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Estimating Ecosystem Services in Southern Ontario

By: Spatial Informatics Group, Austin Troy & Ken Bagstad (2009)

Estimation of Ecosystem Service Values for Southern Ontario

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Contents

Background

Ecosystem Services

Goods and services provided by functioning ecosystems contribute to human welfare, both directly and indirectly, and therefore represent a significant, yet often uncounted, portion of the total economic value of the landscapes we live in[1]. While there are many ways that humans can value landscapes, the ability to estimate the economic value of the ecosystem goods and services provided by them is increasingly recognized as a valuable tool in weighing tradeoffs in environmental decision making and land-use planning.[2]

Ecosystem services have been defined as the benefits people obtain either directly or indirectly from ecological systems.[3] They include products such as food, fuel and fiber; regulating services such as climate stabilization and flood control; and nonmaterial assets such as aesthetic views or recreational opportunities. Ecosystem goods and services occur at multiple spatial scales, from climate regulation and carbon sequestration at the global scale, to flood protection, water supply, soil formation, nutrient cycling, waste treatment and pollination at the local and regional scales. They also vary with regard to how directly connected they are with human welfare, with services like carbon sequestration being highly indirect in its connection, while food, raw materials, and recreational opportunities are far more direct.[4] The 2003 Millennium Ecosystem Assessment[5] places ecosystem services into four categories: provisioning (e.g. food, fresh water, fuel, genetic resources), regulating (e.g. climate, disease and flood regulation), cultural (e.g. recreation, aesthetics, and education), and supporting (services necessary for production of other ecosystem services, e.g. soil formation, waste treatment, and nutrient cycling).

The process of identifying and quantifying ecosystem services is increasingly recognized as a valuable tool in assessing the allocation of environmental resources. By estimating the economic value of ecosystem services, social costs or benefits that otherwise would remain hidden can potentially be accounted for in the regulatory decision making process at local, national, and international scales, allowing for tradeoffs to be weighed in land use decisions. By attaching economic values to elements of nature—even if they are only lower-bound estimates—we can begin to include environmental concerns in standard decision-making

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[1] Wilson, M., A. Troy, et al. (2004). The Economic Geography of Ecosystem Goods and Services:Revealing the monetary value of landscapes through transfer methods and Geographic Information Systems. Cultural Landscapes and Land Use. M. Dietrich and V. D. Straaten, Kluwer Academic**:** 69–94.

[2] Bingham, G., R. C. Bishop, et al. (1995). "Issues in Ecosystem Valuation: improving information for decision making." Ecological Economics **14**: 73-90, Millennium Ecosystem Assessment (2003). Ecosystems and Human Well-Being: A Framework for Assessment. Washington DC., Island Press.

[3] Costanza, R., R. d'Arge, et al. (1997). "The Value of the World's Ecosystem Services and Natural Capital." Nature **387**: 253-260, de Groot, R. S., M. A. Wilson, et al. (2002). "A typology for the classification, description and valuation of ecosystem functions, goods and services." Ecological Economics **41**(3): 393-408.

[4] Wilson, M. A. and S. R. Carpenter (1999). "Economic Valuation of Freshwater Ecosystem Services in the United States 1971-1997." Ecological Applications **9**(3): 772-783, Farber, S., R. Costanza, et al. (2006). "Linking ecology and economics for ecosystem management." Bioscience **56**(2): 121-133.

[5] Millennium Ecosystem Assessment (2003). Ecosystems and Human Well-Being: A Framework for Assessment. Washington DC., Island Press. Available online at http://www.millenniumassessment.org/en/Framework.aspx.

procedures like cost-benefit analysis and scenario analysis. This approach recognizes that there is an opportunity cost associated with natural capital, and that its loss comes at a price to society. We may never know that price with full accuracy, but by making an attempt to at least partially value that opportunity cost our decisions can better reflect at least some of the otherwise hidden societal costs that are so often a result of human activities.

Southern Ontario is an area where significant environmental resources co-exist with a large population, including one of North America's largest cities—Toronto. Amidst the region's vast and economically important agricultural lands, Southern Ontario also contains forest, savanna, and grassland remnants of the biologically important Mixedwood Plain ecosystem, a system that is under-represented in the region's publicly owned lands[6]. In addition to its extensive forests and agricultural lands, this region is blessed with an abundance of aquatic resources. This includes not only the surrounding Great Lakes of Erie, Ontario and Huron, but also a vast network of inland lakes, rivers, and embayments—particularly the vast Bay of Quinte. These surface waters support significant fisheries and they provide extensive opportunities for recreation. These recreational opportunities are not only critical to Ontario's substantial tourism economy, but also in providing a key amenity that attracts workers and businesses to the region. Compromising these waterways would not only impact recreation and tourism, but also fresh water supplies. Southern Ontario also has significant coverage in various types of wetlands, from coastal marshes, to riverine wetlands, to fens and bogs. Many of these are hydrologically connected to cities and town and provide vital services such as processing nutrients in the water, improving water quality, and reducing flood intensity. Among the greatest threats to southern Ontario's natural capital at this time are runoff from urban areas, agricultural and sewage plants; soil erosion and sedimentation, and loss of wetlands and riparian habitat to development.[7]

The Spatial Value Transfer Methodology

When planners and policy-makers wish to incorporate ecosystem service values into their decision-making, they are faced with the question of how to estimate those values. Conducting original valuation studies at the policy site can be extremely costly and take years. Therefore, a common practice is to use information generated in other research sites which are contextually similar to the policy site. This approach of appropriating information from a study site for use in a policy site is known as "value transfer," or "benefits transfer."

Value transfer involves the adaptation of existing valuation information to new policy contexts where valuation data is absent or limited, using valuation estimates from the established literature.[8] For ecosystem service valuations (ESVs), this involves searching the

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[6] Sverrisson, D., P.C. Boxall, and V. Adamowicz. (2008). Estimation of the passive use values Associated with Future Expansion of Provincial Parks and Protected Areas in Southern Ontario. Report to the Ontario Ministry of Natural Resources.
[7] Olewiler, N. (2004). The Value of Natural Capital in Settled Areas of Canada, Ducks Unlimited Canada and the Nature Conservancy of Canada.
[8] Loomis, J. B. (1992). "The Evolution of a More Rigorous Approach to Benefit Transfer - Benefit Function Transfer." Water Resources Research **28**(3): 701-705, Desvousges, W. H., F. R. Johnson, et al. (1998). Environmental policy analysis with limited information: principles and application of the transfer method., Edward Elgar.

literature for valuation studies on ecosystem services associated with ecological resource types (e.g. forests, wetlands, etc.) present at the policy site. Value estimates are then transferred from the original study site to the policy site based on the similarity of both the ecological resources themselves and the socioeconomic context of the human beneficiaries of ecosystem services present at the policy site. Primary valuation studies use a variety of techniques to value a resource, such as contingent valuation (a survey method for eliciting willingness to pay), hedonic pricing (statistical analysis of housing prices), travel cost (analysis of how much travelers pay to visit a resource), factor income (analysis of a natural resource as a factor of production in another resource), and replacement cost (the cost of engineering a solution to replace the function provided for by that natural resource).

Value transfer is generally done in aggregate—that is, a single value is derived for an entire study area without accounting for spatial variability. However value transfer can also be performed in a spatially disaggregate manner, allowing for the assessment of geographic variability in ecosystem service provision. In this approach, estimates of ecosystem service flow value (typically measured in dollars per hectare per year) can be summarized by geographic units, such as by watershed or parcel. Such information can be valuable in planning applications.

SIG conducted a spatially explicit ecosystem service valuation for southern Ontario using its proprietary Natural Assets Information System™ database and query engine along with the spatial value transfer-based methodology outlined by SIG Principal Dr. Austin Troy and former SIG Principal Matthew Wilson in their 2006 article "Mapping ecosystem services values: Practical challenges and opportunities in bridging GIS and value transfer."[9]

Project Methods

This project used the following workflow, based on Troy and Wilson's article: 1) study area definition 2) typology development; 3) literature search and updating of Natural Assets database; 4) mapping; 5) total value calculation; and 6) geographic summaries. Steps 2 and 3 are presented together because of their iterative nature.

Step 1: Study area definition

In this step we worked with the Ontario Ministry of Natural Resources (MNR) to determine the exact boundaries of the study area for which value transfer will be undertaken. It was decided that this would include Ecoregions 7E and 6E in southern Ontario, in addition to the portions of the Great Lakes bordering those Ecoregions (which do not extend into the Great Lakes), up to the international border. However, only the nearshore margin portions of the Great Lakes (defined below), were actually valued.

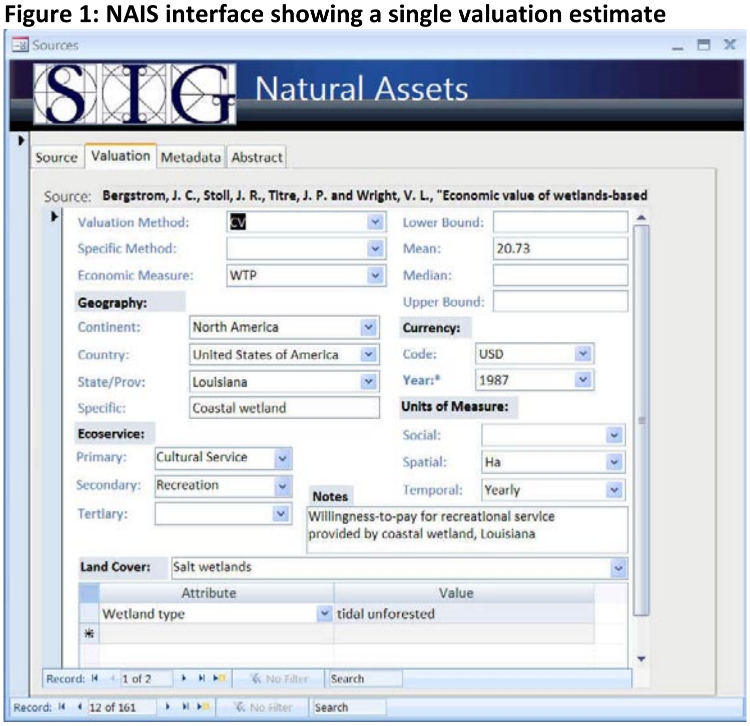
[9] Troy, A. and M. A. Wilson (2006). "Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer." Ecological Economics **60**(2): 435-449.

Steps 2-3: Typology development and literature search

We first developed preliminary typologies for land cover and ecosystem services to serve as the value transfer linkage. This typology was initially based on the Southern Ontario Land and Resource Information System (SOLRIS[10]) but significant alternations to the typology were made to better fit our initial understanding of the classes described in the valuation literature. In particular, SOLRIS' classes do not adequately consider socio-economic context (e.g. urban forest vs. non-urban forest), which is critical in value transfer.

Then, the Natural Assets database was queried to search for valuation studies for land cover types that were comparable to those in the study area and valued in geographic and socio-economic contexts that were relatively similar to that of the study area. The Natural Assets database consists of a large number of summaries of valuation studies, tagged with extensive information about the valuation (e.g. value per unit area or household, year of valuation, valuation method used, economic models used, etc.), the ecosystem service (we use the hierarchical system of classifying ecosystem services from the Millennium Assessment), the land /aquatic types valued (we used our own proprietary relational typology that can be adapted to almost any application), and the location(s) in which the study was performed, as is shown in Figure 1. This allows us to easily write queries to yield only those studies that are relevant to a particular application.

Figure 1: NAIS interface showing a single valuation estimate



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[10] Southern Ontario Land Resource Information System. 2008. Ontario Ministry of Natural Resources

In addition to developing a land cover typology, we also developed a customized categorization of ecosystem services. We based this categorization on that from Millennium Assessment, but with some modification. The insufficient number of studies in the literature and the lack of information in many of those studies required us to lump some ecosystem service categories together. Our list includes the following services: 1)recreation, 2) aesthetic/amenity, 3) other/general cultural services, 4)pollination and seed dispersal, 5) habitat refugium and biodiversity, 6)atmospheric regulation, 7)soil retention and erosion control, 8)water quality maintenance and nutrient/waste regulation, 9)water supply and regulation, and 10)disturbance avoidance. In all cases, we attempted to avoid any studies that included direct market values (that is, benefits based on actual expenditures). This is a particular concern in recreation studies because recreation's benefits reflect both market and non-market components. All of the recreation studies used in this project looked at non-market goods. Of the many recreation studies used here, only two (Wilson 2008 and Olewiler 2004) included some element of market expenditures, blended with non-market values, but separating out the market from non-market expenditures in these studies was not possible given the scope of this project.

The determination of criteria for contextual and categorical comparability was to be made in consultation with the client. We determined that we would include studies from temperate areas of North America, Europe, and New Zealand, as these represent roughly comparable environmental and socio-economic contexts. Many candidate studies had to be individually excluded based on factors that made them incompatible, such as studies that quantified the regulating ecosystem services associated with salt water estuaries. On the other hand, a study looking at the amenity value of a salt water estuary could potentially be considered for inclusion because that amenity value could be construed to be comparable for both salt- and fresh-water contexts. To the best extent that the information in the studies allowed, we attempted to avoid any double counting[11] of services. For example, if a certain study valued a supporting service for a land cover type and another study valued a service dependent on that supporting service for the same cover type, we would only include one of those.

We decided with the client to include both peer-reviewed and "gray literature" studies. However, the vast majority of the studies used in this project are from peer-reviewed journals. With one exception, only primary studies were used as sources of value transfer. The exception is the secondary study by Olewiler (2004). Olewiler's estimates came from a different study and the text of that study could not be obtained, so we cite Olewiler although the information contained is secondary. However, we felt it was important to include these estimates because they were from the Grand River watershed in Ontario, which is part of the project study area, and hence they did not actually need to be geographically "transferred." After consultation with the client, we also decided to include Olewiler's estimates from the Mill River watershed in Prince Edward Island, as that are is relatively proximate and ecological

[11] Double counting occurs when some component of the same benefit is measured twice, producing an inaccurately inflated value. For instance, including estimates of the value of pollination and the value of crops produced counts the valuation of pollination twice.

similar to the study area. We also excluded economic values from other value transfer reports (that is, where averages of multiple estimates were used), unless these values were original economic values developed in these reports. In several cases, we did include data points where value transfer reports included original valuation data, for example, on the hedonic value of urban green space[12], or other ecosystem services.[13,14]

Using the Natural Assets database, we ran a query to return all relevant records of valuation studies. From this result we conducted a gap analysis. Based on identified gaps, we then conducted a literature search to update the database with studies to fill these gaps, where available. Increasing the number of economic studies used in a value transfer project achieves several purposes. First, it fills in gaps where the value of a particular service associated with a particular land cover type may previously have been unknown. Second, multiple studies for a given ecosystem service provide a range of estimates that allow the analyst to determine if any given estimate appears unreasonable.

We focused our literature search on three main areas. First, we looked for studies of ecosystems and ecosystem service types that are underrepresented in the literature. Grasslands, savannas, hedgerows, and Great Lakes wetlands were among the underrepresented ecosystems, while many of the regulating services (e.g., nutrient regulation, soil retention, flood control) were less represented in the Natural Assets database prior to our literature review. Second, we reviewed new articles recently published in the leading ecological and environmental economics journals, such as *Ecological Economics*, *Environmental and Resource Economics*, *Journal of Environmental Economics and Management*, and *Water Resources Research*. Finally, we searched for regionally-appropriate studies for Ontario and neighboring parts of Canada. We searched the Environmental Valuation Reference Inventory (EVRI) database[15], which can be queried geographically or by ecosystem or ecosystem service type. This produced a list of primary valuation studies, which we screened for applicability to relevant ecosystem services and land cover types in Southern Ontario. This literature search uncovered 25 new valuation studies that were applicable to Southern Ontario, some of which provided values that could be applied to multiple land cover and ecosystem service types. By adding these studies, reclassifying other studies to more accurately reflect the final land cover typology, and removing studies that were not applicable to Southern Ontario or could not be converted to $/ha-yr values, we added 54 new valuation estimates and removed 13 estimates from our initial NAIS query.

Regrettably many primary valuation studies do not contain enough information to enable us to convert their results into geographically-appropriate estimates ($/ha-yr). Many of these

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[12] Costanza, R., M. Wilson, et al. (2006). The value of New Jersey's ecosystem services and natural capital. Report to the New Jersey Department of Environmental Protection.
[13] Olewiler, N. (2004). The Value of Natural Capital in Settled Areas of Canada, Ducks Unlimited Canada and the Nature Conservancy of Canada.
[14] Wilson, S.J. (2008). Ontario's wealth, Canada's future: Appreciating the value of the Greenbelt's eco-services. Vancouver: David Suzuki Foundation.
[15] Available online at http://www.evri.ca.

studies fail to include adequate information about the land area, the ecosystem being valued, or the relevant human user population, making the task of finding appropriate studies more difficult. Also, many primary studies do not classify their results into one of the Millennium Ecosystem Assessment ecosystem service categories. Based on our past experience with value transfer, we divided the studies into ten different ecosystem services: recreation, aesthetic/amenity, other cultural, pollination and dispersal, habitat refugium/biodiversity, atmospheric regulation, soil retention/erosion control, water quality/nutrient regulation/waste assimilation, water supply/regulation, and disturbance avoidance. While these categories do not correspond perfectly with the Millennium Assessment categories, they do enable us to systematically describe the valuation estimates commonly found in the literature while avoiding double counting.

As we updated the literature database, we revised the typology accordingly. Land cover types designated in the typology for which no transferable valuation studies exist were dropped from the typology and all land cover areas falling under those categories were re-assigned to several "no known value" categories. New categories or subdivisions of existing categories were added to the typology where the updated literature search indicated that such a category could be economically valued. The final typology is given below in Table 1, along with general definitions and the numeric code for each category. Underlined terms in the table are defined at the bottom of the table. More detailed class definitions and descriptions of the data and methods used to create them are given in Appendix 1. Class 61 (Beach) is an aggregated category used for the region-wide study. For the case studies (Ecodistricts 6E-6 and 7E-5), beaches were broken down into classes 62 (beach near structure) and 63 (beach not near structure), as the table below indicates. The intent for the case studies was not only to break down beaches into two categories, each with significantly different valuation estimates, but also to map them manually, as SOLRIS greatly underrepresents beaches throughout the study area. Beaches near structures provide recreational, aesthetic, and disturbance regulation services, while beaches not near structures provide only recreation services. For the general beach category, we averaged the overall values for beaches near structures and beaches not near structures.

The land cover typology was custom-designed for this project with a number of considerations in mind. First and foremost, as previously mentioned, it was constrained by the number of valuation studies in the literature and the information on land cover contained in those studies. Within those constraints, one of the key considerations behind our categorization was the relationship between the ecosystem and beneficiaries. Because the ecosystem service framework is based on consumer utility, there must be consumers who benefit from the ecosystem or that system's valuation is limited to mere existence value. Some services are global (e.g. carbon sequestration), so beneficiary proximity does not matter, but other are local, and benefits increase with proximity. Hence, we chose to subdivide several land cover classes into subclasses based on the surrounding population density. As can be seen in Table 1, we broke up forests into a number of categories including non-urban and urban and suburban classes to account for the fact that forests near human communities yield far greater ecosystem services because of the larger number of beneficiaries. The urban-suburban distinction was made to account for differing levels of population density. Ideally, a function continuously relating population density to ecosystem service value would have been used instead, but insufficient data exists to estimate such a function. Urban and suburban forests were found to have higher estimated values for several ecosystem services, including recreation and water supply. Non-urban forests were further broken down into several additional biophysical categories, including hedgerow forests and stream-proximate (riparian) forests because studies existed on these distinct sub-categories and because they delivered different values. Wetlands are another ecosystem type whose value is also highly dependent on location relative to beneficiaries, so we also broke it down into subclasses. In this case only two classes were used to characterize population density context: urban/suburban and non-urban. This was done because the number and type of studies were insufficient to distinguish between urban and suburban. Great Lake-proximate wetlands was added as a sub-category of non-urban wetlands. It was used because several studies show that these wetlands yield services—particularly cultural services—that are not quantified for other wetlands.

For classes that were subdivided across both socio-economic and biophysical dimensions, like wetlands and forests, a question arose about how to classify combinations of the two. Unfortunately, we did not have enough studies to create categories that would fully cross tabulate these dimensions—for example urban Great Lake wetland vs. non-urban Great Lake wetland. Instead, for any unit of land to which two possible classes applied (e.g. an urban wetland near the Great Lakes), the class with the higher value was used.

Once the typology was finalized, we generated a matrix cross-tabulating the number of studies by both land cover and ecosystem service types, as shown in Table 2. In this table, studies are not double counted for a particular ecosystem service-land cover type combination. Hence, if one study gives three estimates for nutrient regulation for wetlands, it is only counted as one. Because there are often multiple valuation estimates per study, the number of valuation estimates would be higher. For each ecosystem service-land cover type combination, we use a conservative "average of averages" approach. For each individual study, we report the highest and lowest valuation estimate for that service and cover type. We then average the high and low estimates, producing a single point estimate for that study. For ecosystem service-cover type combinations with multiple studies, we take an average of all these averaged values as the final value for that cover type (Appendix 2). While this method accounts for the effects of very high or very low value estimates, it can average very high or low values up to twice, producing a more conservative value estimate. As can be seen, there are a number of gaps in this matrix. Some are because certain ecosystem services may not be provided by a given land cover type. But in other cases this is due to a lack of research. In particular, there is a paucity of valuation studies on regulating services like disturbance, soil and water regulation, as well as supporting services like pollination, relative to cultural services like recreation and aesthetic/amenity value. This is because so much of the research comes from the economic literature, which largely uses economic methods to determine stated or revealed human preferences, and so is biased towards services that humans directly experience.

Table 1: Finalized land cover typology for entire study area (See Appendix 1 for a detailed description of each class and a description of the spatial methods used to develop them)

Code	Class Name	Class Description
Valued Classes		
11	Agriculture	Areas suitable for row crops outside of designated urban areas
12	Grassland/pasture/hayfield	Likely areas for pasture or hayfields, or identified native grasslands outside of urban areas
21	Forest: non-urban	Areas of tree cover located outside of designated urban, suburban, riparian or hedgerow areas
22	Forest: urban	Areas of tree cover located in designated urban areas
23	Forest: suburban	Areas of forest cover located in designated suburban areas
24	Forest: adjacent to stream	Areas of forest cover located within 30 meters of the banks of 2nd order or greater streams, excluding urban /suburban areas
27	Forest: hedgerow	Forested belts located along the margins of agricultural fields
31	Urban herbaceous greenspace	Herbaceous open space in designated urban areas
41	Open water: river	Areas of open water within the banks of 4th order or greater rivers
42	Open water: urban/suburban river	Areas of open water within the banks of 4th order or greater rivers and streams that are also located in designated urban or suburban areas
43	Open water: inland lake	Perennial inland lakes and reservoirs, not including the Great Lakes or Lake St. Claire
44	Open water: great lake nearshore	Nearshore zones of lakes Erie, Ontario and Huron to the international border, in addition to all of Lake St. Clair to the international border
45	Open water: estuary/tidal bay	Areas of the Great Lakes forming significant embayments, estuaries or coves
51	Wetlands: non-urban, non-coastal	Wetlands, bogs, marshes, swamps, and fens, excluding those in urban/suburban areas and those considered coastal
52	Wetlands: urban/suburban	Wetlands, bogs, marshes, swamps, and fens in urban/suburban areas, including those considered coastal
53	Wetlands: Great Lakes coastal	Wetlands, bogs, marshes, and fens designated by the client as coastal but not located in urban/suburban areas
61	Beach	Open and treed sand barrens/dunes located within 1 km of the coast
For case studies only		
62	Beach near structure	Sandy beach along the shore of a great lake, within approximately 200 meters of structures
63	Beach not near structure	Sandy beach along the shore of a great lake, not within 200 meters of a structure
Unvalued classes		
197	Undifferentiated: poor agricultural pote	Land undifferentiated by SOLRIS with no known agricultural potential.
198	Other unvalued terrestrial	All remaining types of land for which no valuation exists
199	Unvalued aquatic	All remaining types of surface water for which no valuation exists

Definitions

Urban: designated as areas in or within 2km of a Census dissemination area with a population density greater than 386 people/sq km (1000 people/sq. mile) located within a municipality of 50,000+ people. This is based on the US Census definition of an urban area, which includes areas with population density greater than 1000 people/sq mile (386/sq km) located within jurisdictions of 50,000+ (StatsCan uses 400/ sq km). Also included areas that were designated as "built up" in the " Built Boundary for the Growth Plan for the Greater Golden Horseshoe" layer, that were also located within a municipality of 50,000+, as some of these designated "built-up" areas within major municipalities were slightly under the 386 person per square mile criterion.

Suburban: designated as areas in or within 5km of a Census dissemination area with a population density greater than 100 people/sq km located within a municipality of 50,000+ people or in a municipality that shares a border with a 50,000+ municipality. The 100 person/sq km criterion was based on an article by Pozzi and Small.[16]

Nearshore: surface waters of the Great Lakes in the shallow margin near the shore. This is defined variably as areas where depth is less than 10 meters for Lake Erie, 20 m for Huron and 30 m for Ontario. Nearshore depths were based on a document by the US Advisory Committee on Water Quality. The intent of this zone is to indicate areas of the lakes that could see significant bottom-habitat degradation as a result of land use change. Hence, this includes areas whose bottoms receive sufficient light to support nursery and other habitat.

[16] Pozzi, F. and C. Small (2001). Exploratory analysis of suburban land cover and population density in the USA. Proceedings of the IEEE/IEPRS joint Workshop on Remote Sensing and Data Fusion over Urban Areas. Rome, Italy.

We then cross tabulated per hectare ecosystem service value flow estimates by land cover type and ecosystem service, as shown in Table 3. The values in the cells contain mean per hectare per year flow values in 2008 Canadian dollars. Where only one study exists for a cell, only that value is given. The final column gives the total estimated value, summed across all ecosystem services, for each land cover type.

Additionally, we generated a complete detailed listing of all individual valuation estimates, broken down by source study and ecosystem service, using a function in the Natural Assets Database. This is given in Appendix 2. Appendix 3 has the complete list of references.

Step 4: Mapping

Once the typology was finalized for the entire study region (Ecodistricts 6E and 7E), we created a map based on that typology. This map built upon SOLRIS, but used many other data sources to generate new categories not contained in SOLRIS. The map was created in the raster environment, using raster queries to update and reclassify SOLRIS pixel values. A detailed description of the steps used to create each class is given along with class descriptions in Appendix 1. Because of the extreme size and complexity of this map, it was worked on in close consultation with MNR and a number of intermediate versions of it were sent to MNR for review, resulting in continuous improvements and fine-tuning. The resulting map layout is given below in Figure 2. Estimated areas for each category are given in hectares in Table 4.

Additional mapping work was conducted for the case study ecodistricts 6E-6, 6E-10 and 7E-5. Given the extreme level of categorical and spatial detail with which the entire study region was mapped, it was found that the only class that was valued in the literature but could not be feasibly valued for the entire study area was beaches. While there was a sand dunes class in SOLRIS, it only accounted for a miniscule proportion of the actual sand beaches in the study region. Furthermore, we determined that there was a difference in valuation between beaches near and not near structures, particularly for the disturbance regulation services and aesthetic/amenity values. Hence, for the case study areas, we manually digitized beaches over high resolution imagery, coding them as near or not-near a structure. The methods for this process are described in detail in Appendix 1. We found there to be a large amount of beach (almost all near structures) in districts 6E-6 and 7E-5, but none in 6E-10, probably because its coastal area is more estuarine. Hence, only the first two districts are included in the case study, as only they contain differences from the region-wide map. The maps of these two Ecodistricts with enlargements for several beach areas are given in Figure 3.

Table 2: Cross-tabulation of number of studies by land cover and service type

CATEGORY	Recreation	Aesthetic/ amenity	Other cultural	Pollination & dispersal	Habitat refugium/ biodiversity	Atmospheric regulation	Soil retention, erosion control	Water quality/ nutrient & waste regulation	Water supply/ regulation	Disturbance avoidance	# studies used for cross tab
Agriculture											
Agriculture	1 (1)		5 (7)	2 (3)		1 (1)					9 (12)
Grassland/Pasture/Hayfield	2 (11)		3 (4)	1 (1)	1 (2)	2 (5)	1 (4)	1 (2)		1 (2)	13 (30)
Forest											
Forest: Non-urban	9 (19)		3 (6)		4 (5)	1 (1)		1 (1)			20 (36)
Forest: Urban	2 (7)		1 (1)	1 (2)		1 (1)		1 (1)	1 (1)		8 (15)
Forest: Suburban	3 (8)		1 (1)			1 (1)		1 (1)	1 (1)		8 (14)
Forest: Adjacent to stream	1 (2)				2 (6)	1 (1)	1 (2)	1 (1)	2 (3)	1 (2)	10 (19)
Forest: Hedgerow			1 (1)	1 (1)		1 (1)					4 (5)
Urban herbaceous											
Urban herbaceous greenspace		2 (3)	1 (1)								3 (4)
Open water											
Open water: River	5 (10)		1 (2)		1 (6)			1 (1)	1 (3)		9 (22)
Open water: Urban/suburban river	1 (3)	1 (1)						2 (2)	1 (3)		5 (9)
Open water: Inland lake	5 (10)	1 (3)	1 (2)					1 (1)			8 (16)
Open water: Great Lake nearshore	3 (6)	1 (1)									4 (7)
Open water: Estuary/tidal bay	3 (6)	2 (3)			2 (3)			1 (1)	1 (2)		9 (15)
Wetlands											
Wetlands: Non-urban, non-coastal	3 (4)	3 (5)	2 (4)		2 (4)	1 (1)		6 (9)			18 (29)
Wetlands: Urban/suburban	1 (2)	2 (3)				1 (1)		5 (6)	1 (1)	2 (6)	12 (19)
Wetlands: Great Lakes coastal	1 (2)	1 (9)	1 (2)			1 (1)		6 (8)			10 (22)
Beach											
Beach: General	7 (9)	3 (7)								2 (3)	12 (19)
Beach: Near structures	6 (8)	3 (7)								2 (3)	11 (18)
Beach: Not near structures	5 (7)										5 (7)

Cells highlighted in gray represent cases where we do not expect a given land cover type to provide a particular ecosystem service (e.g., pollination by open water).
The first number indicates total the number of studies; the second number (in parentheses) indicates number of valuation point estimates for each ecosystem service and cover type.

Table 3: Per-hectare ecosystem service value estimates cross-tabulated by land cover and service type

CATEGORY	Recreation	Aesthetic/ amenity	Other cultural	Pollination & dispersal	Habitat refugium/ biodiversity	Atmospheric regulation	Soil retention erosion control	Water quality/ nutrient & waste regulation	Water supply/ regulation	Disturbance avoidance	TOTAL
Agriculture											
Agriculture	$137		$97	$28		$31					$291
Grassland/Pasture/Hayfield	$53		$134	$19	$95	$19	$4	$25		$5	$353
Forest											
Forest: Non-urban	$270		$240		$2,428	$992		$513			$4,443
Forest: Urban	$14,903		$249	$7,536		$992		$513	$1,649		$25,843
Forest: Suburban	$11,373		$249			$992		$513	$1,649		$14,777
Forest: Adjacent to stream	$559				$133	$992	$779	$621	$1,320	$148	$4,552
Forest: Hedgerow			$7	$25		$992					$1,023
Urban herbaceous											
Urban herbaceous greenspace		$43,539	$249								$43,788
Open water											
Open water: River	$8,655		$25		$10			$33,906	$12,957		$55,553
Open water: Urban/suburban river	$172,691	$242						$45,768	$17,690		$236,392
Open water: Inland lake	$3,820	$593	$25					$612			$5,050
Open water: Great Lake nearshore	$554	$240									$795
Open water: Estuary/tidal bay	$451	$1,289			$13			$54	$45		$1,852
Wetlands											
Wetlands: Non-urban, non-coastal	$3,551	$6,446	$2,286		$75	$14		$2,779			$15,171
Wetlands: Urban/suburban	$9.861	$129				$14		$3,168	$48,929	$99,318	$161,420
Wetlands: Great Lakes coastal	$590	$2,527	$8,970			$14		$2,660			$14,761
Beach											
Beach: general	$72,892	$1,386								$15,330	$89,608
Beach: Near structures	$96,635	$2,773								$30,660	$130,068
Beach: Not near structures	$49,150										$49,150

Figure 2: Land and aquatic type map for Southern Ontario

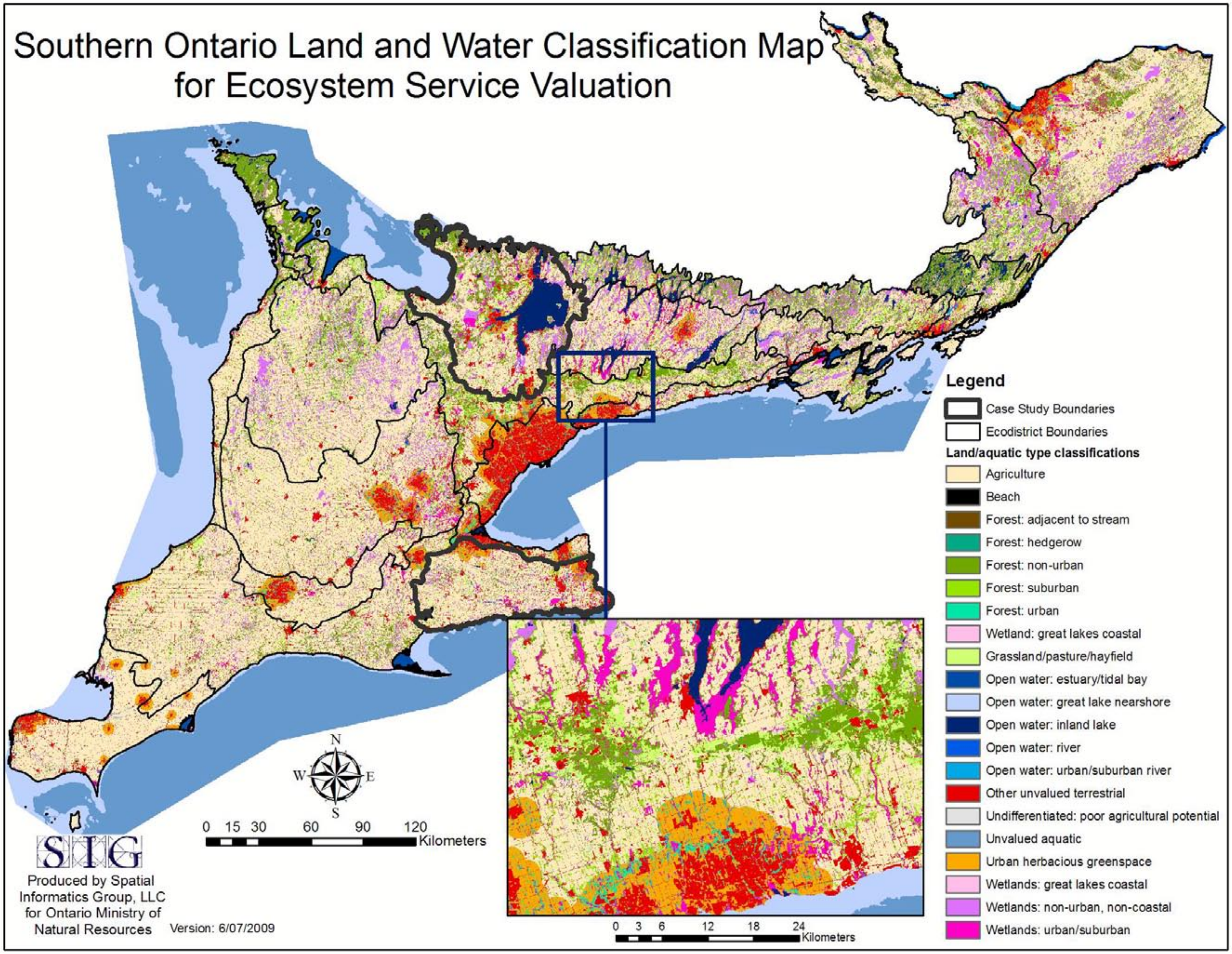
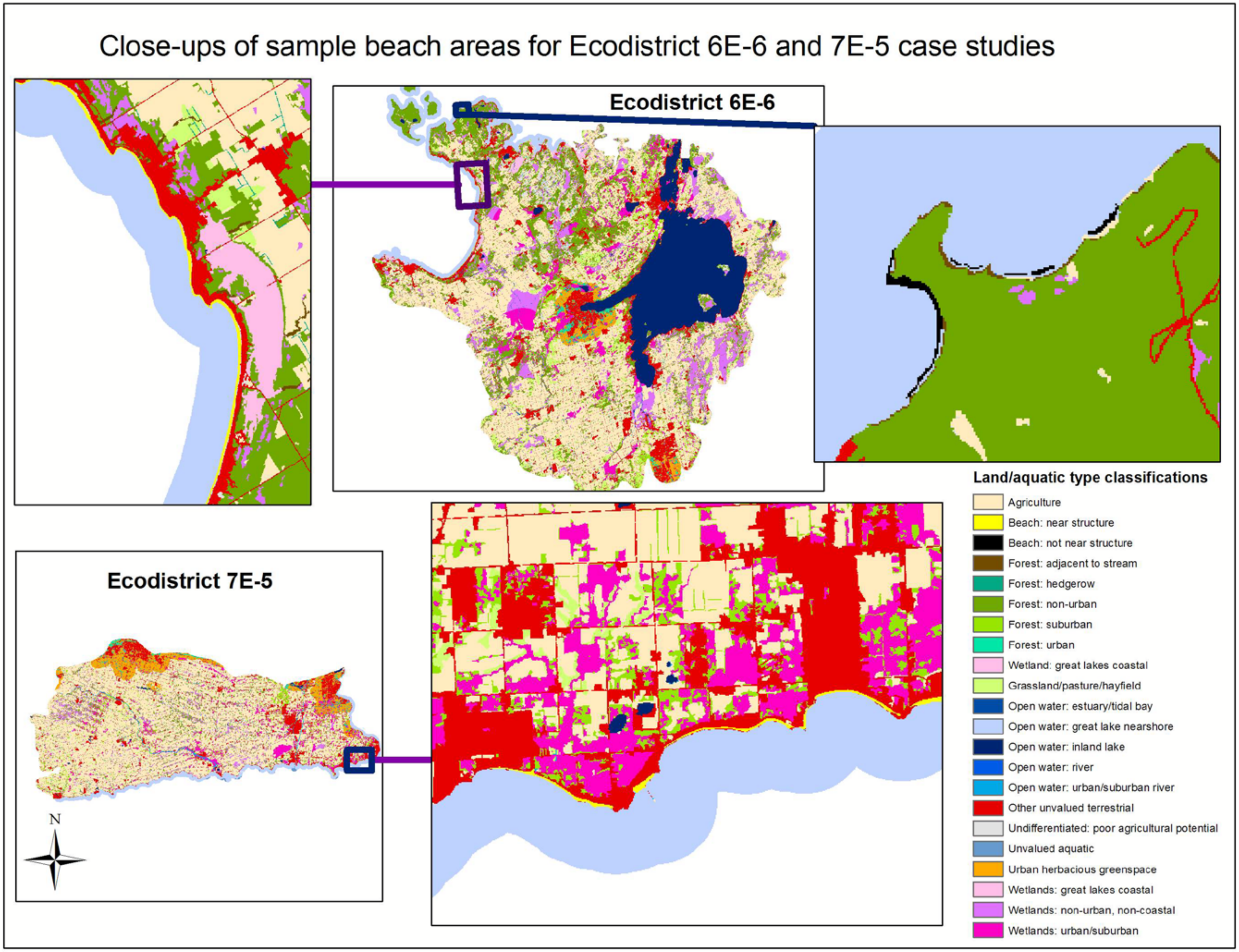


Figure 3: Maps of land cover types for case study districts with enlargements of beach areas



Step 5: Total Value Calculation

Total ecosystem service flow value was estimated in aggregate and broken down by land cover type. To get ecosystem service value flows by land cover, the row total column from Table 3 is simply multiplied by the area of that corresponding land covering, according to the following

$$V(ES_i) = \sum_{k=1}^{n} A(LU_i) \times V(ES_{ki})$$

Where $A(LU_i)$= area of land cover type (i) and $V(ES_{ki})$= annual value per unit area for ecosystem service type (k) generated by land cover type (i). Total ecosystem service value can be derived by adding up the values for all land cover types. Total estimated values by land cover type are given in Table 4 on the next page. The same values are given just for the case study districts in Table 5, along with percentages indicating the amount of a given land cover type in each case study region relative to the total amount for southern Ontario.

Step 6. Geographic Summaries

We then summarized land cover type by watershed and 500 hectare hexagon using the Arc GIS Tabulate Areas function. The output of this is a table where columns give cover type, rows give geographic units and cells give areas. Using a model built in Arc Model Builder, these areas were then multiplied by the per area value multipliers to yield a total estimated ecosystem service value flow, which is given for the hexagons (Figure 4). The total value was then divided by area to get average per hectare value for watersheds (Figure 5). Total value by 500 hectare hexagon was also mapped for the two case study districts using the same approach. (Figure 6).

Table 4: Total ecosystem service value flow estimates by land cover type (2008 CAD $/year) for entire study region

Land cover type	Areas (ha)	$/ha	Total Value Estimate
Agriculture			
Agriculture	4,117,478	$ 291	$ 1,198,186,103
Grassland/pasture/hayfield	501,347	$ 353	$ 176,975,516
Forest			
Forest: non-urban	949,293	$ 4,443	$ 4,217,710,998
Forest: urban	56,572	$ 25,843	$ 1,462,000,016
Forest: suburban	112,132	$ 14,777	$ 1,656,981,398
Forest: adjacent to stream	47,447	$ 4,552	$ 215,979,916
Forest: hedgerow	33,097	$ 1,023	$ 33,858,420
Urban Herbaceous			
Urban herbacious greenspace	283,781	$ 43,788	$ 12,426,211,405
Open water			
Open water: river	57,574	$ 55,553	$ 3,198,402,867
Open water: urban/suburban river	25,013	$ 236,392	$ 5,912,767,311
Open water: inland lake	206,324	$ 5,050	$ 1,041,934,205
Open water: great lake nearshore	1,360,653	$ 795	$ 1,081,719,481
Open water: estuary/tidal bay	56,400	$ 1,852	$ 104,453,147
Wetlands			
Wetlands: non-urban, non-coastal	751,754	$ 15,171	$ 11,404,861,679
Wetlands: urban/suburban	244,444	$ 161,420	$ 39,458,202,134
Wetlands: great lakes coastal	50,927	$ 14,761	$ 751,731,713
Beach			
Beach (general)	746	$ 89,608	$ 66,886,772
Undifferentiated: poor agricultural potential	90,701		
Other unvalued terrestrial	636,254		
Unvalued aquatic	2,867,100		
Total	**12,449,039**		**$ 84,408,863,080**

Table 5: Total ecosystem service value flow estimates by land cover type (2008 CAD $/year) for case study areas

Land Cover Type	$/ha	Area (ha)		Value		% of total study area	
		6E-6	*7E-5*	*6E-6*	*7E-5*	*6E-6*	*7E-5*
Agriculture							
Agriculture	$ 291	233,215	233,432	$ 67,865,559	$ 67,928,784	6%	6%
Grassland/pasture/hayfield	$ 353	21,720	8,042	$ 7,666,999	$ 2,838,685	4%	2%
Forest		89,611	13,823				
Forest: non-urban	$ 4,443	3,385	3,859	$ 398,143,261	$ 61,415,409	9%	1%
Forest: urban	$25,843	12,018	14,044	$ 87,466,522	$ 99,734,032	6%	7%
Forest: suburban	$14,777	2,725	1,594	$ 177,595,112	$ 207,524,438	11%	13%
Forest: adjacent to stream	$4,552	1,873	782	$ 12,404,317	$ 7,254,409	6%	3%
Forest: hedgerow	$ 1,023	7,730	23,711	$ 1,916,201	$ 799,875	6%	2%
Urban Herbaceous		1,123	788				
Urban herbacious greenspace	$43,788	379	2,409	$ 338,462,220	$ 1,038,260,744	3%	8%
Open water		80,644	1,503				
Open water: river	$55,553	23,494	16,391	$ 62,374,318	$ 43,751,112	2%	1%
Open water: urban/suburban river	$236,392	3	1	$ 89,680,624	$ 569,567,169	2%	10%
Open water: inland lake	$ 5,050	48,632	12,538	$ 407,253,958	$ 7,590,122	39%	1%
Open water: great lake nearshore	$ 795	25,607	23,699	$ 18,677,770	$ 13,030,601	2%	1%
Open water: estuary/tidal bay	$1,852	3,471	481	$ 6,167	$ 1,125	0%	0%
Wetlands		233,215	233,432				
Wetlands: non-urban, non-coastal	$ 15,171	21,720	8,042	$ 737,797,532	$ 190,221,271	6%	2%
Wetlands: urban/suburban	$161,420	89,611	13,823	$ 4,133,543,179	$ 3,825,459,388	10%	10%
Wetlands: great lakes coastal	$ 14,761	3,385	3,859	$ 51,238,199	$ 7,094,137	7%	1%
Beach							
Beach (general)	$89,608						
Beach near structure	$130,068	289	101	$ 37,556,159	$ 13,178,165		
Beach not near structure	$49,150	8	1	$ 373,786	$ 50,870		
Undifferentiated: poor agricultural potential		6,740	855	$ 331,253,245	$ 42,005,003		
Other unvalued terrestrial		49,460	36,277	$ -	$ -		
Unvalued aquatic		-	337	$ -	$ -		
Total				**$ 6,961,275,127**	**$ 6,197,705,338**		

Figure 4: Total ecosystem service value flow by pixel for the entire study area

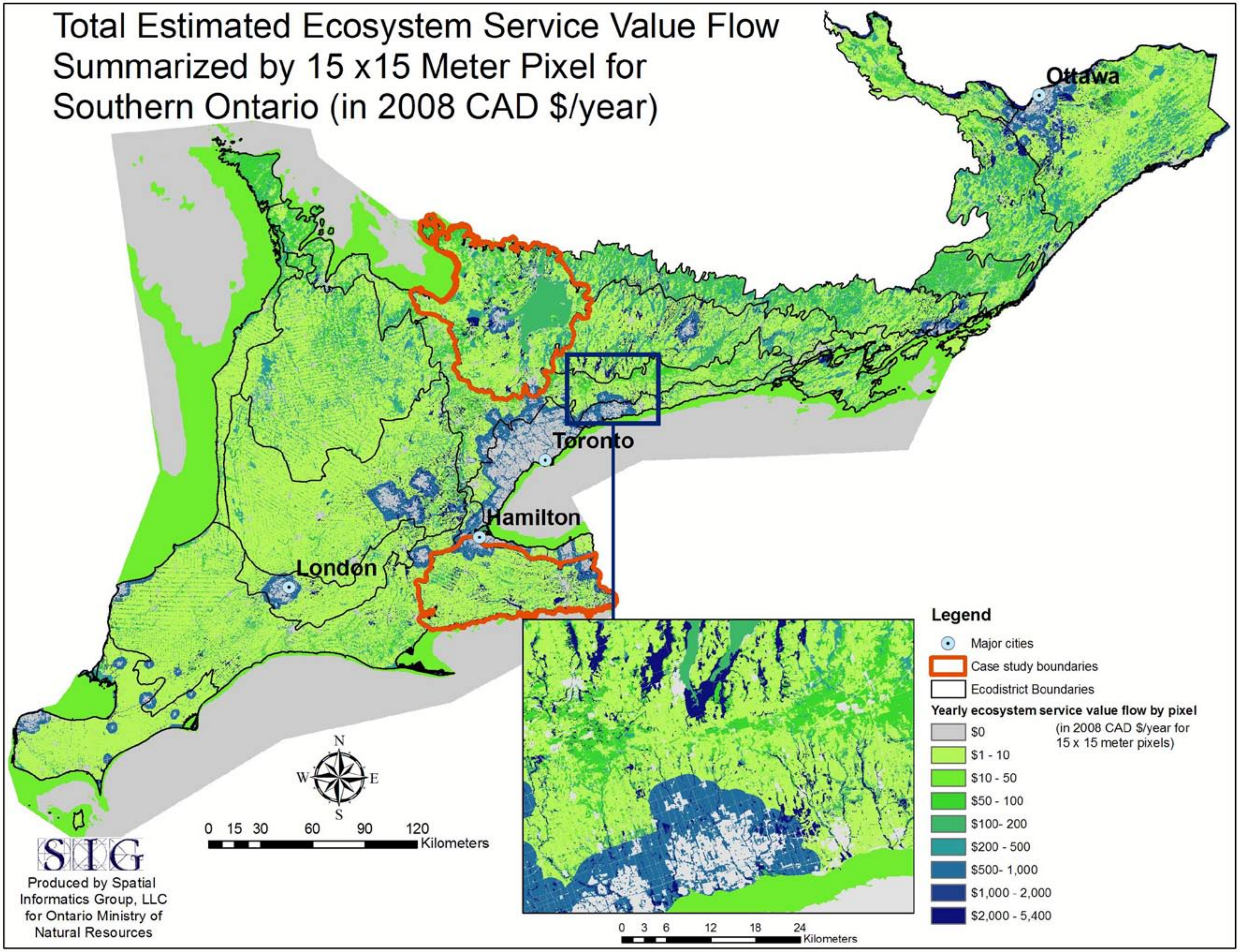


Figure 5: Average per hectare ecosystem service value flow by watershed for the entire study area

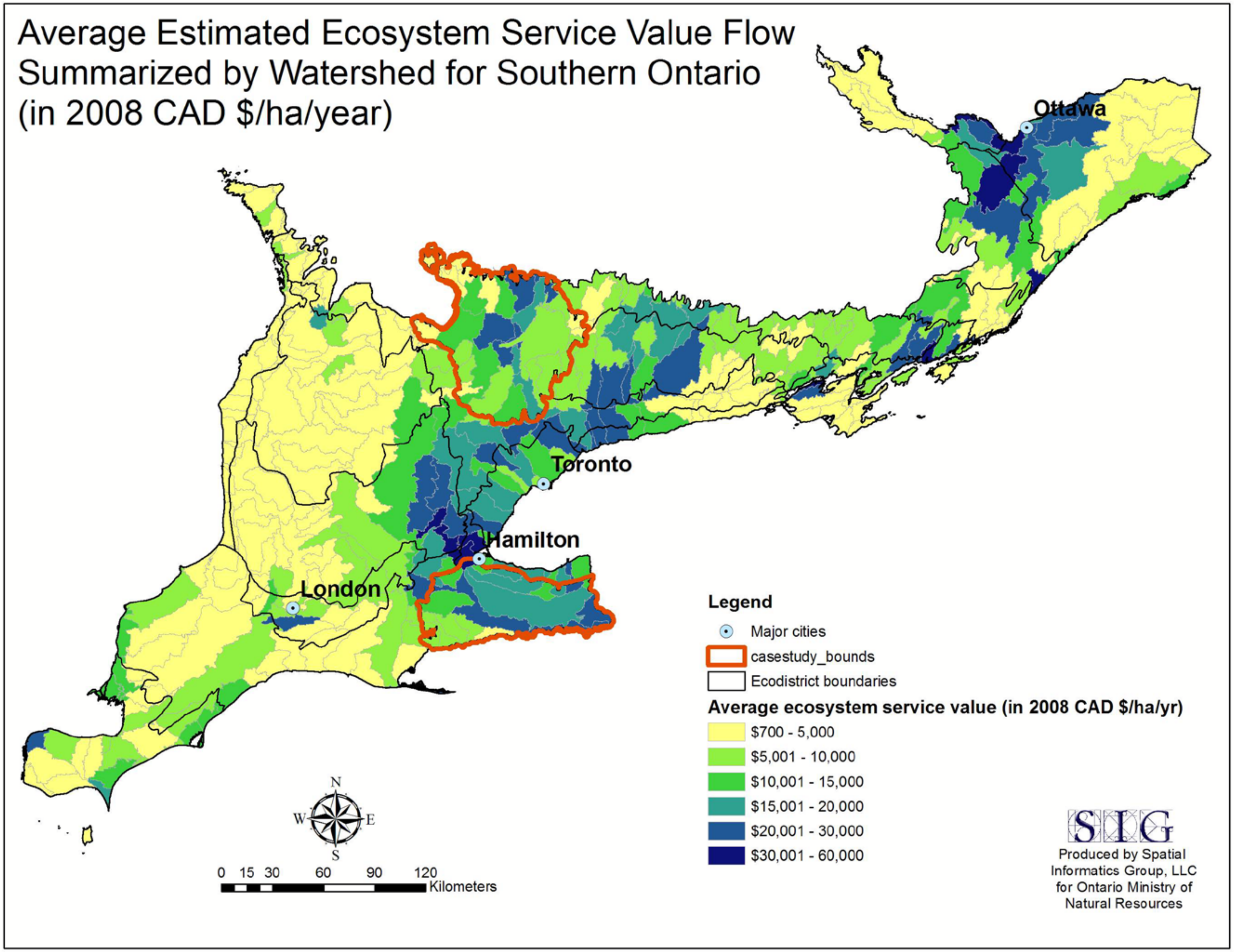
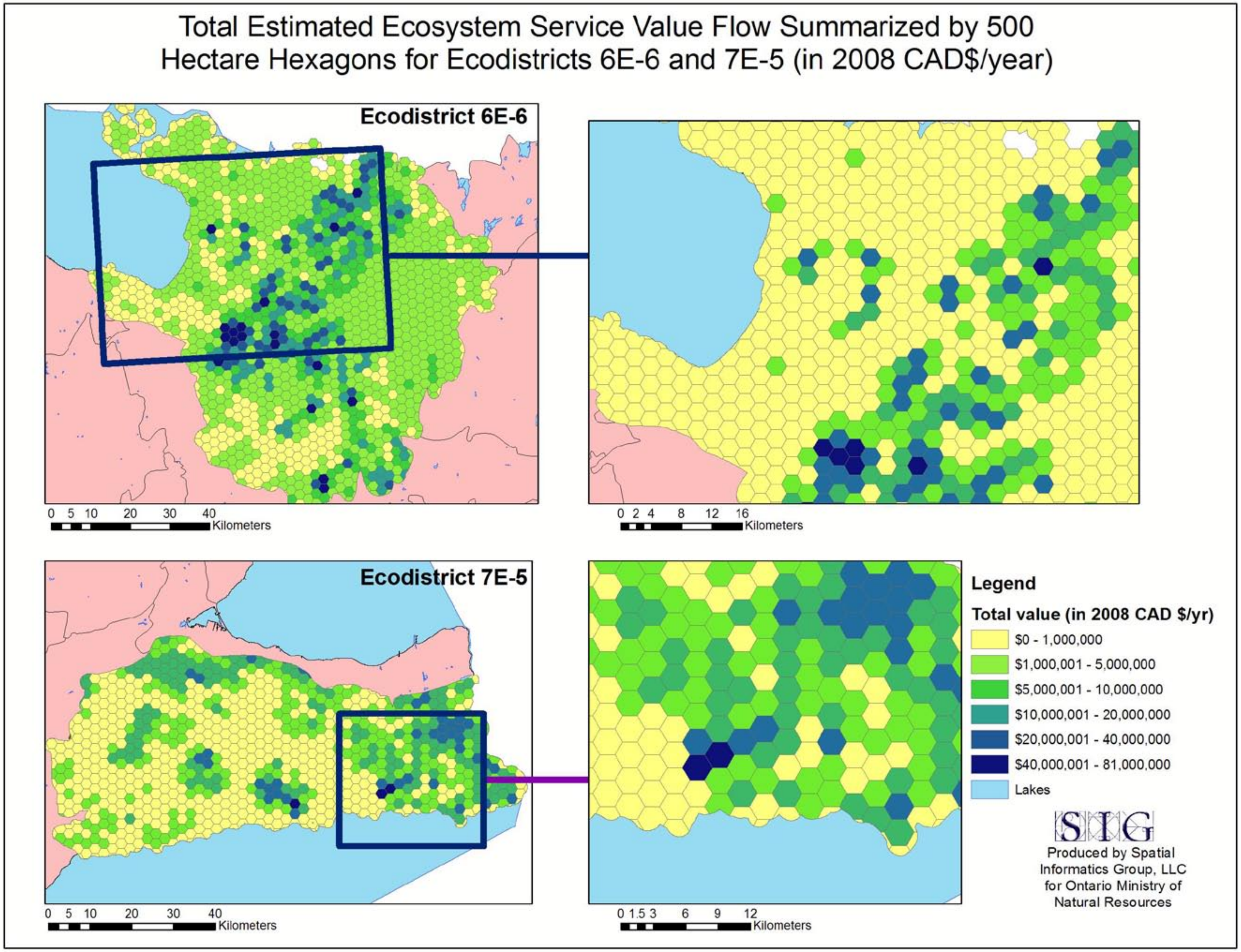


Figure 6: Average ecosystem service value flow per hectare by 500 hectare hexagon for the case study Ecodistricts



Discussion

This project shows one approach for estimating the economic benefits associated with natural landscapes. It generates estimates of the yearly flow of ecosystem service values for southern Ontario, and it shows the geographic variation in these values.

There was considerable variability in the value estimates for particular services and land cover types, with differences sometimes encompassing multiple orders of magnitude. In most cases, these differences simply represent high and low ranges of human use of a resource. Open space in urban and suburban contexts is highly valued due to its scarcity and the large number of benficiaries. Similar circumstances exist for ecosystems that provide services like disturbance or nutrient regulation to large population centers. While we attempt to account for context by separating urban and rural land use types, large value ranges may persist. In presenting high, low, and average values, we underscore that the service value of ecosystems varies significantly under different contextual conditions. One of these contextual factors is scarcity. Intuition suggests that as a particular ecosystem type becomes scarcer locally, each unit area of the remaining ecosystem will become increasingly valuable to the beneficiaries. Unfortunately, there is insufficient literature on the valuation of scarcity of different ecosystem types to allow for scarcity to be included as a contextual factor.

Ecosystem processes depend on landscape configuration including patch sizes, shapes, distributions, and disturbance processes[17]. These processes affect ecological indicators like net primary productivity, biodiversity, soil quality, runoff, sedimentation rates, nutrient cycling, and natural disturbance processes, which in turn underlie the provision of most ecosystem services. However, ecosystem service valuation has not yet progressed to the point of matching changes in landscape configuration and ecosystem processes to levels of provision and values of corresponding services. Much of the stated and revealed preference literature in economics is relatively crude in this regard. Emerging ecological economic models of ecosystem services may eventually improve representation of the links between landscape configuration, ecosystem processes, ecosystem service delivery, and valuation of ecosystem services.

It is critical to underscore that this merely represents a lower bound estimate of value. We are constrained by what has actually been valued in the literature, which is relatively limited. The paucity of empirical economic valuation studies is one of the most significant constraints to spatially explicit value transfer today. As shown in Table 2, a large number of gaps exist in our characterization of value by land cover and ecosystem service types. In cases where we know of no valuation estimate, we have no choice but to treat the value as zero, even though this greatly underestimates the value of natural systems.

[17] Alberti, M. (2005). "The effects of urban patterns on ecosystem function." International Regional Science Review **28**: 168-192.

Furthermore, it is likely that many of estimates used greatly understate the actual value for particular ecosystem service-land cover type combination. This makes it difficult to have a large number of land cover type categories, as when land cover is split into a greater number of more precise classes (e.g. from “forest” to “early”, “middle” and “late” successional stage forest), the number of blank valuation estimates will, by definition increase.

Despite our efforts to obtain values for all relevant ecosystem services and land cover types, the primary valuation literature continues to be skewed toward studying recreation, aesthetic/amenity, and other cultural services. Land cover types in the literature are skewed towards wetlands, open water, and forests, with grassland and savanna ecosystems being particularly poorly studied from an economic valuation perspective. This is particularly notable given the inherent value arising from the rarity and biological importance of grasslands in places like Southern Ontario. While we did find several studies to improve the valuation estimates for these ecosystems and service types, they remain undervalued.

Yet growth in the primary literature is enabling us to use more precisely defined land cover typologies than we could several years ago. These typologies more accurately reflect the socioeconomic importance of ecosystem services and show very high values of ecosystem services in urban and suburban settings where a combination of scarce ecosystems and high population density leads to highly-valued open space. This demonstrates the importance of protecting open space in cities or on the rapidly developing urban fringe where environmental amenities are a key component to preserving a high quality of life. The high value of urban-proximate ecosystems is evidenced visually in Figure 5, which shows that almost all of the watersheds in the highest per hectare average value class are located immediately around major cities.

The importance of urban ecosystems as components of value underscores a paradox in this approach, however. Because ecosystem service valuation primarily takes account of utility enhancements for human beneficiaries, ecosystems remote from human settlement tend to receive lower valuations, particularly for services that are based on proximity or connectivity to human populations. The paradox is that if we propose to build a city or town in the midst of a wilderness, suddenly those surrounding ecosystems will greatly rise in value because of the utility they will now deliver to the human beneficiaries. But wilderness and non-human dominated ecosystems have great intrinsic value which is lost when humans become part of that system. Those intrinsic values (often referred to as existence values or option values) are fundamentally different from the utilitarian values generally measured in ecosystem service valuation. Because they do not benefit humans directly or indirectly in any quantifiable way, they are very difficult to measure. In other words, these “non-use” values are clearly important to humans, but not in a way that can be made fungible with economic values. This is a critical caveat that should be included with any ecosystem service valuation attempt. Nevertheless, it does not obviate the usefulness of ecosystem service valuation which, despite this shortcoming, is still of great value as a tool for weighing tradeoffs and evaluating management and policy decisions. If anything, this caveat underscores that ecosystems are generally far more valuable than an ecosystem service valuation might estimate, but that much of this value is simply not able to be quantified in dollars.

Another finding of this pilot study is that primary valuation research should always be the preferred strategy for gathering information about the value of ecosystem goods and services when time and money allow. However, while it is not uncommon for *some* services and *some* ecosystem types to be the subject of primary valuation research at a policy site, it is almost never feasible to conduct a full valuation of *all* services and ecosystems at a policy site using original research, given the vast amount of time and money required to conduct these studies. In this context, the value transfer method represents a meaningful “second-best” strategy and a starting point for the evaluation of environmental management and policy alternatives. While value transfer is far from perfect, we believe that it is better than the status quo approach of assigning a value of zero to ecosystem services.

Perhaps the most critical question that this research raises is how ecosystem service values should be used in policy and decision making. As this is being written, the ecosystem services framework has played only a limited role in the public decision-making arena. Ecosystem service valuation in particular has had little to no role. Among the few preliminary efforts at integrating ecosystem services into policy are Costa Rica’s payment for ecosystem service (PES) scheme in which the government pays private landowners to not cut down rainforest or to undertake reforestation. However, the prices paid are not based on ecosystem service valuation, but rather on opportunity cost, and there is no spatially-explicit accounting for different types of ecosystems or ecosystem services. The US government has a similar system with its Conservation Reserve Program, which pays farmers on environmentally sensitive land to keep that land out of intensive production. Again, payments are not based on ecosystem service values. A slightly more sophisticated PES program is under development in Lombok, Indonesia, where the World Wildlife Fund is working with the government to develop a system where upland forest owners get paid not to cut down the forest by downstream agriculturalists. There are other examples of policies designed to manage for single ecosystem services—most notably carbon forest offset regulations. In this scheme, landowners get a payment for reforestation, based on the market price of carbon which, in theory, should reflect its social cost. However, despite this peripheral use of ecosystem service-based concepts, there are no good examples of governments using valuations of the whole suite of ecosystem services to help inform policy.

Such a holistic approach to ecosystem service valuation has the potential to yield much more efficient policies than an approach that focuses on merely one objective—which is typical of environmental policy-making. For instance, if a government agency were weighing the implementation of a watershed protection ordinance that would conserve forest land around key drinking water reservoirs, but they only analyzed the benefits to water quality (or avoided costs of extra filtration), this single-objective approach may fail to find the policy cost-effective, while if all the other services associated with forest protection were analyzed (e.g. recreation, habitat, gas regulation, etc.), the policy’s benefits might then be found to greatly outweigh its costs, but this would not be known without looking at the full suite of services.

There are many ways in which this type of spatially explicit multi-service valuation could be useful to policy makers. For instance, it could greatly enhance cost-benefit analysis for large-scale projects that can impact large areas of land, like the building of highways, reservoirs, canals, strip mines, etc. Currently, most cost-benefit analyses—required in numerous countries for large projects—fail to incorporate non-market ecosystem services. Instead, environmental concerns are generally evaluated based on meeting a set of static criteria. But including these ecological factors as dollar values could alter the cost benefit ratios estimated for many of these projects and dramatically change the ranking of scenarios.

Ecosystem service valuation can also be used design better policies by serving as a tool for comparing outcomes under different policy configurations. For instance, if a state or province were considering modifying the criteria dictating development setbacks from surface waters, a spatial ecosystem service valuation framework could be used to compare how the likely benefits might vary relative to the costs under various scenarios by simulating changes in ecosystem service flow at individual locations under each set of criteria. This would allow policy makers to look not only at predicted aggregate changes in welfare, but also at the spatial distribution of these effects. This framework could also be used for scenario analysis in municipal land use planning, to assess the hidden costs associated with buildout projections under different zoning and planning scenarios.

It can additionally be a valuable tool in assessing the non-market return on investment from environmental restoration or other "green investments." In particular, it can help quantify whether the cost of restoring systems like wetlands, riparian areas, streams and lakes is justified given the benefits delivered. It can also be used to compare the benefits derived from acquisition of different land parcels. Because the benefits are comparable to costs, this might help leverage additional funds for these efforts.

Finally, little consensus exists as to how long the results of a given ecosystem service valuation analysis remain current. While the results of a value transfer study start becoming dated the moment they are committed to paper, this is less of a problem than it might seem. Peer reviewed literature rarely loses its usability or acceptability. Hence, we use many studies in this analysis that are over two decades old. As long as the correct inflators are used to convert those to current dollars, there is no reason why old studies cannot be used, unless their methods or data were found subsequently to be flawed, which is a rare occurrence in this field. The bigger problem is that new primary valuation studies are coming out all the time, and so after several years, a value transfer analysis will be out of date in terms of representing the state of practice. However, updating a value transfer analysis is straightforward and requires only a new literature search, reading the studies, and creating metadata for them. The appropriate interval for updating a database depends on the ecosystems, regions, and services being studied, for one combination of those may receive no new valuation research over many years, while another may see a great deal. Hence, the approach taken towards keeping such analyses current is largely at the discretion of the analyst and the client.

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Appendices

Appendix 1: Detailed description of land cover typology and spatial methods used to develop classes

Descriptions and methods for classes with economic values:
For key of SOLRIS class names, see end of this Appendix)

11. Agriculture (SOLRIS class 99):
    - Class description: Areas suitable for row crops outside of designated urban areas. Includes pixels with "undifferentiated" (99) SOLRIS class that also have a crop capability class (CLI1) of 1, 2, 3, and 4 from the Canadian Agricultural Land Inventory for Agriculture (1,2,3 and 4 refer to "no significant limitations in use for crops," "moderate limitations on use for crops,"" moderately severe limitations on use for crops" and "severe limitations on use for crops" respectively).
    - Methods: 1)Selected polygons with suitable classes from agriculture inventory layer. 2) Rasterized output. 3)Conducted Conditional function to update modified SOLRIS layer with new code for all agricultural pixels.

12. Grassland/pasture/hayfield (SOLRIS classes 20,21 ,22, 99):
    - Class description: Likely areas for pasture or hayfields, or native grasslands. Includes: 1) pixels with "undifferentiated" (99) SOLRIS class that also have a crop capability class (CLI1) of 5 or 6 from the Canadian Agricultural Land Inventory for Agriculture (5 and 6 refer to "very severe limitations for annual crops" and "natural grazing only" respectively) and 2) pixels with SOLRIS grassland classes, including 20, 21, 22.
    - Methods: 1)Selected polygons with suitable classes from agriculture inventory layer. 2)Rasterized output. 3)Conducted Conditional function to update modified SOLRIS layer with new code for all grassland/pasture pixels. Later reclassed pixels with SOLRIS classes 20,21 and 22 to that same code as well.

21. Forest: non-urban (SOLRIS classes 27,28,29,30,36) :
    - Class description: Areas of tree cover located outside of designated urban, suburban, riparian or hedgerow areas. Includes all forested land from the SOLRIS pixel classes given above that do not fall into the following categories: urban forest, suburban forest, riparian forest, hedgerow (see class definitions below)
    - Methods: Reclassified pixels with the SOLRIS classes mentioned above after having already coded pixels designated as urban forest, suburban forest, riparian forest, and hedgerow categories (described below). Therefore reclassification only applied to pixels that were not in one of those four designations.

22. Forest: urban (SOLRIS classes 27,28,29,30,36,37):
    - Class description: Areas of tree cover located in designated urban areas. Includes all forested land from the SOLRIS pixel classes given above that fall in designated urban areas. Urban areas were designated as areas in or within 2km of a Census dissemination area with a population density greater than 386 people/sq km (1,000 people/sq. mile) located within a municipality of 50,000+ people. This is based on the US Census definition of an urban area, which includes areas with population density greater than 500 people/sq mile located within jurisdictions of 50,000+. Also included areas that were designated as "built up" in the " Built Boundary for the Growth Plan for the Greater Golden Horseshoe" layer, that were also located within a municipality of 50,000+, as some of these designated "built-up" areas within major municipalities were slightly under the 386 person per square mile criterion.
    - Method: 1)Did a spatial join of communities point layer (which had data on population) to municipal boundary layer, choosing to sum population, resulting in a new population attribute field for that layer. 2)Queried the resulting municipalities layer and created a layer giving only municipalities greater than 50000 people. 3)Queried for census polygons with population density greater than 386 people/ sq km that were located within a municipality of more than 50000 people. 4)Selected polygons from the Built Boundary layer that were in municipalities greater than 50,000 and did a union (combines all geometry of both layers) of that with the selected census polygons from the previous step. 5)Created a 2km buffer around those polygons. 6) Rasterized the resulting layer and set each urban pixel equal to a value of 200. 6) Added the resulting raster mask to modified SOLRIS layer and reclassed all forest pixels with a value greater than 200 as urban forest pixels.

23. Forest: Suburban (SOLRIS classes 27,28,29,30,36, 37):
    - Class description: Areas of forest cover located in designated suburban areas. Includes all forested land from the SOLRIS pixel classes given above that fall in designated urban areas. Suburban areas were designated as areas in or within 5km of a Census dissemination area with a population density greater than 100 people/sq km located within a municipality of 50,000+ people or in a municipality that shares a border with a 50,000+ municipality. The 100 person/sq km criterion was based on an article by Pozzi and Small.[18]
    - Methods: 1)Selected all municipalities that shared a border with those greater than 50,000 population. 2) Combined that layer with the layer of 50,000+ municipalities. 3)Selected dissemination areas with population density greater than 100 people/ sq km that were located in a municipality of more than 50,000, or in a neighboring

[18] Pozzi, F and C. Small. 2001. Exploratory analysis of suburban land cover and population density in the USA. Proceedings of the IEEE/IEPRS joint Workshop on Remote Sensing and Data Fusion over Urban Area. Rome, Italy.

municipality. 4)Created a 5km buffer. 5) Used the Erase function to subtract out all urban areas (as defined in urban forest class above) from suburban areas, to keep them mutually exclusive. 6)Rasterized resulting layer and reclassed all suburban pixels to a value of 400. 7) Added the resulting raster mask to modified SOLRIS layer and reclassified all forest pixels with a value greater than 400 as urban forest pixels

24. Forest adjacent to rivers/streams (SOLRIS classes 27,28,29,30,36):
    - Class description: Areas of forest cover located within 30 meters of the banks of larger-order rivers and streams that are not urban or suburban. Includes forest pixels from SOLRIS that are not classified as urban/suburban (due to their higher valuations) and are located within 30 meters of class 2 or greater streams.
    - Methods: 1)Clipped streams layer to study area. 2)Selected larger order streams by querying for lines where STHAHLER>1 resulting in a new layer lacking the smallest streams. 2)Created vector buffers for 30 m and converted that to raster. 3)Buffered all river polygons (double-lines) that were available, using the river polygons layer described under the "open water: river" category, below, and converted that to raster. 4) Used a conditional function to update the value of all pixels that were classified as non-urban/suburban forest that fell within either of the raster buffer masks.

27. Forest: hedgerow/bocage (SOLRIS class 37):
    - Class description: Forested belts located along the margins of agricultural fields. Includes pixels classified by SOLRIS as forested hedgerows, not including belts located within urban or suburban areas. This class was included because several valuation estimates were found that were specific to treed hedgerows.
    - Methods: Conducted a raster reclassification of pixels that still had a SOLRIS class 37 after urban/suburban forest pixels had already been reclassified.

31. Urban herbaceous greenspace (SOLRIS classes 44,99,20,21,22):
    - Class description: Herbaceous open space in designated urban areas. Includes pixels located within urban areas that are classified by SOLRIS as undifferentiated, grassland, or developed pervious.
    - Methods: 1)Created KMZ file of parks and overlaid on Google Earth imagery to investigate what SOLRIS was generally classifying urban non-forest pervious area as. This was found to include developed-pervious, grassland classes 44, 99, 20, 21, and 22. 2)Using the urban mask layer described above, ran a conditional function to update the value of all pixels located in the urban mask with the aforementioned SOLRIS values.

41. Open water: river (SOLRIS class 66):
    - Class description: Areas of open water within the banks of perennial rivers. Includes all SOLRIS "open water" pixels that could be feasibly classified as river or stream from available data, with intent to exclude those with a stream order (Strahler) of 4 or less. This was done because it was assumed that only the larger rivers would have a width of open water greater than SOLRIS' pixel size of 15 meters. By representing streams of width less than 15 meters using 15 pixels, it would overstate the area of open water.
    - Method: 1)Extracted all water features from the original SOLRIS layer by created a binary raster using a raster query. 2)Converted query result to polygon layer and created a new field which was calculated to be equal to the perimeter-area ratio for each feature. 3)Ran a query for ratio>.04 to try to isolate longer and narrower features (rivers) from more compact ones (lakes). Many rivers were broken up into separate polygons, and many lakes were connected to river polygons, necessitating manual editing. 4)Manually selected many rivers that did not make selection and added them to the previous selection. 5)Converted the resulting combined layer to raster. 6)Selected segments from the vector stream network layer where the stream order (Strahler) was greater than 4, leaving only the largest order rivers, and created a new layer from the output. 7)Converted new layer to raster. 8) Performed a raster query for areas where both raster layers had a value of 1, resulting in a river mask layer showing those river features derived both from SOLRIS and the streams vector layer. 9) While in the process of conducting this analysis, received "water_polygons" feature class from Steve Voros, which has lakes and rivers classified. A visual assessment indicated that the rivers layer created above was better than the "water_polygons" layer in terms of river characterization, so no change was made. 10) Used the conditional function to update the values of pixels in the modified SOLRIS layer overlaying designated lake pixels.

42. Open water: urban/suburban river (SOLRIS class 66):
    - Class description: Areas of open water within the banks of perennial rivers and streams that are also located in designated urban or suburban areas. Includes all SOLRIS "open water" pixels that could be feasibly classified as river or stream, located in urban/suburban areas.
    - Methods: Used a conditional function to update the value of pixels that had been already classified as open water: river (above) and that also overlaid an urban or suburban area, as designated in urban and suburban forest category methods.

43. Open water: inland lake (SOLRIS class 66):
    - Class description: Perennial inland lakes and reservoirs, not including the Great Lakes or Lake St. Claire. Includes all SOLRIS "open water" pixels that could be feasibly classified as lakes.

- Methods: 1)Took the inverse of the selection of features (derived from SOLRIS) from the SOLRIS-derived layer that had been used to create the rivers layer above and exported the result to a new preliminary lakes layer. 2) Compared this preliminary layer with information in the water polygons layer sent by Steve Voros. Found that the water polygons layer was superior for lakes (although it had not been for rivers). 3)Selected lakes from the water polygons layer and exported to new layer and converted it to raster. 4) Used Conditional function to update the values of pixels in the modified SOLRIS layer identified as lakes from the new lakes layer.

44. Open water: great lake nearshore margin (SOLRIS class 66):
    - Class description: Nearshore zones of lakes Erie, Ontario and Huron to the international border, in addition to all of Lake St. Clair to the international border. Defined as surface waters of the Great Lakes in areas where depth is less than 10 meters for Lake Erie, 20 m for Huron and 30 m for Ontario. Nearshore depths were based on a document by the US Advisory Committee on Water Quality. The intent of this zone is to indicate areas of the lakes that could see significant bottom-habitat degradation as a result of land use change. Hence, this includes areas whose bottoms receive sufficient light to support nursery and other habitat.
    - Methods: 1)Obtained 1m bathymetry contours from NOAA in line format for each lake. 2)Merged bathymetry layers for each lake with the coastline layers for each lake, also from NOAA. 3)Selected coastline features (those with null elevations) and set the elevation fields for these features equal to lake level elevation for each (173.5 m for Erie, 577 for Huron, 74 for Ontario). 4)Converted each bathymetry layer to Triangulated Irregular Network layer and then converted those layers to raster surfaces. 5)Did a raster query for water from original SOLRIS layer and converted the resulting raster layer to polygons. Then manually selected the polygons for the great lakes and exported selection to a new layer. 6)Used this layer to clip the bathymetry raster layers, using extract by mask, resulting in three layers. 7) For Huron, had to use a coarser 90m grid for the northernmost part of the analysis region due to computer memory constraints. 8)The high and lower resolution grids were mosaiced together to form one grid for querying. 9) For each of lake raster surface, conducted a raster query for pixels meeting depth criteria specified above. This was evaluated relative to height above sea level in meters. For Erie, queried for value>=163.5; for Huron, value>=156; for Ontario value>=44. Output was binary (true/false) raster layers. 10) Joined the resulting layers to the modified SOLRIS layer using the Mosaic tool.

45. Open water—Estuaries and Tidal Bays (SOLRIS class 66):

- Class description: Areas of the Great Lakes forming significant embayments, estuaries or coves. This included pixels with a SOLRIS designation of open water that visually appeared to meet these criteria, with additional input from MNR personnel.
- Methods: 1)Edited the Great Lakes polygon layer from above and hand digitized polygons defining bays/estuaries. 2)Selected the resulting polygons and exported to a new layer. 3) Rasterized the resulting layer. 4)Used the Conditional function to update the value of pixels in the modified SOLRIS layer overlaying designated embayment pixels.

51. Wetlands: non-urban, non-coastal (SOLRIS class 50, 55, 59, 63):
    - Class description: Wetlands, bogs, marshes, swamps, and fens, excluding those in urban/suburban areas and those considered coastal.
    - Methods: Used raster reclassification to give a new value to pixels from the modified SOLRIS layer that had any of the four aforementioned values.

52. Wetlands: urban/suburban (SOLRIS class 50, 55, 59, 63):
    - Class description: Wetlands, bogs, marshes, swamps, and fens in urban/suburban areas, including those considered coastal (because of higher valuation estimate)
    - Methods: Used the Conditional function to update the value of pixels coded as wetlands or coastal wetlands that also fell within urban/suburban areas.

53. Wetlands: Great Lakes coastal(SOLRIS class 50, 55, 59, 63):
    - Class description: Wetlands, bogs, marshes, and fens designated as coastal but not located in urban/suburban areas
    - Methods: 1)Obtained Great Lakes Coastal Wetlands Inventory (GLCWC) dataset from Steve Voros. 2)Converted SOLRIS wetlands to vector through a raster query followed by conversion. 3)On instructions of Steve Voros, selected all those SOLRIS-derived wetlands that intersected GLCWC polygons. 4)Exported selection to new layer. 5)Unioned exported layer with GLCWC layer. 6)Converted output to raster.

61. Beach (SOLRIS class 10,12):
    - Class description: Open and treed sand barrens/dunes located within 1 km of the coast.
    - Methods: 1)Created a 1 km buffer of the coastline (using a layer of the coast from NOAA). 2)Rasterized output. 3)Ran a conditional function to update the value of pixels with aforementioned SOLRIS classes that also overlaid the 1 km coastal buffer.

For Case Study Ecodistricts only

These classes were used in place of the generic beach (61) class for ecodistricts 6E-6 and 7E-5, for which there was no mapped beach in SOLRIS (7E-5 was supposed to be a case study ecodistrict, but it does not border a great lake).

62. Beach near structure (not present in SOLRIS):
    - Class description: Open sandy beach along the shore of a great lake, within approximately 200 meters of a structure.
    - Methods: 1) selected ecodistricts for the case study. 2)Created a 1 km buffer of those ecodistricts to account for the fact that many of the mapped beaches would be located outside the boundaries of those ecodistricts, which are designed to be at or near the shoreline. 3) Clipped the region-wide land classification map described in this document to those buffered regions. Hence, some area designated as "great lake nearshore" was included in the clipped output. 4)Ecodistricts were exported to Google Earth for overlay. 5) All beaches were then digitized in Google Earth. Beaches near structures were stored with a different file name prefix than those that were not near structure (the vast majority of beaches fell in the near-structure category—only those in designated parks did not). The resulting KML files were imported to ArcGIS as a single geodatabase file. 6)A new code was created for each polygon designating whether the polygon was near or not-near a structure. 7)The resulting polygon layer was then unioned (where all geometry is combined) with the buffered ecodistricts layer). 8) The resulting unioned layer was converted to raster, using the beach code as the gridcode. Because of the narrowness of many beaches, the output raster cell size was designated as 7.5 meters, or half the dimensional distance of a SOLRIS pixel. 9)The clipped classification map (step 3, above), was then updated using the Conditional function in order to recode all pixels that overlaid a beach.

63. Beach (not present in SOLRIS):
    - Class description: Open sandy beach along the shore of a great lake, not within 200 meters of a structure.
    - Methods: See class 62 above.

Unvalued classes:

197. Undifferentiated—poor agricultural potential (SOLRIS class 99)
    - Class description: All land categorized as "undifferentiated" with a CLI rating of greater than 6 from the Canadian Land Inventory of Agriculture that was not in a designated urban or suburban area.
    - Methods: Reclassed all pixels that still had a value "undifferentiated" after those that were agriculture or pasture/grassland had been reclassified.

198. Terrestrial no value (SOLRIS classes 2,3,5,6,42,43,44,45,66)

- Class description: All other terrestrial land use/land cover types that are not valued in the literature database, including developed, transportation, extractions, etc.
- Methods: Reclassified all pixels that still had the aforementioned SOLRIS codes after all other terrestrial classes had been reclassified. This ensured that valued classes which were derived from one of these SOLRIS codes (such as urban herbaceous greenspace, which includes some pixels with the value 44, or built-up, pervious) retained their new classification.

199. No value-aquatic (SOLRIS class 66)

- Class description: All water features that could not be classified as river or lake or great lake nearshore. This included all areas of the great lakes between the nearshore zone and the international boundary.
- Methods: Reclassified all pixels that still had a SOLRIS class of 66 after all other open water types had been classified.

SOLRIS code key

SOLRIS code	SOLRIS description
2	Open Cliff and Talus
3	Alvar
5	Shoreline
6	Open Shoreline
10	Open Sand Barren and Dune
12	Treed Sand Barren and Dune
20	Open Tallgrass Prairie
21	Tallgrass Savannah
22	Tallgrass Woodland
27	Forest
28	Coniferous Forest
29	Mixed Forest
30	Deciduous Forest
36	Plantations - Tree Cultiv
37	Hedge Rows
42	Transportation
43	Extraction
44	Built-Up Area Pervious
45	Built-Up Area Impervious
50	Swamp
55	Fen
59	Bog
63	Marsh
66	Open Water
99	Undifferentiated

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units

All figures in 2008 Canadian Dollars (CAD)

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
Agriculture								
	Gas Regulation							
		2008	Wilson, S.J.			31.40	31.40	
							31.40	*per Hectare per Year*
	Recreation							
		2007	Knoche, S. and Lupi, F.			137.21	137.21	
							137.21	*per Hectare per Year*
	Other Cultural							
		2004	Olewiler, N.	8.36	33.44		20.90	
		1999	Alvarez-Farizo, B., Hanley, N., Wright, R. E. and MacMillan, D.			14.50	14.50	
		1994	Bowker, J.M. and Didychuk, D.D.	36.23	117.74		76.99	
		1988	Turner, M. G., Odum, E. P., Costanza, R. and Springer, T. M.			275.74	275.74	
		1985	Bergstrom, J., Dillman, B. L. and Stoll, J. R.			85.17	85.17	
				8.36	**117.74**		**94.66**	*per Hectare per Year*
	Pollinations and Seeding							

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		1992	Southwick, E. E. and Southwick, L.	7.61	27.11		17.36	
		1989	Robinson, W. S., Nowogrodzki, R. and Morse, R. A.			38.07	38.07	
				7.61	**27.11**		**27.71**	*per Hectare per Year*
				7.61	**117.74**		**290.99**	***per Hectare per Year***
Beach near structure								
	Disturbance Regulation							
		2001	Parsons, G. R. and Powell, M.			25,770.30	25,770.30	
		1995	Pompe, J. J. and Rinehart, J. R.	9,997.05	61,102.79		35,549.92	
				9,997.05	**61,102.79**		**30,660.11**	*per Hectare per Year*
	Recreation							
		2008	Wilson, S.J.			135.36	135.36	
		2004	Nunes, P. and Van den Bergh, J.	2,178.59	3,157.37		2,667.98	
		2003	Hanley, N., Bell, D. and Alvarez-Farizo, B.			37,739.08	37,739.08	
		1998	Kline, J. D. and Swallow, S. K.	111,440.63	138,775.68		125,108.15	
		1992	Silberman, J., Gerlowski, D. A. and Williams, N. A.			80,100.37	80,100.37	
		1990	Ecologistics			334,061.14	334,061.14	
				2,178.59	**138,775.68**		**96,635.35**	*per Hectare per Year*
	Aesthetic and Amenity							

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		2000	Taylor, L. O. and Smith, V. K.	83.43	213.82		148.62	
		2000	Taylor, L. O. and Smith, V. K.	1,390.43	3,563.66		2,477.05	
		1995	Pompe, J. J. and Rinehart, J. R.	5,211.70	10,503.37		7,857.54	
		1991	Edwards, S. F. and Gable, F. J.			607.77	607.77	
				83.43	**10,503.37**		**2,772.75**	*per Hectare per Year*
				83.43	**138,775.68**		**130,068.20**	***per Hectare per Year***
Beach not near structure								
	Recreation							
		2008	Wilson, S.J.			135.36	135.36	
		2004	Nunes, P. and Van den Bergh, J.	2,178.59	3,157.37		2,667.98	
		2003	Hanley, N., Bell, D. and Alvarez-Farizo, B.			37,739.08	37,739.08	
		1998	Kline, J. D. and Swallow, S. K.	111,440.63	138,775.68		125,108.15	
		1992	Silberman, J., Gerlowski, D. A. and Williams, N. A.			80,100.37	80,100.37	
				2,178.59	**138,775.68**		**49,150.19**	*per Hectare per Year*
				2,178.59	**138,775.68**		**49,150.19**	***per Hectare per Year***
Forest: adjacent to stream								
	Gas Regulation							
		1992	Birdsey, R. A.			991.68	991.68	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
							991.68	*per Hectare per Year*
	Disturbance Regulation							
		1999	Rein, F. A.	53.19	243.16		148.17	
				53.19	**243.16**		**148.17**	*per Hectare per Year*
	Soil Regulation							
		1999	Rein, F. A.	288.75	1,268.97		778.86	
				288.75	**1,268.97**		**778.86**	*per Hectare per Year*
	Nutrient Regulation							
		2008	Wilson, S.J.			621.24	621.24	
							621.24	*per Hectare per Year*
	Water Supply							
		2008	Wilson, S.J.			1,649.17	1,649.17	
		1999	Rein, F. A.	368.53	1,614.71		991.62	
				368.53	**1,614.71**		**1,320.40**	*per Hectare per Year*
	Recreation							
		1999	Rein, F. A.	208.96	908.04		558.50	
				208.96	**908.04**		**558.50**	*per Hectare per Year*
	Habitat Refugium							
		2002	Amigues, J. P., Boulatoff, C., Desaigues, B., Gauthier, C. and Keith, J. E.			41.48	41.48	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		2002	Amigues, J. P., Boulatoff, C., Desaigues, B., Gauthier, C. and Keith, J. E.	49.46	1,158.32	181.88	181.88	
		1989	Willis, K. G. and Benson, J. F.	128.43	222.24		175.34	
				49.46	**1,158.32**		**132.90**	*per Hectare per Year*
				49.46	**1,614.71**		**4,551.75**	***per Hectare per Year***
Forest: hedgerow								
	Gas Regulation							
		1992	Birdsey, R. A.			991.68	991.68	
							991.68	*per Hectare per Year*
	Other Cultural							
		1997	Bonnieux, F. & Le Goffe, P.			6.82	6.82	
							6.82	*per Hectare per Year*
	Pollinations and Seeding							
		2006	Morandin, L.A. and Winston, M.L.			24.52	24.52	
							24.52	*per Hectare per Year*
							1,023.02	***per Hectare per Year***
Forest: non-urban								
	Gas Regulation							

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		1992	Birdsey, R. A.			991.68	991.68	
							991.68	*per Hectare per Year*
	Nutrient Regulation							
		2008	Wilson, S.J.			513.27	513.27	
							513.27	*per Hectare per Year*
	Recreation							
		2008	Wilson, S.J.			362.75	362.75	
		2005	Hunt, L.M., Boxall, P., Englin, J., and Haider, W.			0.04	0.04	
		2000	Haener, M. K. and Adamowicz, W. L.			4.24	4.24	
		2000	Scarpa, R., Chilton, S. M., Hutchinson, W. G. and Buongiorno, J.			9.48	9.48	
		1999	van Kooten, G.C. and Bulte, E.H.					
		1993	Shafer, E. L., Carline, R., Guldin, R. W. and Cordell, H. K.			8.50	8.50	
		1993	Shafer, E. L., Carline, R., Guldin, R. W. and Cordell, H. K.			1,544.04	1,544.04	
		1991	Willis, K. G.	215.81	369.96		292.89	
		1991	Willis, K. G.	88.64	161.86		125.25	
		1991	Willis, K. G.	50.10	53.95		52.03	
		1991	Willis, K. G.	944.17	1,730.34		1,337.26	
		1991	Willis, K. G.	3.85	15.42		9.63	
		1991	Willis, K. G. and Garrod, G. D.			36.85	36.85	
		1989	Prince, R. and Ahmed, E.	2.99	3.84		3.41	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
				2.99	**1,730.34**		**270.45**	*per Hectare per Year*
	Habitat Refugium							
		2001	Kenyon, W. and Nevin, C.			1,437.85	1,437.85	
		2000	Haener, M. K. and Adamowicz, W. L.			102.75	102.75	
		1998	Haener, M.K. and Adamowicz, W.L.	139.11	243.85		191.48	
		1997	Garrod, G. D. and Willis, K. G.			7,981.53	7,981.53	
				139.11	**243.85**		**2,428.40**	*per Hectare per Year*
	Other Cultural							
		2008	Sverrisson, D., Boxall, P. and Adamowicz, V.	45.87	100.21		73.04	
		1996	Loewen, K.G. and Kulshreshtha, S.N.			6.50	6.50	
		1988	Turner, M. G., Odum, E. P., Costanza, R. and Springer, T. M.			58.33	58.33	
		1988	Turner, M. G., Odum, E. P., Costanza, R. and Springer, T. M.			445.43	445.43	
		1988	Turner, M. G., Odum, E. P., Costanza, R. and Springer, T. M.			615.11	615.11	
				45.87	**100.21**		**239.68**	*per Hectare per Year*
				2.99	**1,730.34**		**4,443.49**	***per Hectare per Year***
Forest: suburban								
	Gas Regulation							

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		1992	Birdsey, R. A.			991.68	991.68	
							991.68	*per Hectare per Year*
	Nutrient Regulation							
		2008	Wilson, S.J.			513.27	513.27	
							513.27	*per Hectare per Year*
	Water Supply							
		2008	Wilson, S.J.			1,649.17	1,649.17	
							1,649.17	*per Hectare per Year*
	Recreation							
		1996	Bateman, I. J., Diamand, E., Langford, I. H. and Jones, A.			36,536.03	36,536.03	
		1996	Bateman, I. J., Diamand, E., Langford, I. H. and Jones, A.			2,052.59	2,052.59	
		1994	Maxwell, S.	80.19	159.27		119.73	
		1992	Bishop, K.	2,088.30	22,101.14		12,094.72	
		1992	Bishop, K.	2,516.91	9,610.03		6,063.47	
				80.19	**22,101.14**		**11,373.31**	*per Hectare per Year*
	Other Cultural							
		1988	Turner, M. G., Odum, E. P., Costanza, R. and Springer, T. M.			249.23	249.23	
							249.23	*per Hectare per Year*
				80.19	**22,101.14**		**14,776.65**	***per Hectare per Year***

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
Forest: urban								
	Gas Regulation							
		1992	Birdsey, R. A.			991.68	991.68	
							991.68	*per Hectare per Year*
	Nutrient Regulation							
		2008	Wilson, S.J.			513.27	513.27	
							513.27	*per Hectare per Year*
	Water Supply							
		2008	Wilson, S.J.			1,649.17	1,649.17	
							1,649.17	*per Hectare per Year*
	Recreation							
		2001	Tyrvainen, L.			5,955.93	5,955.93	
		2001	Tyrvainen, L.			58,738.61	58,738.61	
		2001	Tyrvainen, L.			6,700.54	6,700.54	
		2001	Tyrvainen, L.			4,032.65	4,032.65	
		2001	Tyrvainen, L.			15,904.77	15,904.77	
		2001	Tyrvainen, L.			11,822.21	11,822.21	
		1995	Bennett, R., Tranter, R., Beard, N. and Jones, P.			1,168.39	1,168.39	
							14,903.30	*per Hectare per Year*
	Other Cultural							
		1988	Turner, M. G., Odum, E. P., Costanza, R. and Springer, T. M.			249.23	249.23	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
							249.23	*per Hectare per Year*
	Pollinations and Seeding							
		2006	Hougner, C., Colding, J., and Soderqvist, T.	2,752.32	12,319.92		7,536.12	
				2,752.32	**12,319.92**		**7,536.12**	*per Hectare per Year*
				2,752.32	**12,319.92**		**25,842.77**	***per Hectare per Year***
Fresh wetland: Great Lakes coast								
	Gas Regulation							
		2008	Wilson, S.J.			14.08	14.08	
							14.08	*per Hectare per Year*
	Nutrient Regulation							
		2008	Wilson, S.J.	1,613.43	4,920.43		3,266.93	
		2004	Brauer, I.			28.99	28.99	
		2000	Bystrom, O			10,483.52	10,483.52	
		1993	Gren, I. M.			44.85	44.85	
		1990	Lant, C. L. and Roberts, R. S.	64.99	81.49		73.24	
		1989	Lant, C. L. and Tobin, G.			2,061.43	2,061.43	
				64.99	**4,920.43**		**2,659.83**	*per Hectare per Year*
	Recreation							
		1981	Kreutzwiser, R.			573.82	573.82	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		1981	Kreutzwiser, R.			606.18	606.18	
							590.00	*per Hectare per Year*
	Aesthetic and Amenity							
		2000	Bishop, R.C., Breffle,W.S., Lazo, J.K., Rowe, R.D., and Wytinck, S.M.	592.69	5,630.59	3,066.05	3,066.05	
		2000	Bishop, R.C., Breffle,W.S., Lazo, J.K., Rowe, R.D., and Wytinck, S.M.	1,223.38	4,354.02	2,800.10	2,800.10	
		2000	Bishop, R.C., Breffle,W.S., Lazo, J.K., Rowe, R.D., and Wytinck, S.M.	1,056.21	2,439.16	1,713.49	1,713.49	
				592.69	**5,630.59**		**2,526.55**	*per Hectare per Year*
	Other Cultural							
		1996	Randall, A. and de Zoysa, D.	224.16	17,716.93		8,970.54	
				224.16	**17,716.93**		**8,970.54**	*per Hectare per Year*
				64.99	**17,716.93**		**14,760.99**	***per Hectare per Year***
Fresh wetland: urban/ suburban								
	Gas Regulation							
		2008	Wilson, S.J.			14.08	14.08	
							14.08	*per Hectare per Year*

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
	Disturbance Regulation							
		1997	Leschine, T.M., Wellman, K.F., and Green, T.H.	31,584.06	47,412.39		39,498.23	
		1997	Leschine, T.M., Wellman, K.F., and Green, T.H.			166,693.65	166,693.65	
		1997	Leschine, T.M., Wellman, K.F., and Green, T.H.	143,648.98	206,103.13		174,876.06	
		1981	Thibodeau, F. R. and Ostro, B. D.			16,206.13	16,206.13	
				31,584.06	**206,103.13**		**99,318.51**	*per Hectare per Year*
	Nutrient Regulation							
		2000	Bystrom, O			5,421.94	5,421.94	
		1993	Gren, I. M.			44.85	44.85	
		1990	Lant, C. L. and Roberts, R. S.	64.99	81.49		73.24	
		1989	Lant, C. L. and Tobin, G.			2,061.43	2,061.43	
		1981	Thibodeau, F. R. and Ostro, B. D.			8,239.09	8,239.09	
				64.99	**81.49**		**3,168.11**	*per Hectare per Year*
	Water Supply							
		1981	Thibodeau, F. R. and Ostro, B. D.			48,929.30	48,929.30	
							48,929.30	*per Hectare per Year*
	Recreation							
		1981	Thibodeau, F. R. and Ostro, B. D.	1,039.60	18,683.69		9,861.64	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
				1,039.60	**18,683.69**		**9,861.64**	*per Hectare per Year*
	Aesthetic and Amenity							
		2000	Mahan, B. L., Polasky, S. and Adams, R. M.			104.14	104.14	
		1981	Thibodeau, F. R. and Ostro, B. D.	72.87	233.18		153.03	
				72.87	**233.18**		**128.58**	*per Hectare per Year*
				64.99	**206,103.13**		**161,420.22**	***per Hectare per Year***
Fresh wetlands								
	Gas Regulation							
		2008	Wilson, S.J.			14.08	14.08	
							14.08	*per Hectare per Year*
	Nutrient Regulation							
		2008	Wilson, S.J.	1,613.43	4,920.43		3,266.93	
		2004	Brauer, I.			28.99	28.99	
		2000	Bystrom, O			10,483.52	10,483.52	
		1993	Gren, I. M.			44.85	44.85	
		1990	Lant, C. L. and Roberts, R. S.	64.99	81.49		73.24	
		1989	Lant, C. L. and Tobin, G.			5,093.91	5,093.91	
		1989	Lant, C. L. and Tobin, G.			462.66	462.66	
				64.99	**4,920.43**		**2,779.16**	*per Hectare per Year*
	Recreation							

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		2008	Wilson, S.J.			362.75	362.75	
		1993	Shafer, E. L., Carline, R., Guldin, R. W. and Cordell, H. K.			278.54	278.54	
		1986	Anderson, G. D. and Edwards, S. F.	6,810.10	13,213.63		10,011.87	
				6,810.10	**13,213.63**		**3,551.05**	*per Hectare per Year*
	Aesthetic and Amenity							
		1996	Doss, C. R. and Taff, S. J.			1,464.92	1,464.92	
		1996	Doss, C. R. and Taff, S. J.			2,145.59	2,145.59	
		1990	Lant, C. L. and Roberts, R. S.	59.78	81.35		70.57	
		1986	Anderson, G. D. and Edwards, S. F.			22,183.65	22,183.65	
				59.78	**81.35**		**6,466.18**	*per Hectare per Year*
	Habitat Refugium							
		1992	van Kooten, G. C. and Schmitz, A.			143.28	143.28	
		1992	van Kooten, G. C. and Schmitz, A.			20.85	20.85	
		1989	Willis, K. G. and Benson, J. F.	43.39	80.07		61.73	
				43.39	**80.07**		**75.29**	*per Hectare per Year*
	Other Cultural							
		1991	Whitehead, J. C. and Blomquist, G. C.	25.97	84.76		55.37	
		1990	Whitehead, J. C.	3,000.46	6,031.54		4,516.00	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
				25.97	**6,031.54**		**2,285.68**	*per Hectare per Year*
				25.97	**13,213.63**		**15,171.44**	***per Hectare per Year***
Grassland/ pasture								
	Gas Regulation							
		2008	Wilson, S.J.			30.82	30.82	
		2004	Olewiler, N.	9.34	28.02		18.68	
		2004	Olewiler, N.	3.76	11.26		7.51	
				3.76	**28.02**		**19.00**	*per Hectare per Year*
	Disturbance Regulation							
		2004	Olewiler, N.	2.19	7.83		5.01	
				2.19	**7.83**		**5.01**	*per Hectare per Year*
	Soil Regulation							
		2004	Olewiler, N.	2.19	12.04		7.12	
		2004	Olewiler, N.	0.59	2.45		1.52	
				0.59	**12.04**		**4.32**	*per Hectare per Year*
	Nutrient Regulation							
		2004	Olewiler, N.	2.61	46.44		24.53	
				2.61	**46.44**		**24.53**	*per Hectare per Year*
	Recreation							

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		2004	Olewiler, N.	37.06	162.03		99.54	
		2004	Olewiler, N.	11.10	45.67		28.39	
		1995	Boxall, P. C.			50.10	50.10	
		1995	Boxall, P. C.			138.27	138.27	
		1995	Boxall, P. C.			43.25	43.25	
		1995	Boxall, P. C.			16.69	16.69	
		1995	Boxall, P. C.			25.83	25.83	
		1995	Boxall, P. C.			40.80	40.80	
		1995	Boxall, P. C.			30.51	30.51	
				11.10	**162.03**		**52.60**	*per Hectare per Year*
	Habitat Refugium							
		1989	Willis, K. G. and Benson, J. F.	80.07	109.39		94.73	
				80.07	**109.39**		**94.73**	*per Hectare per Year*
	Other Cultural							
		2008	Sverrisson, D., Boxall, P. and Adamowicz, V.	45.87	100.21		73.04	
		1999	Alvarez-Farizo, B., Hanley, N., Wright, R. E. and MacMillan, D.			54.08	54.08	
		1988	Turner, M. G., Odum, E. P., Costanza, R. and Springer, T. M.			275.74	275.74	
				45.87	**100.21**		**134.29**	*per Hectare per Year*
	Pollinations and Seeding							
		2006	Morandin, L.A. and Winston, M.L.			18.88	18.88	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
							18.88	*per Hectare per Year*
				0.59	**162.03**		**353.36**	***per Hectare per Year***
Open water: estuaries/ tidal bays								
	Nutrient Regulation							
		1995	Goffe, L.			53.93	53.93	
							53.93	*per Hectare per Year*
	Water Supply							
		1997	Whitehead, J. C., Hoban, T. L. and Clifford, W. B.	18.68	71.98		45.33	
				18.68	**71.98**		**45.33**	*per Hectare per Year*
	Recreation							
		2002	Johnston, R. J., Grigalunas, T. A., Opaluch, J. J., Mazzotta, M. and Diamantedes, J.			53.92	53.92	
		2002	Johnston, R. J., Grigalunas, T. A., Opaluch, J. J., Mazzotta, M. and Diamantedes, J.			748.24	748.24	
		2002	Johnston, R. J., Grigalunas, T. A., Opaluch, J. J., Mazzotta, M. and Diamantedes, J.			983.19	983.19	
		1997	Whitehead, J. C., Hoban, T. L. and Clifford, W. B.	29.39	274.55		151.97	
		1989	Bockstael, N. E., McConnell, K. E. and Strand, I. E.			317.50	317.50	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
				29.39	**274.55**		**450.96**	*per Hectare per Year*
	Aesthetic and Amenity							
		2002	Johnston, R. J., Grigalunas, T. A., Opaluch, J. J., Mazzotta, M. and Diamantedes, J.			278.12	278.12	
		2000	Leggett, C. G. and Bockstael, N. E.	717.54	3,882.46		2,300.00	
				717.54	**3,882.46**		**1,289.06**	*per Hectare per Year*
	Habitat Refugium							
		1994	Kahn, J. R. and Buerger, R. B.	13.93	30.74		22.33	
		1989	Buerger, R. and Kahn, J. R.			3.54	3.54	
				13.93	**30.74**		**12.94**	*per Hectare per Year*
				13.93	**3,882.46**		**1,852.23**	***per Hectare per Year***
Open water: great lake nearshore								
	Recreation							
		1989	Young, C. E. and Shortle, J. S.			925.72	925.72	
		1986	Kealy, M. J. and Bishop, R. C.	64.92	245.11	67.40	67.40	
		1984	Ribaudo, M. and Epp, D. J.	591.09	749.52		670.30	
				64.92	**749.52**		**554.47**	*per Hectare per Year*
	Aesthetic and Amenity							

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		1989	Young, C. E. and Shortle, J. S.			240.16	240.16	
							240.16	*per Hectare per Year*
				64.92	**749.52**		**794.63**	***per Hectare per Year***
Open water: inland lake								
	Nutrient Regulation							
		1985	Sutherland, R. and Walsh, R. G.			611.71	611.71	
							611.71	*per Hectare per Year*
	Recreation							
		1997	Rollins, K., Wistowsky, W., and Jay, M.			16.39	16.39	
		1997	Rollins, K., Wistowsky, W., and Jay, M.			67.24	67.24	
		1997	Rollins, K., Wistowsky, W., and Jay, M.			23.73	23.73	
		1993	Cordell, H. K. and Bergstrom, J. C.			6,841.23	6,841.23	
		1993	Cordell, H. K. and Bergstrom, J. C.			7,289.59	7,289.59	
		1993	Cordell, H. K. and Bergstrom, J. C.			671.98	671.98	
		1993	Cordell, H. K. and Bergstrom, J. C.			1,821.41	1,821.41	
		1985	Mullen, J. K. and Menz, F. C.			12,341.51	12,341.51	
		1979	Bouwes, N. W. and Scheider, R.			1,656.81	1,656.81	
		1971	Burt, O. R. and Brewer, D.			7,466.79	7,466.79	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
							3,819.67	*per Hectare per Year*
	Aesthetic and Amenity							
		1989	d'Arge, R. and Shogren, J.F.			925.51	925.51	
		1989	d'Arge, R. and Shogren, J.F.			295.65	295.65	
		1989	d'Arge, R. and Shogren, J.F.			559.16	559.16	
							593.44	*per Hectare per Year*
	Other Cultural							
		2000	Forsyth, M.	11.55	38.62		25.08	
				11.55	**38.62**		**25.08**	*per Hectare per Year*
				11.55	**38.62**		**5,049.90**	***per Hectare per Year***
Open water: river								
	Nutrient Regulation							
		1977	Oster, S.			33,906.35	33,906.35	
							33,906.35	*per Hectare per Year*
	Water Supply							
		2003	Brox, J.A., Kumar, R.C., and Stollery, K.R.	7,126.27	14,723.32	12,956.62	12,956.62	
				7,126.27	**14,723.32**		**12,956.62**	*per Hectare per Year*
	Recreation							

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
		2000	Ahn, S., De Steiguer, J. E., Palmquist, R. B. and Holmes, T. P.	42.00	383.02		212.51	
		1997	Rollins, K., Wistowsky, W., and Jay, M.			16.39	16.39	
		1997	Rollins, K., Wistowsky, W., and Jay, M.			67.24	67.24	
		1997	Rollins, K., Wistowsky, W., and Jay, M.			23.73	23.73	
		1996	Garrod, G. D. and Willis, K. G.			14,941.51	14,941.51	
		1996	Garrod, G. D. and Willis, K. G.			3,896.40	3,896.40	
		1993	Shafer, E. L., Carline, R., Guldin, R. W. and Cordell, H. K.			3,122.25	3,122.25	
		1993	Shafer, E. L., Carline, R., Guldin, R. W. and Cordell, H. K.			15,637.72	15,637.72	
		1987	Desvousges, W. H., Smith, V. K. and Fisher, A.			39,975.43	39,975.43	
				42.00	**383.02**		**8,654.80**	*per Hectare per Year*
	Habitat Refugium							
		2003	Knowler, D.J., MacGregor, B.W., Bradford, M.J., and Peterman, R.M.	0.05	0.25		0.15	
		2003	Knowler, D.J., MacGregor, B.W., Bradford, M.J., and Peterman, R.M.	8.77	46.90		27.83	
		2003	Knowler, D.J., MacGregor, B.W., Bradford, M.J., and Peterman, R.M.	0.93	4.93		2.93	
				0.05	**46.90**		**10.30**	*per Hectare per Year*

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
	Other Cultural							
		2000	Forsyth, M.	11.55	38.62		25.08	
				11.55	**38.62**		**25.08**	*per Hectare per Year*
				0.05	**14,723.32**		**55,553.16**	***per Hectare per Year***
Open water: urban/ suburban river								
	Nutrient Regulation							
		2002	Mathews, L. G., Homans, F. R. and Easter, K. W.			57,629.81	57,629.81	
		1977	Oster, S.			33,906.35	33,906.35	
							45,768.08	*per Hectare per Year*
	Water Supply							
		2003	Brox, J.A., Kumar, R.C., and Stollery, K.R.	9,729.76	20,102.29	17,690.15	17,690.15	
				9,729.76	**20,102.29**		**17,690.15**	*per Hectare per Year*
	Recreation							
		1977	Gramlich, F. W.	98,679.00	245,577.59	172,691.14	172,691.14	
				98,679.00	**245,577.59**		**172,691.14**	*per Hectare per Year*
	Aesthetic and Amenity							
		1982	Rich, P. R. and Moffitt, L. J.			242.41	242.41	

Land Cover	Ecoservice	Year	Author	Min Est	Max Est	Single Est	Average	Units
							242.41	*per Hectare per Year*
				9,729.76	**245,577.59**		**236,391.78**	***per Hectare per Year***
Urban herbaceous greenspace								
	Aesthetic and Amenity							
		2006	Costanza, R., Wilson, M., Troy, A., Voinov, A., Liu, S., and D'Agostino, J.	33,542.63	61,773.37		47,658.00	
		1974	Hammer, T.R., Coughlin, R.E., and Horn, E.T.			39,419.08	39,419.08	
				33,542.63	**61,773.37**		**43,538.54**	*per Hectare per Year*
	Other Cultural							
		1988	Turner, M. G., Odum, E. P., Costanza, R. and Springer, T. M.			249.23	249.23	
							249.23	*per Hectare per Year*
				33,542.63	**61,773.37**		**43,787.77**	***per Hectare per Year***

Appendix 3: Bibliography of valuation studies used

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Amigues, J. P., Boulatoff, C., Desaigues, B., Gauthier, C. and Keith, J. E.

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Anderson, G. D. and Edwards, S. F.

Protecting Rhode-Island Coastal Salt Ponds - an Economic-Assessment of Downzoning

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Household Willingness to Pay and Farmers' Willingness to Accept Compensation for Establishing a Recreational Woodland

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Bennett, R., Tranter, R., Beard, N. and Jones, P.

The Value of Footpath Provision in the Countryside: A Case-Study of Public Access to Urban-fringe Woodland

Journal of Environmental Planning and Management 38 : 409-417 1995 **Method:** Contingent Valuation

Bergstrom, J., Dillman, B. L. and Stoll, J. R.

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Restoration Scaling Based on Total Value Equivalency: Green Bay Natural Resource Damage Assessment

US Fish and Wildlife Service Report 2000 **Method:** Multi-attribute Decision Analysis

Bockstael, N. E., McConnell, K. E. and Strand, I. E.

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Marine Resource Economics 6 : 1-18 1989 **Method:** Travel Cost

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The Economic Value of Lottery-Rationed Recreational Hunting

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Brauer, I.

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The replacement value of wetlands in Sweden

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Costanza, R., Wilson, M., Troy, A., Voinov, A., Liu, S., and D'Agostino, J.

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2006 **Method:** Hedonic Pricing

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