers nearly 7,500,000 ha with 61% of the total area covered by agricultural land (Table 1).

2.2. Spatial distributions of potential and realized ecosystem services

To model the potential and realized ecosystem services in the selected region, we used the open source version of Co$ting Nature, an ecosystem services mapping application (Bagstad et al., 2013; Mulligan et al., 2010; Mulligan and Clifford, 2015). Co$ting Nature was accessed in February 2017 at http://www.policysupport.org/costingnature. The web-based tool incorporates pre-loaded global datasets of hydroclimatic, biophysical plus socio-economic data, and the open source version generates maps of the following bundle of six ecosystem services: water provisioning and supply, water quality, carbon sequestration, carbon storage, flood regulation (hazard mitigation), and nature-based tourism (including recreational and aesthetic values). Note that the bundle includes representative ecosystem services that range from global, via regional, to local services.

Co$ting Nature identifies both potential and realized ecosystem services and yields their spatial distributions on a relative scale with corresponding service indices that range between 0 and 1. At its core, Co$ting Nature relies on GIS databases and hydrological and biophysical models to capture distributed hydrological and ecosystem processes, assign potential ecosystem services, and estimate the consumption of these services across the selected area (Silvestri and Kershaw, 2010). Realized ecosystem services are derived based on the local to global scale uses of the corresponding potential ecosystem services. Except for global services, such as carbon sequestration, the realized ecosystem services depend on the corresponding potential ecosystem services, user population and infrastructure in the region. For example, Co$ting Nature estimates the realized water supply service by taking into account the regional availability of clean water, the number of dams and the sum of all downstream users (Mulligan, 2015). However, Co$ting Nature does not directly estimate the monetary value of the ecosystem services (Bowles-Newark et al., 2014). For the

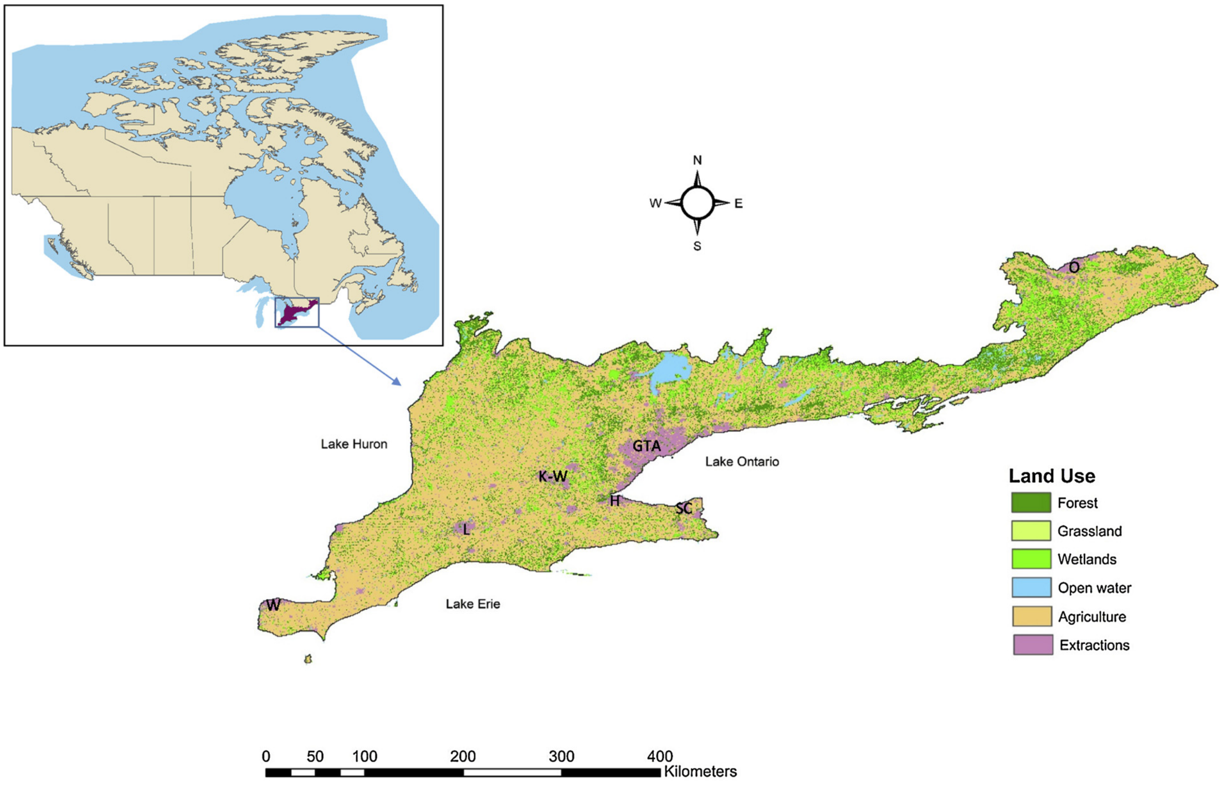

Fig. 1. Land use distribution in Southern Ontario. The land use (sub)categories from the original land use SOLRIS data base (MNR, 2008) are aggregated into six major land use categories. The capital letters on the map represent the cities: W = Windsor, L = London, K-W = Kitchener-Waterloo region, GTA = Greater Toronto Area, H = Hamilton, SC = St. Catharines, O = Ottawa. The figure in the panel (top left) shows the study region (highlighted in brown) within Canada.

Table 1
Areas of land use categories in southern Ontario, Canada.

Land Use	Area (hectares)	Area (%)
Forest	1,021,638	14
Grassland	4,302	0.1
Wetlands	982,312	13
Open water	235,474	3
Agriculture	4,512,295	61
Built-up & extractions	680,062	8.9
Total	**7,436,083**	**100**

valuation of the ecosystem services additional local and regional data are therefore required.

In order to cover the whole region of Southern Ontario, we extracted the results from two adjacent 10 degrees Co$ting Nature tiles. The boundary between the two tiles runs north-south, about 50 km west of the center of Toronto. For both the potential and realized ecosystem services, the observed ranges of the relative potential and realized indices for the selected region were subdivided in 10 equal classes (PS1 to PS10 and RS1 to RS10), to generate the maps shown in Figs. 2 and 3.

Each of the RS1to RS10 realized ecosystem service class was assigned the mean value of its corresponding service index range; the resulting values are given in Table 2. The higher the index value assigned to a class, the higher the fraction of potential ecosystem services that is consumed. Next, the realized service map (i.e., Fig. 3) was overlain onto the land use map (i.e., Fig. 1) using open source QGIS (https://qgis.org/) to obtain the land use within each realized service index raster element. The resulting total land use areas within each realized service class are summarized in Table 2.

2.3. Economic valuation of potential and realized ecosystem service

We selected unit values for ecosystems services that, to the extent possible, are derived from local data for Southern Ontario (Aziz, 2018). For each land use category considered, the unit values for the six Co$ting Nature ecosystem services considered in our analysis (Section 2.2) are given in Table 3. The unit values were taken from the four studies carried out in Ontario that are identified in Table 3. The original unit values were converted to 2017 Canadian dollars (CAD) values by adjusting for inflation.

To estimate the total value of potential ecosystem services across southern Ontario, we applied the value transfer method (e.g., Kreuter et al., 2001) by multiplying the unit values for the different land use categories by their respective total surface areas:

$$ESV_p = \sum_k (A_k \times UV_k) \tag{1}$$

where ESV_p is the total value of potential ecosystem services, A_k is the total land use area (ha) and UV_k the total unit value ($/ha/year) of land use category k (see Table 2 for the categories). The sum in Eq. (1) is taken over all the land use categories considered. (Note: we assume that the built-up plus extractive land use category does not significantly contribute to the ecosystem services included in this analysis.)

Next, the average realized service indices for the RS1 to RS10 classes were combined with the corresponding land use areas in Table 2 and the unit values in Table 3, to estimate the total value of realized ecosystem services in Southern Ontario according to:

$$ESV_r = \sum_i \sum_k (I_{RSi} \times A_{ki} \times UV_k) \tag{2}$$

where ESV_r is the total value of realized ecosystem services, I_{RSi} is the average index value of the i-th ecosystem service class given in Table 2 (with i = 1, …, 10), and A_{ki} is the amount of land use area k that falls within ecosystem service class RSi.

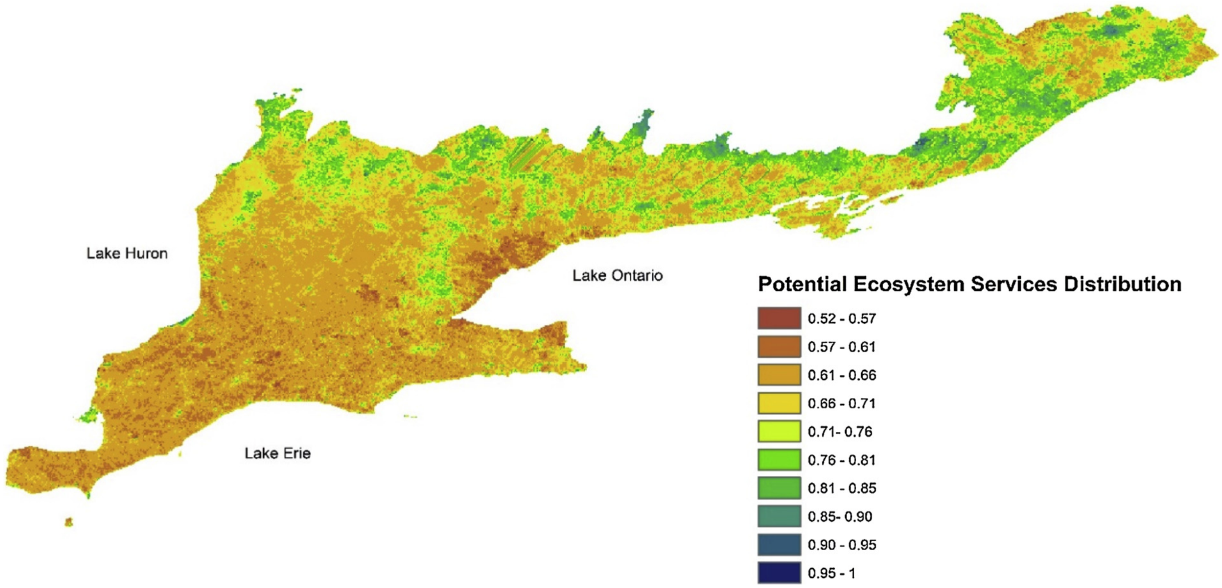

Fig. 2. Distribution of potential ecosystem services in southern Ontario. Potential service indices calculated by the Co$ting Nature application for southern Ontario range from 0.52 to 1. This overall range is divided in the 10 index categories indicated on the map.

3. Results

3.1. Spatial distributions of potential and realized ecosystem services

The areas with the highest potential ecosystem service indices (≥ 0.75) are located along the northern border and in the eastern part of southern Ontario (Fig. 2). They closely match the distributions of natural land covers (forests and wetlands) and open water bodies (Fig. 1). Note that the largest open water body within Southern Ontario is Lake Simcoe, which can be seen on Fig. 1 as the large blue spot located north of the Greater Toronto Area. (Note: services derived from the Laurentian Great Lakes are excluded from our analysis.) Given that the natural areas have the highest unit values for the ecosystem services considered, the distribution of potential services also closely resembles the geographical distribution of the unit values (compare Fig. 2 to Fig. A1 in the Appendix A).

Urban and suburban areas are associated with relatively low potential service index values (< 0.6). Clearly seen in Fig. 2 is the Golden Horseshoe, which surrounds the western end of Lake Ontario. It includes the Toronto conurbation (GTA), while its southern branch

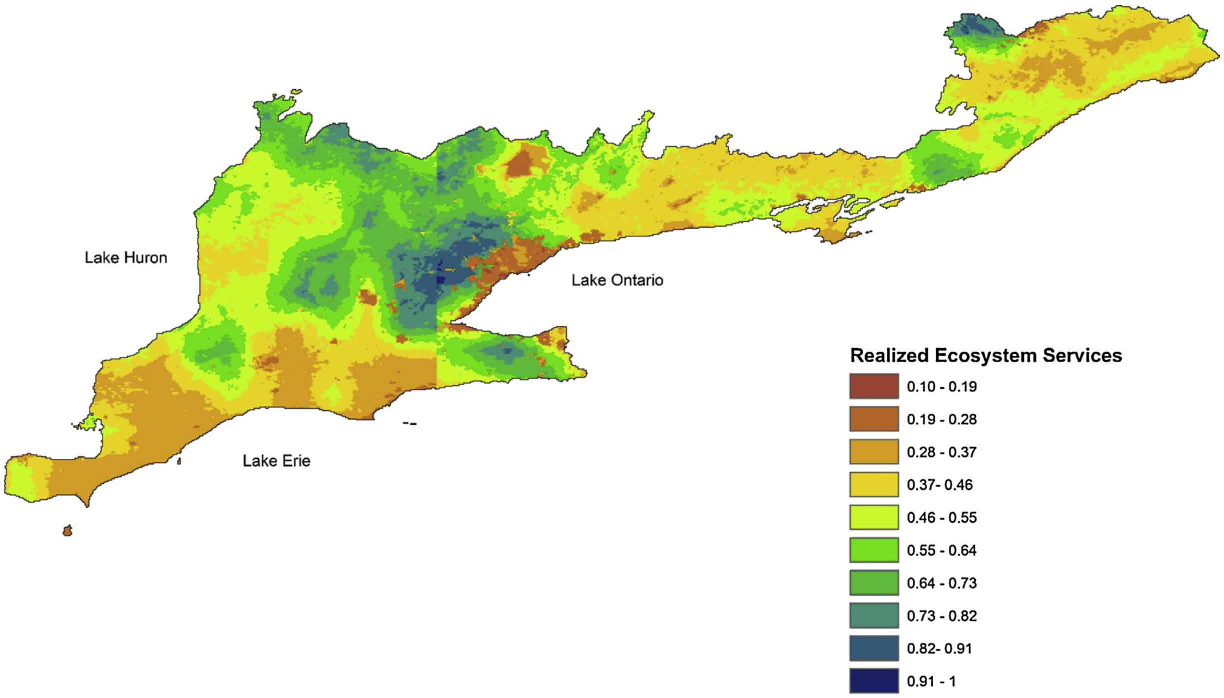

Fig. 3. Distribution of realized ecosystem services in southern Ontario. The higher the value of the realized index, the higher the combined use intensity of the bundle of potential ecosystem services, and vice-versa. The realized service indices calculated by the Co$ting Nature model are distributed over the 10 equal categories indicated on the map, and referred to as R1 to R10 in the text. Each category is assigned its average index value and its distribution is shown on the map. Note the north-south line west of the Toronto region which corresponds to the boundary between the two the two Co$ting Nature tiles that cover the entire region of Southern Ontario.

Table 2
Average indices and land use areas (in hectares) for the realized ecosystem categories R1 to R10. See caption of Fig. 3 for service index ranges defining R1 to R10.

	RS1	RS2	RS3	RS4	RS5	RS6	RS7	RS8	RS9	RS10
Averaged index (I_{RSi})	0.14	0.23	0.32	0.41	0.50	0.59	0.68	0.77	0.86	0.96
Land Use area										
Forest	189	11,883	102,172	277,215	239,993	158,067	134,929	65,201	25,339	1,509
Wetland	189	6,728	74,632	291,676	266,904	148,007	115,061	59,102	18,234	629
Grassland	0	0	0	1,069	1,383	1,446	126	0	0	0
Open water	440	30,243	44,893	56,650	53,318	26,533	13,204	4,024	566	63
Agriculture	629	38,165	758,711	1,136,152	1,054,914	640,255	571,029	237,604	80,480	1,635
Extraction	9,620	152,597	112,735	129,334	107,264	66,144	58,977	35,273	12,323	63
Total Area	11,067	239,616	1,093,143	1,892,096	1,723,776	1,040,452	893,326	401,204	136,942	3,899
Area (%)	0.15	3.22	14.70	25.45	23.18	13.99	12.01	5.40	1.84	0.05

extends eastwards to the city of St. Catharines. With more than nine million people, that is, about a quarter of Canada's population, the Golden Horseshoe is the most densely populated and industrialized region of Canada. Other urban cores that can be recognized in Figs. 2 and A1 are those of Ottawa in northeastern Ontario and, in the southwestern direction away from the Golden Horseshoe, Kitchener-Waterloo, London and, ultimately, Windsor at the Canada-USA border.

With the exception of its northern border region, the western part of Southern Ontario (that is, west of the GTA) exhibits mostly intermediate potential service index values around 0.6. This fertile part of Ontario supports an intensive agricultural industry of livestock and cash crop farms as well as greenhouse operations. The intermediate potential service index values are consistent with the unit values for agricultural land use that fall between those of natural land covers and (sub)urban areas.

As expected, the spatial distribution of realized ecosystem service indices (Fig. 3) in large part reflects the proximity of people to the potential ecosystem services distribution in Fig. 2. The most striking example is the region bordering the northwestern side of the Golden Horseshoe with realized service indices exceeding 0.82 (i.e., the blue areas on Fig. 3). This region is part of the Greenbelt, which was created in 2005 to protect productive farmland, natural landscapes and sensitive ecosystems from fragmentation and urban encroachment (Wilson, 2008a). By contrast, the most western portion of Southwest Ontario with a relatively low population density (1–10 persons per km^2) exhibits realized service index values that mostly fall below 0.4.

3.2. Economic valuation: potential versus realized ecosystem services

The total combined value of the potential ecosystems estimated with Eq. (1) is $19.1 ± 0.8 billion per year, which corresponds to a mean annual value of the bundled ecosystem services of $2.5 per hectare. The individual contributions of the ecosystem services to the total potential value are in decreasing order of importance (values in brackets are in billions of 2017 CAD per year): flood regulation (7.96) > water quality (4.89) > carbon storage (4.05) > nature-based recreation (1.58) > water supply (0.63) > carbon sequestration (0.07). Thus, flood regulation alone accounts for 41% of the total potential value.

As can be seen in Table 2, almost 50% of the area of Southern Ontario falls in two realized ecosystem service classes: RS4 and RS5, with average index values (I_{RSi}) of 0.41 and 0.50, respectively. Only 5% of the total area falls in the RS10 class with an average index value of 0.96. These results imply that the total value of realized ecosystem services deviates significantly from the potential value. Integrated over the entire territory of Southern Ontario, the value of the realized ecosystem service bundles is estimated at $9.7 ± 0.4 billion per year, or just over half the potential value.

4. Discussion

Ecosystem services and their monetary valuation are widely accepted as a useful concept and tool to support policy and decision making (e.g., Laurans et al., 2013). More recently, the importance of distinguishing between the potential supply of ecosystem services and their use intensity by the actual beneficiaries has been gaining traction (Burkhard et al., 2012; Goldenberg et al., 2017; van Jaarsveld et al., 2005; Wainger and Mazzotta, 2011). Burkhard et al. (2012), for instance, proposed an approach for mapping both the supply and demand of ecosystem services. They assigned an index between 0 and 5 to each land use type based on quantitative data, plus expert judgement and knowledge of the landscape. In this approach, natural land use categories incur higher scores for the delivery of regulating, provisioning and cultural ecosystem services, whereas urban areas typically yield higher values for the demand of ecosystem services. However, the routine use of this approach faces major challenges regarding the identification of appropriate indicators as well as the extensive input data requirements for local applications (Burkhard et al., 2012).

In the present study, we rely on open source modeling and GIS tools. We selected Co$ting Nature because it is linked to global databases and therefore does not depend on the acquisition of local input data to produce the relative spatial distributions of potential and realized ecosystem services (Mulligan et al., 2010). These distributions are then combined with unit values of the ecosystem services that are specific to the Southern Ontario region. Because the approach adopted here only uses freely available applications trained on existing datasets, including maps and satellite products, it can easily be implemented in other regions by management agencies, natural resources industries, municipalities, local communities and NGOs.

Table 3
Regional unit values of land use categories for ecosystem services extracted from literature.

Land Use	Unit Values of Ecosystem Services ($/ha/year)						Total
	Water supply	Water quality	Carbon sequestration	Carbon storage	Flood regulation	Recreation	
Forest	300 ± 265[1,3,4]	595[2]	48[3]	1130[3]	1875[3]	360 ± 70[2,3]	**4310 ± 275**
Wetland	265 ± 330[2,4]	3470 ± 345[2,3]	16[3]	865 ± 540[3]	4970[3]	410[3]	**9995 ± 720**
Grassland	60[3]	105 ± 107[2,3]	35[3]	260[3]	10[3]	5[3]	**475 ± 110**
Open water	280 ± 290[1,3,4]	3710[3]	15[3]	830[3]	4970[3]	240 ± 250[2,3]	**10045 ± 380**
Agriculture	–	–	–	410[3]	–	165 ± 10[2,3]	**575 ± 10**

[1]Kennedy and Wilson, 2009; [2]Troy and Bagstad, 2010; [3]Wilson, 2008a; [4]Wilson, 2008b.

Because Co$ting Nature employs global relationships, the generated distributions of the potential and realized ecosystem service indices should be considered as first estimates that need to be further checked against regional and local data and knowledge. The general agreement between the predicted distribution of the potential service index (Fig. 2) and the independently generated land use (Fig. 1) and unit value (Fig. A1) distribution maps suggests that Co$ting Nature yields a reasonable baseline to valuate ecosystem services in Southern Ontario. This is further corroborated by the realized service index map (Fig. 3) which consistently reproduces the known distribution trends of the region's urban and rural populations. Nonetheless, while the overall regional trends appear to be reasonably well captured by the maps in Figs. 2 and 3, it is important not to over-interpret small-scale (≤ 10 km) details. This is emphasized by the north-south linear feature approximately 50 km west of Toronto seen in Fig. 3 which is a data smoothing artefact where the two adjacent Co$ting Nature tiles meet.

The valuation of potential and realized ecosystem services is based on unit values obtained from studies carried out in Southern Ontario, hence yielding economic estimates that are rooted in their regional context (Aziz, 2018). The results imply that, averaged over the entire region, approximately half of the potential value of the bundled ecosystem services is realized. A key variable controlling the differences between potential and realized ecosystem services is population density (Turner et al., 2012), as illustrated by the high realized ecosystem service index values surrounding the Golden Horseshoe. Given that the projected population increase in Southern Ontario will be primarily concentrated in the larger urban centres (Ontario Ministry of Finanace, 2016), a further increase in the relative index values of realized ecosystem services can be expected in the coming decades.

To illustrate the usefulness of mapping and valuating both potential and realized ecosystem services to inform public policy at the regional scale, we consider the case of the Ontario Greenbelt (https://www.greenbelt.ca). The Greenbelt covers 7600 km^2 within the Southern Ontario region (Fig. A2 of the Appendix A). The main motivation behind the creation of the Greenbelt in 2005 was to control urban sprawl along the edges of the Greater Toronto-Hamilton area (Fung and Conway, 2007). However, demands are regularly voiced to override the restrictions on development within the Greenbelt, in order to accommodate the rapid demographic and economic growth of the Golden Horseshoe. One important step in assessing the trade-offs that may accompany such development is the delineation and valuation of the ecosystem services delivered by the Greenbelt. Although Wilson (2008a) previously estimated the economic value of ecosystem services provided by the Greenbelt, their analysis did not explicitly account for the actual use intensity of these services.

The distinctive nature of the Greenbelt is visually evident from the above-average realized index values that characterize large portions of the protected Greenbelt area (Fig. 3). By applying the same approach as for the entire region of Southern Ontario, the potential and realized services delivered by the Greenbelt are valued at $2.07 ± 0.08 billion and 1.27 ± 0.05 billion per year, respectively. Thus, 61% of the potential ecosystem service bundle generated by the Greenbelt is realized, compared to 51% for the entire region of Southern Ontario. Furthermore, the Greenbelt accounts for 13% of the realized services within Southern Ontario, although it covers only about 10% of the region. The highest monetary value of the Greenbelt ecosystem services considered is that of flood regulation, which accounts for 41% of the total potential value of the service bundle, followed by water quality and carbon storage. The large contribution to flood regulation is of particular importance to the downstream residents of the Golden Horseshoe, as flooding represents a major and recurrent natural hazard to urban centres in Southern Ontario (Nirupama et al., 2014).

The estimated economic values of potential and realized ecosystem services for the Greenbelt are preliminary. The uncertainties inherent to the use of the global datasets in Co$ting Nature should be further reduced through the incorporation of more detailed, place-based data and knowledge. Nonetheless, the values reported here provide a starting point in a debate where the social and economic benefits of the Greenbelt take centre stage. An equally important consideration is that our analysis only accounts for a subset of ecosystem services. Moving forward, additional ecosystem services including, for example, biodiversity, regional climate regulation, and pollination, should be considered. The expected population growth and urban densification in the Golden Horseshoe further imply that the realized fraction of the potential ecosystem services will likely continue to rise in the future. Thus, both predicted absolute and relative changes in potential and realized ecosystem services should be part of an evaluation of policy decisions and management strategies for the Greenbelt.

5. Conclusions

Because realized ecosystem services are directly consumed by people, their economic valuation helps to more clearly illustrate the link between ecosystem services and human well-being. That is, realized ecosystem services represent the portion of the corresponding potential ecosystem services that matters most to its beneficiaries. Explicitly valuating both potential and realized ecosystem services, rather than the potential ecosystem services alone, therefore yields added value to evidence-based environmental decision making. However, thus far, very few studies have presented simultaneous economic assessments of the two types of ecosystem services.

Our study presents an approach to valuate realized ecosystem services within Southern Ontario, which uses a freely available web application, Co$ting Nature, together with existing estimates of unit values of six ecosystem services. Although a relatively small region, Southern Ontario is home to about a third of the Canadian population. Notwithstanding the high population density, on average only about 50% of the economic value of the bundled ecosystem services is realized. Not unexpectedly, near urban centers this percentage increases significantly. In particular, for the Greenbelt around the Toronto-Hamilton conurbation the realized fraction of the combined six ecosystem services rises to 61%. Our results therefore provide direct economic support for protecting natural landscapes around urban centers.

Future work should couple the mapping of realized ecosystem services to regional demographic and climate projections. More in-depth analyses would also include the valuation of individual ecosystem services, rather than service bundles, as well as the introduction of more detailed land use categories covering a larger range of unit values. Nonetheless, as this study shows, even a preliminary (and low-cost) assessment of potential and realized ecosystem services already represents an important step in addressing the growing need for policy-relevant research on ecosystem services and their relevance to society.

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Appendix A

A1 Distribution map of unit values

Unit values of ecosystem services (in units of $/ha/year) are obtained from different studies that apply a variety of approaches. We selected the regional studies identified in Table 3 and extracted averages of the reported ranges of unit values for the ecosystem services. Note that even for a

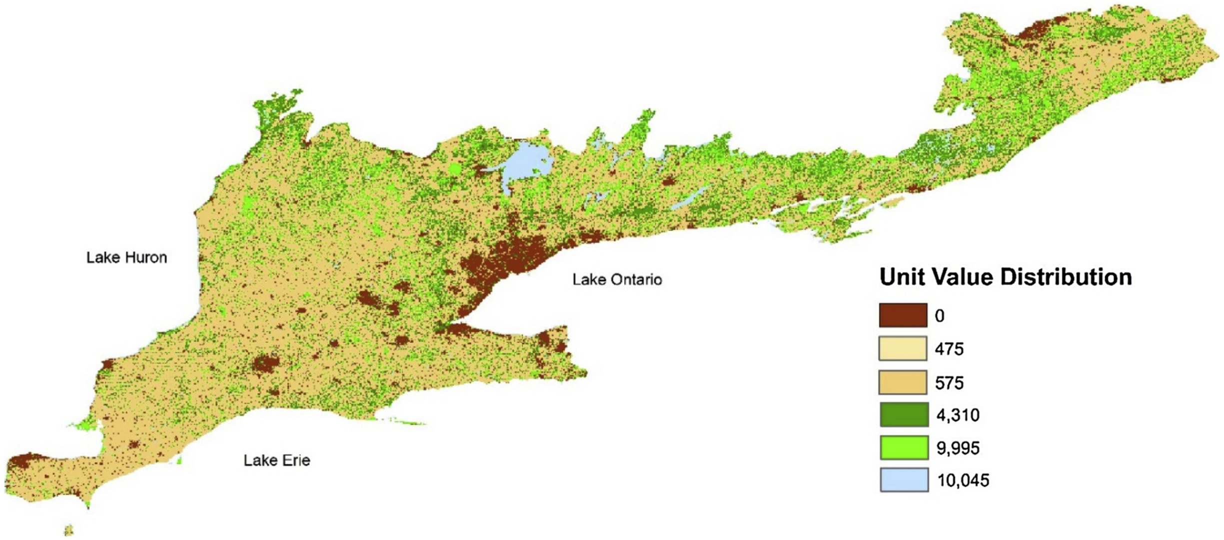

Fig. A1. Unit value distribution map for a bundle of six ecosystem services in Southern Ontario.

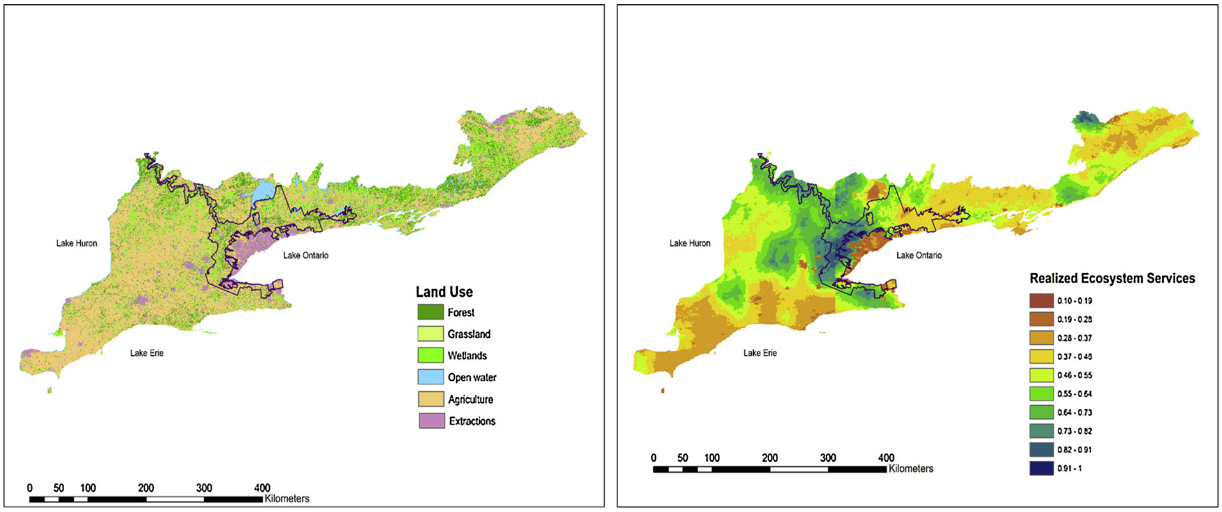

Fig. A2. Land use (left) and realized ecosystem services indices map (right) overlain onto the outline of the Greenbelt (outlined in purple).

given ecosystem service different valuation methods may be used among different studies For example, water supply is valuated using the avoided cost method (Kennedy and Wilson, 2009), the benefit transfer method (Troy and Bagstad, 2010), or a combination of the cost avoided and benefit transfer methods (Wilson, 2008b), while recreation is valuated based on the benefit transfer method (Troy and Bagstad, 2010) or the willingness to pay for nature-based activities (Wilson, 2008a). The unit value distribution was mapped (Fig. A2) using the unit values of the six major land use categories given in Table 2. The extraction area is assigned no unit value (or 0 $/ha/year) because it is assumed that this land cover does not generate the ecosystem services considered in the analysis.

A2 Valuation of Greenbelt ecosystem services

We valuated the potential and realized ecosystem services from the Greenbelt area (outlined in purple in the maps, Fig. A2), a band of protected areas that supports a broad range of ecological, economical and social functions in Southern Ontario (Fung and Conway, 2007). The Greenbelt surrounds the densely populated urban centers of Toronto, Hamilton, and St. Catharines (Wilson, 2008a).

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