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FROM RHETORIC TO MEASUREMENT: THE ECONOMICS OF WETLAND CONSERVATION IN THE CANADIAN PRAIRIES

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From rhetoric to measurement: The economics of wetland conservation in the Canadian prairies

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1. Introduction

Wetland conservation is a pressing issue in Canada as around 200,000 square kilometres of Canadian wetlands have been lost since the 1800s (Federal, Provincial and Territorial Governments of Canada 2010). In the Canadian prairie pothole region, an area of numerous wetlands important for North American waterfowl production, 40% to 71% of wetlands have been lost since European settlement; largely due to agricultural expansion. Estimated wetland area losses have been reported at a rate of ~ 3% per decade or -0.35% per year. In the 1990s wetlands near large urban centres are particularly at risk, as 80 to 98% of wetlands in or adjacent to major urban centres have been converted or affected by expansion.

The loss in wetlands has been extensively studied by wetland scientists who have determined that these ecosystems provide significant ecological functions which are negatively affected by the losses. The development of wetland assessment methods has grouped biophysical processes that involve hydrology, biogeochemistry, and plant and animal habitats, (Smith et al. 1995; Novitski, Smith, and Fretwell 1996). This understanding of their ecological significance, and the magnitudes of their historical loss, has led to consideration of the importance of these functions to human society (Gustavson and Kennedy 2010). This concern, and the emergence of the concept of ecosystem services, has led many researchers to articulate a narrative that wetland functions provide substantial benefits to society through their provision of ecosystem services (Cohen et al. 2016; Creed et al. 2017), and that the loss of these functions is of critical importance. The narrative supports increasing wetland conservation through the development of policy and programs that protect existing wetland basins, and provides for restoration of lost ones largely on the basis of wetland functions (e.g. Alberta Wetland Policy).

The translation of scientific research on wetland function loss into protection efforts has been relatively slow to develop. The emergence of ecosystem service approaches, and the potential to transform the importance of services into economic values, provides a platform for the biophysical information to be used to inform wetland protection efforts. For example, Gustavson and Kennedy (2010) claim that economic valuation efforts have potential to increase the effectiveness of results of biophysical research on functions wetlands, as valuation can be understood by policy makers and thus translated into wetland protection policies and programs. However, the ecosystem services provided by wetlands differ by wetland type, size, location, and ecological function in similar ways to how the productivity of agricultural land differs across the landscape.

For agricultural lands, markets for agricultural products bring consumer's demands and producer's outputs into alignment (Hansen et al. 2015). No such markets exist for most benefits that wetlands provide society, which raises challenges for economic measurement and wetland management. While society reaps the majority of benefits from wetland conservation, private landowners are typically left to bear the costs of supplying wetland services. With this mismatch in benefits and costs, it is perhaps not surprising that wetlands have continued to be drained and degraded in the Canadian prairies. Economics can play a key role in quantifying the relevant benefits and costs of wetland conservation and designing effective and efficient policies to align the interests of the landowner and society.

This interest in protecting wetlands through developing an "economics of wetland conservation" rhetoric has led many conservationists and policy makers to support protection efforts by performing back of the envelope calculations involving simple transfers of economic values from other studies that may be unrelated to the specific wetland at hand. For example, 30 years ago the 1991 Federal Policy on Wetland Conservation (Government of Canada 1991) provided the following narrative on the economic value of wetland functions:

"In financial terms alone, Canada's wetlands are valued in the billions of dollars. This includes the financial value of annual production directly related to wetlands, including both consumptive activities such as hunting, fishing and trapping, and non-consumptive activities such as tourism and recreation. It also includes the value derived from natural functions such as flood control and water purification. Estimates in the internationally recognized book Wetlands of Canada, published in 1988, indicate that the economic returns derived from wetlands exceed $10 billion annually in Canada. The economic values of wetlands alone are a strong argument for their conservation." (Federal Policy on Wetland Conservation 1991, p3).

The translational approach continues to be used by numerous researchers in devising economic value estimates in supporting wetland conservation efforts (Pattison-Williams et al. 2017; 2018; Thompson and Young 1992)

Given the potential for wetlands to provide significant levels and values of ecosystem services, one might expect large numbers of empirical economic studies demonstrating and supporting this significance. This review will show that this in fact is not the case in Canada. There is a general misunderstanding of what ecosystem services are, and how they differ from ecological functions. The distinction is not just semantics. Ultimately, it is ecosystem services that benefit people and only by understanding their provision on their landscape can we begin to understand the economic benefits of wetlands. Further, we believe that the translational approach involving transferring wetland benefit estimates using dollars per hectare metrics that dominates the wetland conservation literature in Canada is not able to provide the site-specific value information that is necessary for effective policy.

Thus, it is the purpose of this paper is to synthesize the current knowledge about wetland conservation economics in Canada, with a focus on prairie landscapes in order to narrow the review. We first synthesize the literature on the costs of wetland conservation and discuss the methods economists have used to uncover various wetland supply curves. We then discuss wetland benefit valuation. While it is often said that wetlands provide important ecosystem services to society, we find only a sparse literature demonstrating and quantifying the economic value of Canadian prairie wetlands. We outline the wetland ecosystem service conceptual framework, review the demand for wetland ecosystem services, and discuss the characterization of economic benefits of wetland conservation. We outline the main approaches used in wetland valuation, discussing their strengths and weaknesses. Further challenges exist with operationalizing this knowledge into wetland conservation policies.

2. The Economics of Supplying Wetland Ecosystem Services

The supply side of the wetland conservation issue is complex due to the issue of property rights, or in many cases the problem of “perceived” property rights. This is particularly relevant in the prairies where agricultural uses dominate many of the landscapes. Given the fact that significant wetland loss has taken place in the settled areas of Canada where most of the land is privately owned, this private provision of public benefits aspect of the problem is particularly acute in a policy context. To understand this, economists have focused on explaining why landowners alter or convert wetland basins to other specific land uses. Much of this literature has focused on privately owned agricultural lands on prairie landscapes where agriculture is the predominant land use and waterfowl production has been a public policy concern.

Understanding wetland conservation is particularly complex in the agricultural landscapes of Canada and the northern US where until the early 1980s agricultural policy and legislation at federal and provincial levels encouraged drainage, and financial assistance was provided to landowners to facilitate removal and alteration of wetlands.[1] Policy makers initially considered financial incentives necessary to facilitate drainage, as research suggested that drainage would be beneficial to agricultural producers. Land recovered from draining a wetland increased the producer's land base for crop or livestock production, thus increasing farm profits. Provincial tax assessors also classify wetlands as non-arable 'wastelands' for the purpose of agricultural tax assessment (Saskatchewan Assessment Management Agency 2015). Wetland basins would be considered a "nuisance" in that in an unaffected state they serve as obstacles for producers operating machinery, and increase the expenses and time for seeding, harvesting or applying fertilizers and chemicals. Nuisance costs can include missed areas (lost revenue), travel and input overlap (added expenditures), and adjacency costs (land near wetlands lower yields). The presence of wetlands also increases the potential for crop damage resulting from increased wildlife populations. Thus, wetland basins impose both opportunity costs and nuisance costs on farming operations, and as Leitch (1983) indicates, higher crop prices and land values serve to make drainage even more attractive to producers. This leads to the conclusion that retaining wetlands on lands within an agricultural operation imposes costs to a producer estimated by:

$$\text{Retention costs} = \text{Opportunity costs} + \text{nuisance costs} - \text{cost of drainage}. \qquad (1)$$

Besides retaining existing basins, conservation efforts have also focused on restoring previously drained wetlands. But what specifically is being restored is a complex question. One approach is to simply consider restoring the hydrology through removing or plugging drainage ditches; while another considers restoring wetland functions. This then leads to restoration goals that focus on

[1] Gustavson and Kennedy (2010) cite Tomcik (1991) in outlining for Ontario some of the relevant legislation such as such as the Drainage Act, the Provincial Special Drainage Assistance Program, and the Farm Improvement Loans Act.

wetland area or on wetland functions. The former is relatively simple, while the latter is exceedingly complex. Restoring the ecosystem services that wetlands provide would add another layer of complications.

Regardless of the approach, drained areas need to be acquired, and from a producer's perspective, hydrology needs to be restored. Thus, restoration would reduce productive areas and increase nuisance costs or the first two terms of equation (1). These costs can be summed to represent what restoration practitioners call *securement costs,* which refer to the payments made to producers for securing the land area on which drained basins could be restored. Given that restoring either hydrology and function would in itself require negotiation and engineering efforts, the complete costs of restoration would also need to consider administration and construction costs; thus:

Restoration costs = Securement costs + Administration costs + Construction costs.

Much of the existing literature on restoration costs consists of wetland construction and engineering studies. For example, King and Bohlen (1994) initially scoped the problem of wetland restoration costs and collected over 1000 estimates across a number of ecozones. They claim "It is no more useful to focus on the average cost of restoring an acre of wetland than to focus on the average cost of restoring a damaged automobile" (p 1). The restoration cost estimates they found ranged from \$5 to \$1.5 million/acre[2] and were related to the wide range of scope of restoration projects as well as site-specific and wetland-specific differences. They note, however, that the most reliable cost estimates were from US federal agencies that restored converted agricultural lands back to wetlands. Their review suggested that wetland restoration in agricultural settings is cheaper than in other land-use settings or ecosystems (i.e. salt marshes). However, it is instructive that their cost range estimates excluded the costs of acquiring the lands on which the restoration would occur. In their study of restoration to mitigate flood damage in the Red River region of North Dakota, Shultz and Leitch (2003) provide a summary of studies that focused on the prairie pothole region in the USA. Most studies in their summary provide wide ranges in cost estimates, with the highest costs in the ranges resulting from engineered structures that would include dikes, impoundments, and outlet flow structures. For example, wetland restoration costs in Minnesota averaged $3,000/acre and ranged from $95 - $30,000/acre depending on the restoration purpose (Minnesota Board of Water and Soil Resources 1992) A North Dakota example of large-scale wetland restoration (3,500 acres) where dikes and outlet flow structures were required cost of about approximately $265 - $930,000/acre excluding land acquisition costs (Renner 1999). The Shultz and Leitch (2003) case study used these estimates adjusted for wetland size and scope of the restoration (i.e. installation of drain plugs, outlet control devices etc) and using regional estimates of economic damages of floods, they concluded that restoration benefit cost ratios were less than 1.0. They included land acquisition cost estimates by using land rental rates specific to the region; in addition, they assumed that costs for any maintenance of the restored basins and associated structures would be covered by the land rental rates.

In Alberta, the Alberta Wetland Mitigation Directive lists wetland replacement in-lieu fee rates which include average land values, materials and labour to restore a previously existing wetland, cost of monitoring restored wetland, administrative fee (Alberta Government 2018). Rates on non-public lands range from $17,700/ha to $19,400/ha ($7,200 to $7,900/acre). Further, the government guidelines specify a wetland replacement ratio whereby the final replacement costs will be influenced by the estimated value of the drained wetland and the replacement wetland and the replacement ratio.

It is noteworthy that the restoration cost literature has not successfully dealt with land acquisition, or as we call it above securement costs. This is because the securement component of the restoration cost equation would be the most difficult to determine. In practice, land rental rates are commonly used to set payments for wetland retention. For example, the Alternative Land Use Services (ALUS) program provides per-acre annual payments for wetland retention and restoration, with payments usually based on the average rental rates in the local area. Manitoba Habitat Heritage Corporation provides a one time payment based on the assessed value of the land with a Wetland Restoration Incentive Program (WRIP) payment of $200/acre for restored wetlands (Manitoba Habitat Heritage, n.d.). While the costs of retention discussed above can provide a guide, other factors can influence these costs. One of these is producer cost heterogeneity, which can become important in understanding the level of payment required for securement. This is why land rental rates may not be appropriate as they represent an average (note the King and Bohlen (1993) comment above). Heterogeneity in securement arises from farm characteristics such as soil quality, elevation etc.; and from producer characteristics such as management techniques, machinery etc. This results in the potential for varying securement payments across producers, and this could make life difficult for restoration practitioners who likely desire a consistent securement payment level.

The rest of this section describes the main methods economists have used to estimate the costs of supplying wetlands on the Canadian Prairies. The focus is on securement costs, which are closely related to the costs to the private landowner of retaining existing wetland basins.

Farm-level economic modelling

The most popular approach to estimate the cost of supplying wetlands/private benefits as well as wetland drainage on agricultural land is the use of a farm-level economic model. These models use information on yields, rotations, agricultural prices, and drainage costs to calculate the private costs of retaining or restoring wetlands on the landscape.

Leitch (1983) examined the possible benefits of drainage to agricultural producers by comparing estimated costs of drainage to returns from increasing areas of land under crop production that resulted from drainage. He benchmarked his estimates by surveying 97 producers in the prairie pothole regions of central Minnesota who had drained basins on their properties. Leitch's analysis considered maintenance costs on drainage infrastructure, as well as various discount rates and tax scenarios. Depending on discount rates, taxes, and region in the state, the resulting benefit cost ratios (BCRs) ranged from 1.3 to 5.2 for drainage ditching, and 0.6 to 1.5 for more expensive tile drainage structures. Leitch ignored nuisance costs which he considered unknown at the time. His research suggested that wetland drainage is economically beneficial to agricultural producers; a methodology that explicitly includes nuisance costs would serve to make the BCRs even larger.

van Kooten (1993) took a different approach by constructing a dynamic programming model of a producer's decision process in undertaking wetland conversion to cropping. While his model was developed to specifically examine the role of government payments to farmers in the drainage decision, the model setup is instructive. His model assumed that grain producers maximized net returns, and in so doing would convert wetlands to crops until the marginal opportunity cost of conversion was related to the marginal return on wetlands.[3] Calibrating the model using a survey of 67 Saskatchewan farmers to a typical 1200 acre grain farm in the province, and by considering the wetland inventory at the time of the study, van Kooten was able to represent historical conversion. This approach allowed him to examine the role of grain prices, conversion costs, avoidance costs, livestock production, and government payments on conversion.

Cortus (2011) developed a model of a representative grain farm in east-central Saskatchewan and simulated cash flows with and without drainage. They calibrated this model using spatial data on wetland basins for the region as well as information on farm sizes, crop yields, input costs and machinery costs. Their approach incorporated both opportunity costs and nuisance costs, which were benchmarked by varying wetland basin numbers on cropped fields from the spatial wetland inventory. The results found that annual net private benefits were positive in favor of drainage, and that they increased with farm size, ranging from \$27.76/ha of wetland area drained for a small farm to \$40.66/ha for a large farm.

De Laporte (2014) developed an economic farm-level model in East Central Saskatchewan based on a wheat-barley-canola-flax rotation over a 20-year time horizon. Cost heterogeneity was introduced by varying expected yields by soil quality (100% yields for highest quality Class 1 soils, 85% for Class 2, 75% for Class 3, and 65% for Class 4), site-specific drainage costs that varied by wetland area, and nuisance costs. A key result of this study is a relationship between hectares of wetland area drained and agricultural prices. Historically high crop prices would result in almost all wetlands being drained whereas relatively low prices would result in no additional wetland drainage.

One policy relevant aspect of these models is the effect of government support payments to producers on wetland drainage. van Kooten (1993), Cortus et al. (2009), and Jeffrey et al. (2017) examined this in some detail concluding that government payments to support farm income and mitigate business and production risks serve to increase wetland drainage and conversion to annual crop production and provide significant disincentives to undertake restoration. This unintended consequence of agricultural production subsidies merits discussion on how to avoid these perverse incentives (e.g. van Kooten 1993). Given that historically some of this government support was

[3] This theoretical result suggests that at present, existing wetlands on agricultural land may be too expensive to convert, and that existing drained basins were cheaper to eradicate. This come as a revelation to wetland conservationists.

designed to encourage wetland drainage to favor increased crop production, we wonder if the financial support system has resulted in the formation of social norms among producers in rural communities that result in wetland conversion as a "good" farming practice.

One challenge with these farm-level modelling of wetland costs is understanding the spillover effects of wetlands on adjacent lands. A major concern from producers is that agricultural lands adjacent to wetlands have poorer quality yields. Part of this challenge is delineating where the wetland ends and the field begins as it is likely more similar to a continuous gradient compared to a clearly defined edge.

These studies show that wetland drainage provides positive economic benefits to agricultural producers and provides information to policy makers on the magnitude of possible financial incentives required to arrest continued drainage activity in supporting the public benefits arising from wetlands. While uptake from Canadian governments on incenting wetland retention has been limited, interest has shifted to *restoring* drained basins which raises its own measurement challenges.

Boxall et al. (2009) combine farm-level information with administrative and wetland construction costs to illustrate the issue of cost variation in a case study of restoration in a Manitoba watershed. Their research utilized historic land use, yield, and input, soil and climate data provided by producers over a 15-year period in the watershed. Merging this information with an existing and drained wetland inventory, as well as a hydrologic model, the authors were able to forecast foregone yields over a 12-year future rotation. In constructing this, they used an approach similar to that of Leitch (1983). Adding information on administration and construction costs from Ducks Unlimited Canada restoration staff, the authors developed restoration cost estimates at the producer level. The drained inventory found that the average wetland size to be restored would be less than 0.5 acres. The average total cost (in $2008) for restoring an individual wetland in the watershed was estimated to be about $440, resulting in an annualized cost of $65 for the 12-year period. However, variation in these costs was high with a SD of $447 similar to the mean cost. The average annual cost per acre to restore wetlands would be about $1,396/acre in that Manitoba watershed with high variation around this mean.

To illustrate this variation within an individual landowner's property, Figure 1 shows the cost distribution of 61 drained/converted basins for landowner ID 103. The average cost of restoration per wetland acre over the period examined is about $1679 per basin, and range from $104 to $17,000 per acre for drained basins on this farmer's land. Further, the distribution of all restoration costs by basin for the entire watershed are shown graphically in Figure 2, and some of the drained basins held by the individual landowner ID 103 are shown to demonstrate that the costs for wetlands on his/her operation fall across the entire distribution of restoration costs in the watershed.

Figure 1 The distribution of estimated wetland restoration costs over a 12-year period for individual drained basins on one producer's (ID 130) agricultural land in South Tobacco Creek Manitoba.

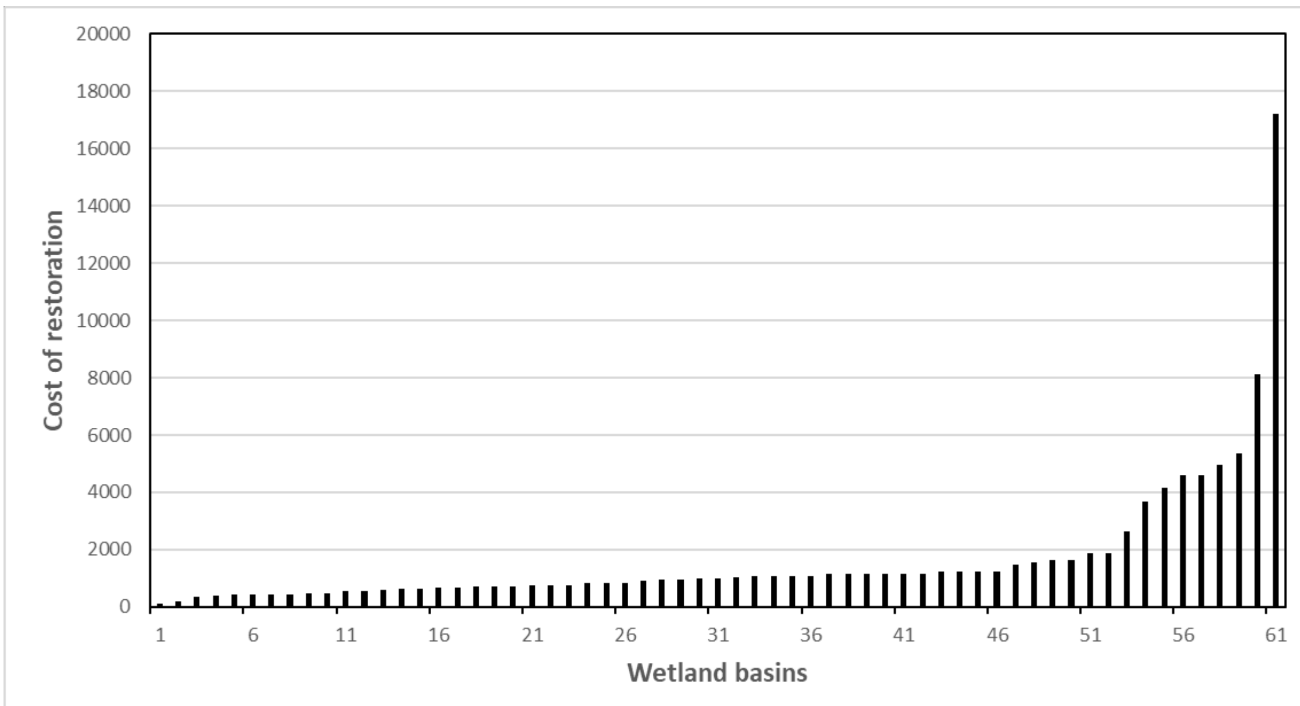


Figure 2 Estimated wetland restoration costs over a 12-year period for individual drained basins on agricultural lands in South Tobacco Creek Manitoba.

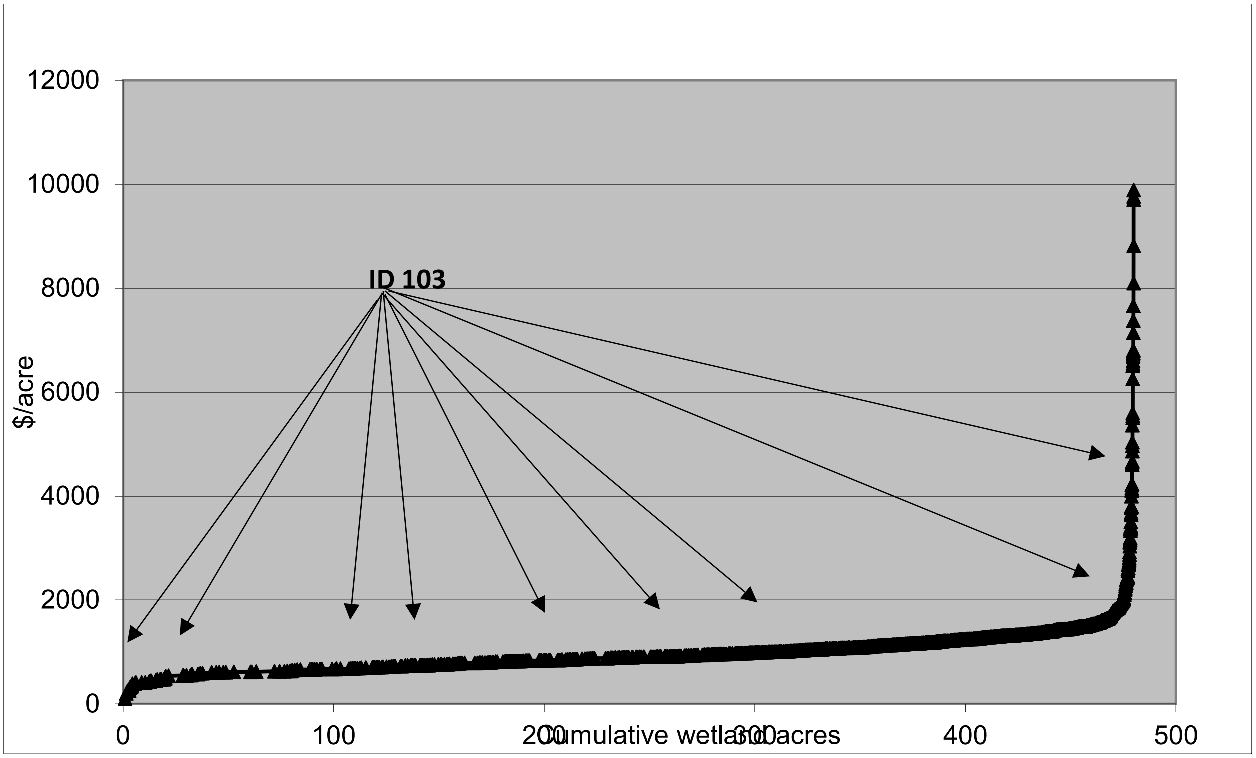
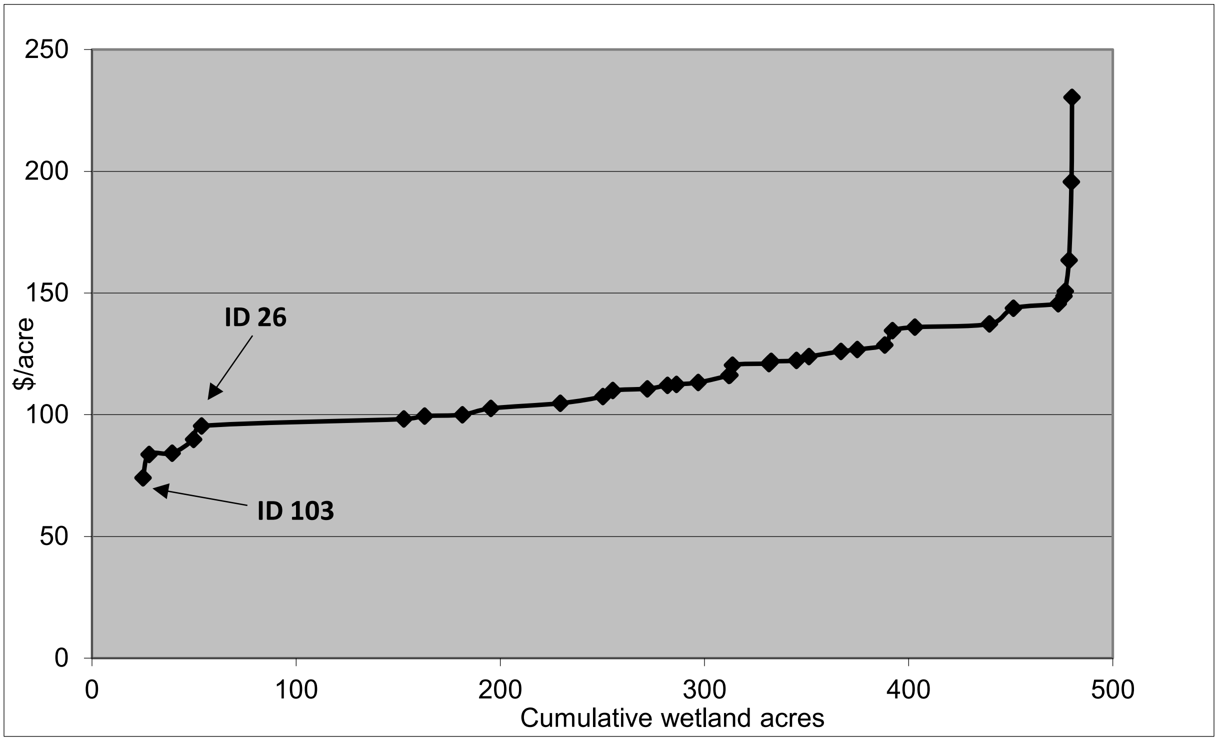
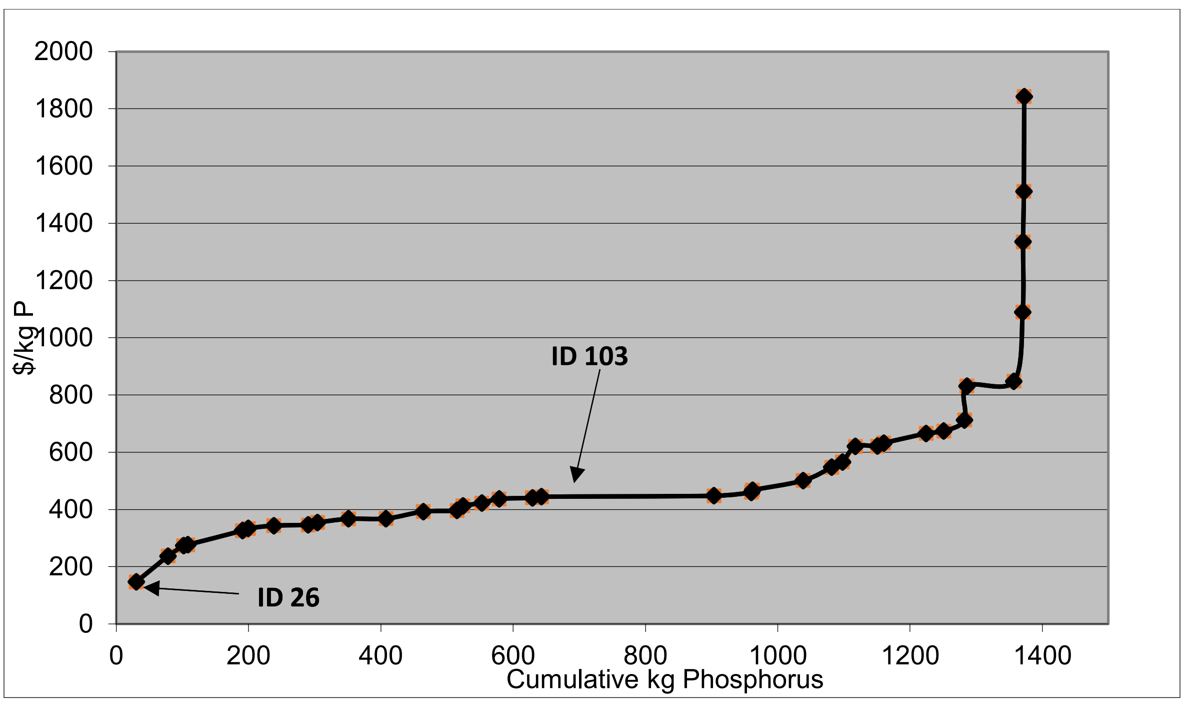


Figure 3 shows the distribution of total costs ($/acre) of restoring every basin on each farm, by farm owner (N=37) in the watershed. While 100% restoration is an unrealistic scenario, this figure further illustrates the relevant unit of analysis (the producer) and the variation in these costs. The cheapest set of basins to restore are held by producer ID 103 in the $/acre space (see top panel of Figure 3). When these costs at the producer level are merged with the nutrient abatement potential of the restored basins in $/kg P using estimates from the hydrologic model (Yang et al. 2016), the distribution of producers along the curve changes (bottom panel of Figure 3). For example the cheapest restoration in $kg/P space would now be those wetlands held by producer ID 26; the wetland restoration costs for producer ID 103 have moved further down the cost curve.

The information in these figures illustrates the significant variation in restoration costs associated with individual basins as well as farming operations where producers might agree to have wetland restoration conducted. This heterogeneity largely arises from estimated securement costs, which include nuisance and opportunity costs for productive farming areas. These securement costs have largely been ignored by the literature on restoration costs, and could be one reason why wetland restoration has been difficult to implement in agricultural areas.

FIGURE 3 ESTIMATED COSTS OVER A 12-YEAR PERIOD TO RESTORE ALL DRAINED BASINS ON LANDS OWNED BY EACH OF 37 PRODUCERS IN SOUTH TOBACCO CREEK MANITOBA BY WETLAND AREA (TOP) AND PHOSPHORUS ABATEMENT POTENTIAL (BOTTOM).





Willingness-to-accept surveys

One approach to dealing with restoration cost heterogeneity on private lands is to simply ask landowners what their willingness to accept compensation level (WTAC) would be for wetland conservation. Landowners typically have the best information on the unique factors affecting costs on their land and thus may be best positioned to determine the costs. The main benefit of this survey approach is that monetary expenses, forgone opportunity costs, and any non-market or nuisance costs can all be included (Norton, Phipps, and Fletcher 1994). Furthermore, any green preferences landowners have towards stewardship and conservation and overall cost perceptions are also incorporated. However, this is not a trivial exercise in that the questioning process would need to consider the potential for landowners to inflate their compensation level. The main challenge, as with all survey methods, is ensuring valid and reliable responses.

Van Kooten and Schmitz (1992) conducted a random survey in Southeastern Saskatchewan asking 66 local producers to provide their WTAC amounts for participating in an agreement to maintain wetlands on their land. They used an open-ended format to elicit the amount of money that the government would need to pay them to not drain and farm a 15 to 20 acre slough and riparian area totalling 30 to 40 acres. Only 38 (64%) of the 66 respondents provided answers to the WTA question.

A second survey of 212 landowners in Saskatchewan by Yu and Belcher (2011) was conducted in 2007. They elicited WTAC amounts through single binary choice (‘accept or reject offer’) question to participate in a conservation program and receive an annual payment to adopt wetland and riparian conservation management on their land for 10 years. Landowner’s with experience with wetland management are more willing to participate in these conservation programs. Around 40% of respondents did not answer the WTA question which may reflect some of the low participation or protest behaviour found in reverse auctions.

Most recently, Kanjilal (2015) surveyed 15 Alberta and 14 Saskatchewan landowners to elicit WTAC for restoration of wetlands. Respondents were asked to restore 7 acres of wetlands on cropland and pastureland which would remove this land from agricultural production for 12 years. A stochastic payment card format was used to elicit values with payment amounts ranging from \$0 to \$1,280 per acre per year for cropland and \$0 to \$240 per acre per year for pastureland.

Reverse auctions

The challenge of eliciting valid and reliable WTAC amounts through surveys has led to the introduction of reverse or conservation auctions which ground WTAC questions in a real, incentivized context. These have been widely employed in Australia and other countries to provide funding to landowners to improve environmental performance in their land management approaches (Stoneham et al. 2003). Very few applications of this approach have been implemented in Canada. However, the few reported Canadian reverse auctions all involved wetland securement/restoration, and all of them have in some way involved Ducks Unlimited Canada (DUC) as the buyer or auctioneer (see Brown et al. 2011; Hill et al. 2011; Boxall and Kauffman 2018).

DUC's mandate involves ensuring healthy waterfowl populations, and due to waterfowl's dependence on wetlands for breeding, this NGO has been involved in numerous retention and restoration programs across the Canadian prairies. DUC typically utilizes conservation easements as a securement tool and has faced challenges associated with setting prices for desired easements on private lands. In general easement prices will fall somewhere between DUC's (the buyer) willingness to pay (WTP) and the landowners' WTAC. DUC has used reverse auctions to uncover information on landowners' WTAC for wetland basin securement in their program to protect or restore as much area as possible within their constrained operational budgets.

The approach involves the auctioneer (DUC) posting a request for bids from sellers (landowners) to provide impacted basins for restoration activities. Thus, this auction is reversed in that there is not one seller and many buyers, but one buyer and many sellers. The auctioneer (buyer) typically has a fixed budget, and sellers provide sealed bids to capture the auctioneer's funds. The auctioneer then ranks the bids on some metric, for example, $$/ha or $$ per some environmental performance measure such as expected number of hatched nests (e.g. Hill et al. 2011). Once the bids are ranked, the auctioneer signs contracts with the "cheapest" seller and continues up the bid rank order until funds are exhausted.

The most common method used in reverse auctions for conservation services is a sealed bid discriminative-price auction in which winning bidders receive the value of their actual offers as payments. Here the sellers would earn no profits if they submit bids equal to their opportunity costs associated with providing drained basins to DUC. Thus, bidders have incentives to shade their offers beyond the true costs they face with permitting restoration on their land; in essence bidders trade off gains from winning with an inflated offer against the risks of not winning a contract. A potential solution to inflated bidding is the uniform-price rule in which all winning bidders receive the same price. In this approach the price paid by the buyer is that of the lowest rejected offer, or the highest winning bidder. This induces incentive compatible cost revelation because the cost reflected in an offer is not related to the payment received and bid shading would not generate a higher payment to the bidder (Latacz-Lohmann and Schiizzi 2005). This has been supported by experimental economic research reported by Boxall et al. (2013). The downside of the uniform price approach is that all sellers (under the lowest rejected offer), or all but one seller (under the highest accepted offer), may receive payments higher than their opportunity costs.

There have been four reverse auctions used to retain or restore wetlands in Canada. Table 1 summarizes some results of these. These auctions involved impacted basins located on agricultural operations; specifically the auction designers sought ditch-drained wetland areas where restoration would involve the installation of plugs in the drainage ditches. Thus, restoration involves restoring basic hydrological function of the basins rather than explicitly examining projections of ecosystem service provision following restoration.

The first auction was a uniform price, single round, sealed bid auction reported by Brown et al. (2011). This auction involved conservation easements aimed at retaining undisturbed wetland and grasslands at four sites across three Canadian prairie provinces and had a reserve price ceiling equal to the assessed value of land in each site. This auction was complex in that it involved bidders in the four sites in provinces with different land values. In addition, successful bidders were expected to sign *perpetual* easements with DUC on the contracted properties. In general the auction had a very low participation rate (<1%) in terms of submitted bids. As one might expect given the geographic coverage and scope of habitat being sought, the submitted bid levels were widely dispersed for easements involving wetlands ranging from \$2.50/acre (0.7% of assessed land value) to \$750/acre (432.7%). The auction permitted bidders to offer impacted basins on lands where the easement would permit some agricultural land uses that would be compatible with wetland conservation, and/or where the easement would prohibit any agricultural uses completely. Most of the bids received were for easements that permitted some agricultural use.

The second auction, described by Hill et al. (2011), took place in Saskatchewan during 2009. In this auction, DUC utilized a sealed bid, discriminant price approach with an opportunity for bidders to revise their bids after initial submission was scrutinized by DUC staff. Bids were assessed using an environmental benefits index based on predicted incremental increases in hatched waterfowl nests relative to bid price. In addition, bidders were provided the option to bid on a 12-year contract with DUC or a perpetual conservation agreement, and they could vary their bid prices between the two. Similar to the auction described by Brown et al. bid prices in the Saskatchewan auction that exceeded the fair market value of the quarter section in which basins to be secured were located, were rejected in the first bidding round and bidders were invited to revise their offers; very bidders revised their offers. Bids for impacted basins on cropland were higher than those associated with forage and pasture as expected. In addition, no bids were submitted for perpetual easements.

The other two auctions occurred in two counties in Alberta in 2015-16 and used the sealed bid uniform price approach, with one bidding round. These auctions were more geographically localized than those reported above, and the market values of land in these areas were much higher (Table 1). The geographical focus led to a smaller pool of potential bidders, and thus fewer bids were received with fewer corresponding wetland acres to be restored (Table 1). In these Alberta auctions, considerable effort was made to understand the size of the potential bidder pool, allowing an understanding of the levels of participation in the two auctions. These ranged from 6-8% but cannot be compared to the participation in the Brown et al. (2011) and Hill et al. (2011) auctions as information on the potential number of eligible bidders was not available.

These auctions generated bids and acres to be restored and allowed DUC to understand potential prices for securement of wetland basins in their restoration programs. Boxall and Kauffman (2018) were able to demonstrate that the information rents sought by bidders in the Hill et al. (2011) discriminative price auction were higher than rents sought in the two Alberta uniform price auctions, which is consistent with theory. This supports the use of the uniform price as the method to use in price discovery. However, the levels of interest in allowing wetland basin securement among landowners was not high, as evidenced by low participation rates or few bids received across the four studies. While low rates of participation by potential bidders for conservation are not unique to wetland restoration (Rolfe et al. 2018), the rates seem to be lower than those reported for other types of landowner conservation activities.

One other advantage of reverse auctions is that offers have the potential to include "green" preferences held by bidders for wetland conservation. What this means is that some landowners are willing to conserve them even if it costs them money. Two of the auctions reported above received bids for $0/acre for restoration, signifying significant value for conserving and restoring wetlands.

TABLE 1 A SUMMARY OF CANADIAN REVERSE AUCTIONS FOR WETLAND RESTORATION

	Brown et al.	Hill et al.	Boxall and Kauffman	Boxall and Kauffman
Pricing format	Uniform	Discriminant	Uniform	Uniform
Number of bids/bidders	33[a] / 46[b]	118 / 22	27 / 8	14 / 4
Number of wetland acres	2334	665	276	51
$2019/acre	284	2,383	3,211	5,453
Average land value ($2019/acre)	266 – 496[c]	321	2,159	6,233
Contract length (yrs)	Perpetuity	12	10	10
Number of potential bidders	3665[b]	~6000[b]	87	66

[a] This number is an underestimate as Brown et al. indicate that some cell counts for two of their sites were too low to report.

[b] These estimates do not consider "eligible" bidders who would have drained basins on their properties but the total number of landowners in the relevant study areas. In the Brown et al. study the 46 bidders includes those who may have submitted bids for other types of habitats.

[c] This range involves areas in three provinces from the year 2002. Agricultural land markets differ considerably between the three provinces and also between the year this auction took place (2002) and the other three studies (2008/9 for Hill et al.; and 2015-16 for Boxall and Kaufman).

Hedonic price method and land valuation studies

Agricultural land markets convey a lot of information on the value of land characteristics. Suppose there are two identical quarter sections, Property A with a 5 acre wetland and Property B without any wetlands. Property A and B are otherwise comparable in all other respects (soil quality, weather, distance to amenities, etc). Comparing the sale prices of these two comparable pieces of agricultural lands would help inform the private financial costs of having a 5 acre wetland on the property. If Property B sold for $500 more, then the wetland costs are $100 per acre. This intuition forms the basis for the hedonic price method.

The hedonic price method uses land sales data to estimate statistical relationships between sale prices and land characteristics. Lawley and Towe (2014) use the hedonic price method to estimate the effects of conservation easements on farmland prices in Manitoba. The conservation easements were placed on both wetlands and upland with the purpose of maintaining waterfowl habitat. Conservation easements on wetlands and uplands reduced farmland prices by $86 per eased acre on average. The hedonic price method can also be used to understand how these costs have changed over time. Lawley (2014) uses farmland transactions in Manitoba and finds that the price discount for wetland acreage has increased by 40% between 1990 and 2009. This suggests that the costs to landowners of having wetlands on their land has increased over time.

Summary of wetland cost methods

Table 2 presents a summary table of the four main approaches economists use to estimate the costs of wetland conservation. The strengths and limitations of the various methods is provided along with illustrative examples.

TABLE 2 SUMMARY TABLE OF WETLAND COST APPROACHES

Method	Strengths	Limitations	Examples
Farm-level economic model	Can include behavioural responses to policies, can simulate counterfactual scenarios based on changing economic conditions	Need to make assumptions on rotations, crop production practices, only economic drivers; realism; difficult to include nuisance costs	(Cortus et al. 2011; Laporte 2014; Kanjilal 2015; Jeffrey, Trautman, and Unterschultz 2017)
Willingness-to-accept surveys	Includes perceptions of costs based on combination of economic and social factors (option value)	Sample representativeness Low survey response rates May not reflect actual decisions	(Yu and Belcher 2011; G. C. van Kooten and Schmitz 1992; Kanjilal 2015)
Reverse auctions	Incentivized elicitation of costs.	Low participation rates, Resource intensive to conduct, need information on environmental effectiveness	(Brown et al. 2011; Hill et al. 2011; Boxall and Kauffman 2018)
Hedonic price method / land valuation	Based on actual decisions by landowners	Data availability, challenge to control for all relevant factors	(Lawley 2014; Lawley and Towe 2014)

Table 3 summarizes the annual cost estimates per acre of wetland retention from the reviewed studies. The numbers in the table report average costs in 2019 Canadian dollars for comparison. There is wide range of cost estimates found using the various methods. Also note that these values are averages for each study and thus ignore any cost heterogeneity within each study.

TABLE 3 SUMMARY TABLE OF PRAIRIE WETLAND COST ESTIMATES

Study	Study Area	Annual cost estimate per acre (CDN $2019)	Retention or restoration
Farm-level economic model			
Cortus et al., (2011)	Saskatchewan	$79 to $119	Retention
Kanjilal (2015)	Saskatchewan	$552	Restoration
	Alberta	$566	Restoration
Jeffrey et al. (2017)	Alberta	$83 to $96	Restoration
Asare et al., (2020)	Alberta	$28 to $39	Retention
WTA survey			
Kanjilal (2015)	Saskatchewan	$978	Restoration
	Alberta	$684	Restoration
Yu and Belcher (2011)	Saskatchewan	$35 to $38	Retention
Van Kooten and Schmitz (1992)	Saskatchewan	$52	Retention
Reverse auction			
Hill et al. (2011)	Saskatchewan	$2,383 one-time payment	Restoration
Boxall and Kauffman (2018)	Alberta	$3,211 to $5,453 one-time payment	Restoration
Hedonic price method			
Lawley and Towe (2014)	Manitoba	$117 [a]	Retention
Lawley (2014)	Manitoba	$551	Retention

[a] Conservation easements more generally, not just wetlands.

3. The Economics of Demand for Wetland Ecosystem Services

Wetlands have economic value attributed to the ecosystem service benefits they provide people. Wetlands can have ecological, social and other non-economic values that can be important for decision-making and policy, but this paper focuses on their economic value. Important ecosystem services provided by wetlands are hydrological including water supply and flood regulation; improvements in water quality by filtering out nutrients and other pollutants; climate regulation through carbon sequestration; recreation opportunities by providing natural spaces for people to visit and habitat for animals, and biodiversity benefits by providing habitat for rare and endangered species. Identifying wetland ecosystem services is a crucial first step, but actually quantifying the benefits and valuing these benefits remains a challenge.

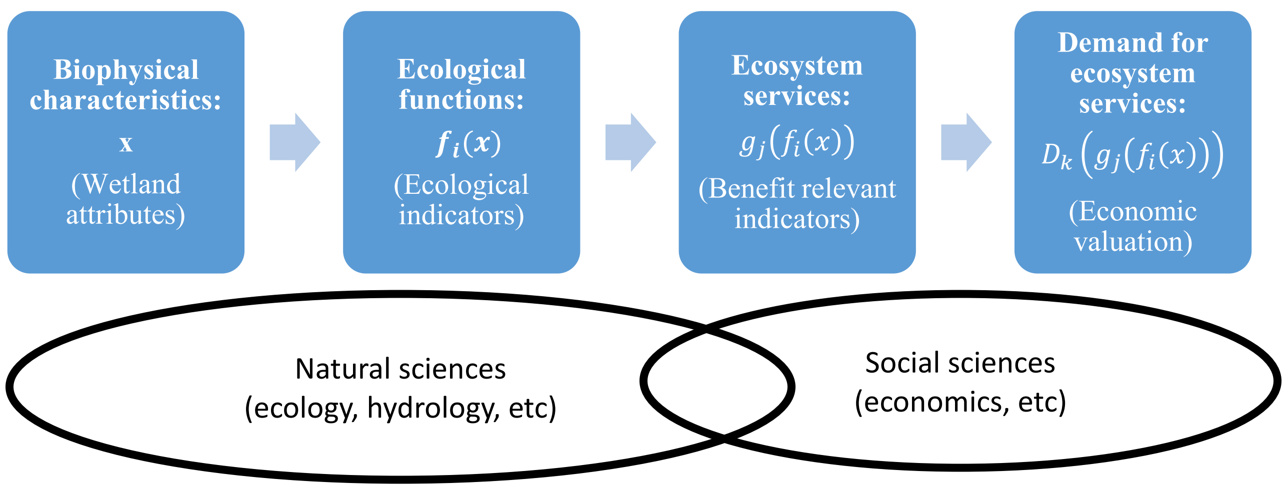
There are two main challenges for quantifying the value of wetland ecosystem services. First, determining the relevant quantities of ecosystem services faces numerous conceptual and empirical challenges. The relationships between wetlands and people is complex and modelling these relationships requires interdisciplinary expertise and a coherent framework. The second challenge is that many of the benefits people derive from wetland ecosystem services are not reflected in markets and can be considered public goods in nature. Understanding the total economic value of wetlands requires the use of non-market valuation methods, summarized earlier in this paper, which have their own limitations and there is a paucity of applications in Canada. Even if market prices are available, further analysis is often required to derive meaningful economic values from this information and to ensure values are locally relevant.

The rest of this section provides guidance towards these twin challenges. We first provide a conceptual framework for linking wetlands and the demand for their associated ecosystem services. We then describe the methods economists use to ascribe economic values to wetland ecosystem services and compare various applications of these approaches in the Canadian prairie context.

3.1. **Conceptual framework for assessing the economic value of wetlands**

Wetlands are heterogeneous in terms of their size, permanence, hydrological position and socioeconomic context. The capability of wetlands to provide ecosystem services depends on wetland attributes, environmental conditions, proximity or availability to humans, and the neighbouring land-use. Wetlands designed for stormwater retention will provide different ecosystem services than a long-term wetland that has a well established community of flora and fauna and is habitat for endangered species. The demand of these ecosystem services depends on people who differ in their preferences for ecosystem services as well as their location; and all of these differences suggest that the demand for ecosystem services are going to be quite diverse across the landscape. To guide this discussion, we outline a conceptual framework for assessing the economic value of wetlands that relates the wetland's biophysical structure to the demand for the ecosystem service. Figure 4 provides an overview of this conceptual framework and each component is discussed in detail below. This framework has been adapted from Hansen et al. (2015).

FIGURE 4 RELATIONSHIP BETWEEN WETLAND BIOPHYSICAL CHARACTERISTICS AND THE DEMAND FOR ECOSYSTEM SERVICES



A wetland can be characterized by a vector of x biophysical characteristics including wetland size, permanence, climatic conditions, and surrounding land use. The ecological functions (i) that are produced by a wetland such as retention of water or removal of nitrogen are a function of these biophysical characteristics, $f_i(x)$. These are typically measured using ecological indicators such as water storage volume in wetlands or kilograms of nitrogen removed. These ecological functions produce ecosystem services *(j)* through a set of ecological production functions $g_j(f_i(x))$. Ecosystem services are ideally measured using benefit relevant indicators that measure the connections between ecosystems and people (Schultz et al. 2012). Benefit relevant indicators combine ecological and social information that represent something that impacts human well-being and can form the basis for economic valuation (Boyd and Krupnick 2013; Jensen, Johnston, and Olsen 2019). For example, water storage is an ecological indicator and the amount of water available for irrigation would be the benefit relevant indicator. Increased duck abundance might be an ecological indicator, and the resulting increase in duck hunting trips would be the benefit relevant indicator. The demand for these ecosystem services by people is the last step in the framework. In this step, changes in ecosystem services are related to changes in human well-being through the demand function $D_k\left(g_j\left(f_i(x)\right)\right)$. How much do people value additional duck hunting days and what is the value of increased water available to irrigation?

The same ecosystem service can be associated with different and separate demand functions. For example, a reduction in algal blooms can enhance both swimming demand and recreational fishing demand at a particular lake. Furthermore, even if two wetlands are equally effective at reducing algal blooms at two different lakes, they can have different impacts on recreation if one of the lakes has substantially less visitors.

The benefit of this framework is that it makes explicit all the linkages and relationships between wetlands and the benefits people receive. The framework also highlights the appropriate roles for natural and social sciences and the required interdisciplinary effort.

Ecosystem services such as the sequestration of carbon takes place in the wetland but other ecosystem services can occur offsite and thus will require additional modelling beyond the particular wetland site. For example, wetlands can filter nutrients that improve water quality in a lake downstream and understanding this relationship would require the use of fate and transport modelling.

Benefit relevant indicators are at the core of the valuation framework and quantify the appropriate ecosystem services that is relevant for economic valuation. Ecosystem services has been an increasingly popular interdisciplinary concept or framework to describe various processes, functions, and benefits nature provides and has been defined and used in a multitude of ways by people working in the natural sciences and at the human-environment interface. In the framework, the ecosystem service of recreation should be quantified using a benefit relevant indicator such as the number of hunting trips or days.

The framework is useful for focusing our valuation efforts on benefit relevant indicators that are directly relevant to human well-being rather than ecosystem functions and intermediate ecosystem services that do not. Double counting of benefits is a concern when separate valuation estimates are aggregated and some of these values are for ecosystem functions or intermediate ecosystem services that are inputs for other ecosystem services. The Millennium Ecosystem Assessment (MEA) categorizes ecosystem services into supporting, regulating, provision, and cultural services. However, this categorization provides little guidance on how, or if, these separate ecosystem services should be aggregated to derive a final value. For example, nutrient cycling as a supporting service and water flow regulation as a regulatory service both provide usable water and are intermediate ecosystem services; whereas recreation as a cultural service is a final human benefit of this usable water (Fisher, Bateman, and Turner 2013). If we aggregated the values of nutrient cycling, water flow regulation, and recreation we would likely be double counting. If you buy a live chicken, you do not pay the price of the egg and the feed, you simply pay the price of the final chicken.[4] Ensuring the focus of economic valuation is on benefit relevant indicators rather than ecosystem functions and intermediate ecosystem services is essential to avoid double counting.

3.2. Methods to value the benefits of wetlands

This section describes the methods economists use in the final step of the framework, understanding the demand for ecosystem services to estimate an economic value of these benefits. This is not to suggest that economists should only be involved in this last step as economic principles are necessary to appropriately define, describe, and quantify benefit relevant indicators.

Economists have developed four main methods to value non-market benefits: revealed preference, stated preference, market valuation, and value transfer methods (Champ, Boyle, and Brown 2017). Revealed preference methods study individual behaviour in related markets such as the choice of a recreation site, the purchase of a home, or the purchase of flood insurance to measure economic values. Examples of these methods are travel cost, hedonic price, and averting behaviour. Stated preference methods use structured conversations with people to elicit trade-offs and preferences for ecosystem services. Market valuation methods such as market prices, production function approaches, and avoided damage costs use prices or costs as proxies for values. Market valuation

[4] This chicken analogy is a modification of the original one in Fisher, Bateman and Turner (2013).

methods are intuitively appealing by focusing on dollar proxies and relatively easy to compute. However, these approaches have been criticized for having weak or no ties to welfare measures derived using economic theory (EPA Science Advisory Board (SAB) 2009). Value transfer methods use value estimates from existing studies and apply this information to the new context.

The valuation methods have been employed in multiple ways and we have grouped the main approaches used to value wetland benefits intro four main categories:

1. Per hectare value transfer
2. "Bottom-up" ecosystem service by ecosystem service approach
3. "All-in-one" stated preference approach
4. Meta-analysis

We discuss each of these categories in turn and provide a comparison summary at the end.

Per hectare value transfer

The first approach, and by far the most common, is to use a dollar per hectare value from an existing study or some summary statistic from more than one study. This valuation approach is termed unit transfer or in the literature and is the simplest of the value transfer methods (Pattison-Williams et al. 2017; Anielski, Thompson, and Wilson 2014; Pattison-Williams et al. 2018). These transfers can be conducted easily and quickly as the quantity to be valued is well defined (i.e. hectares of wetlands) and values can be drawn from existing 'lookup' tables for different ecosystem services. For example, if an existing study has estimated the value of a 100 hectare wetland is \$100,000 then an analyst would transfer the \$1,000 per hectare estimate to the new context. The main concern with this type of transfer is that no comparison is made between the biophysical characteristics of the hectares and no adjustment is made to account for the socioeconomic context of the study wetland(s). Using the conceptual framework introduced above, a per hectare value transfer implicitly assumes that the biophysical characteristics, x, ecological functions, $f_i(x)$, ecosystem services, $g_j(f_i(x))$, and demand for ecosystem services, $D_k\left(g_j(f_i(x))\right)$, are all the same between study and policy site. This assumption is unlikely to hold in the majority of cases.

This process suffers from the same concerns as, for example, assessing the value of Whitehorse's housing stock by taking the value of a single home in Vancouver and multiplying this value by the number of homes in Whitehorse. There can be important differences in housing characteristics between the locations, but there are also substantial differences in the supply and demand for housing leading to quite different values in the housing markets.

Ecosystems are different and the economic benefits of ecosystem services accrue to people, who are unique. The flood control benefits of a particular wetland adjacent to a river in an urban area are quite different from the flood control benefits in a less populated area of the boreal forest. Thus, these peopleless per hectare values that are not adjusted for local socio-demographic characteristics may not accurately reflect the types of ecosystem services received at a certain site, nor their value. Consequently, while easy to conduct, the results of per hectare value transfers should be interpreted cautiously.

The one case where per hectare transfers might be more appropriate is for aspatial ecosystem services such as carbon sequestration where the benefits accrue regardless of where they occur and the same social cost of carbon value is used. However, the usefulness of a per hectare transfer in these contexts also depends on the wetlands' biophysical characteristics being similar across sites such that the same amount of carbon is sequestered.

"Bottom-up" ecosystem service by ecosystem service approach

The second approach is more bottom-up and uses ecological production functions to quantify each ecosystem service and then uses various non-market valuation methods to value each service independently. Perhaps the best example of this approach in Canada is an ecosystem service pilot approach conducted by the Government of Alberta and applied to wetlands by Calgary (Wang et al. 2011). The study quantified and valued a number of ecosystem services including flood control, water purification, water supply, carbon sequestration, recreation, and aesthetic/amenity benefits. A different methodology was developed and applied for each category of ecosystem service. For example, aesthetic and amenity benefits were monetized using a hedonic price method while recreation benefits were valued using information on bird watching behaviour and expenditures. Flood control and water purification were monetized using the damage cost avoided and replacement cost methods. Ecosystem services that could not be monetized were presented quantitatively using benefit relevant indicators.

Another example of this approach is Jenkins et al., (2010) who value the ecosystem service benefits of restoring forested wetlands to agricultural lands. One appeal of this research is that they use explicit process based models to link wetland restoration with changes in quantified ecosystem services which are subsequently monetized. Jenkins et al., (2010) measured the economic value of three ecosystem services: GHG mitigation, nitrogen mitigation, and waterfowl recreation. For greenhouse gas emissions, they measured carbon sequestration rates in soils and other live biomass as well as non-CO_2 GHG emissions such as methane and nitrous oxide. For nitrogen mitigation, they calculate the forgone fertilizer runoff losses associated with crop production and the removal of nitrate via denitrification. The value of nitrogen mitigation is calculated to be $25.27/ kg N ($2008 USD) and is based on output from the U.S. Agricultural Sector Mathematical Programming (USMP) model. The recreation benefits flowing from increased waterfowl habitat is also estimated. The potential productivity of the wetlands is calculated using Duck Energy Days (DED). They first calculate the net DED increase moving from pre-restoration cropland to post-restoration wetland.[5] Once the DED is calculated, they linked the increase in waterfowl habitat to changes in hunting behaviour. They assume that a 1% increase in DED would increase waterfowl hunting days by an equivalent amount. The change in the number of hunting days is multiplied by a per-day consumer surplus value from a large meta-analysis of recreation studies (Rosenberger and Loomis 2001).

The advantages of this approach is that the unique biophysical characteristics of the wetlands are accounted for through the use of ecological production functions. Wetlands that are particularly productive for waterfowl would be associated with a higher recreational benefits. Similarly, wetlands closer to population centres would likely have a larger impact on the number of hunting days or benefits related to water quality.

The main challenge with this approach is the time, resources, and data required to link wetland specific information to particular ecosystem services and benefit relevant indicators. Ecological production functions need to be estimated and the benefit relevant indicators need to be valued using appropriate valuation methods. Another challenge with this approach is that the ecosystem services need to be additive to avoid double counting as described earlier.

[5] One DED represents the amount of daily energy required by a duck that is supplied by the habitat area. In the Mississippi Alluvial Valley, a DED value of 294.35 kcal reflects an average duck wintering.

"All-in-one" stated preference approach

The third approach takes a more holistic approach and uses stated preference methods to place an overall economic value of a wetland protection program. The method can account for non-use values people hold for wetlands ecosystem services. For example, wetlands can provide habitat for endangered species which can form the basis for non-use values people hold for wetlands. Another advantage is that the approach can explicitly avoid the double counting because a unified valuation approach is used as long as the ecosystem endpoints are clearly differentiated and defined. Furthermore, a well-designed instrument can encourage respondents to carefully consider trade-offs between the costs and benefits of wetland conservation.

There have been two applications of stated preference methods for wetland valuation in the Canadian prairie context: Pattison et al. (2011) in Manitoba and Dias and Belcher (2015) in Saskatchewan. Pattison et al. (2011) use survey responses from almost 2,000 Manitobans to estimate the willingness-to-pay to retain remaining wetlands on the landscape at 2008 levels is $251 per household for 5 years. People were willing to pay $333 to restore wetlands to 1968 levels. Dias and Belcher (2015) estimate that the benefits to people in Saskatchewan for an ambitious wetland management scenario are $135 per household. An important feature of a stated preference survey is describing the ecosystem service endpoints of wetlands to people. The two Canadian studies used similar but somewhat different endpoints in their description of the benefits of wetlands. Table 4 compares the ecosystem service endpoints valued in these two studies.

TABLE 4 COMPARISON OF ECOSYSTEM SERVICE ENDPOINTS USED IN CANADIAN PRAIRIE WETLAND STATED PREFERENCE SURVEYS

Ecosystem Service Endpoints	Pattison et al. (2011)	Dias and Belcher (2015)
Wetland area	Relative and absolute change in wetland areas	
Water quality	Amount of fertilizer filtered	Percentage change in number of boil water advisories
Flood control	Number of cubic metres of water controlled	-
Soil erosion	Tonnes of soil conserved	-
Wildlife habitat	Number of breeding pairs of ducks	Habitat and wildlife populations change

Carbon sequestration	Number of cars removed from roads	-
Riparian zone	-	Metres of buffer around wetland

The holistic SP approach has several advantages, but also has its limitations. The challenges of implementing a stated preference study is that they can be time and resource intensive and require specific expertise in these methods. There will always be concerns and challenges regarding the validity of value estimates derived from survey responses (Johnston et al. 2017). Furthermore, SP studies have been conducted at a regional or provincial scale which can provide limited guidance on which wetlands to keep at the watershed level.

Meta-analysis

Meta-analyses use information from many studies to value the ecosystem services provided by wetlands through statistical models. Meta-analyses model the wetland values as a function of observable biophysical characteristics such as wetland type and size, provided ecosystem services, and indicators for demand such as local income and population density. Meta-analyses use the systematic relationship between the independent variable and these dependent variables to generate a function that can be used to value wetlands in a new context. Meta-analyses require a substantial number of available appropriate primary valuation studies and make use of more sources of information on the relationship between value estimates and biophysical and population characteristics as well as other factors to derive case-specific value estimates to be transferred. Meta-analyses have also advanced considerably over the last decades.

The first generation of wetland valuation meta-analyses included hundreds of studies from around the world and specified a dollars per hectare value estimate as the dependent variable (Ghermandi et al. 2010; Brander, Florax, and Vermaat 2006; Woodward and Wui 2001; Brouwer et al. 1999). The huge heterogeneity in value estimates across the world and valuation methods raises some concerns with these early applications. One of these concerns is with the use of dollar per hectare values as the dependent variable which may not be appropriate as social values are not linked to a specific surface area of a wetland. There are further concerns regarding the commensurability of including value estimates from many different valuation methods such as replacement cost and stated preference as well as studies from such disparate places as the United States and Cameroon. A final concern is that these models did not use frameworks that are consistent with economic theory.

Setting aside some of the limitations of these studies, they also provide insights into how wetland biophysical characteristics, ecosystem services, and demand for these ecosystem services affect value estimates. A summary of some of the factors affecting the value estimates per hectare is provided below:

- Wetland size (-): Larger wetlands are valued less per hectare than smaller wetlands (Ghermandi et al. 2010; Brander, Florax, and Vermaat 2006; Woodward and Wui 2001).
- Human-made wetlands (+): Constructed wetlands have a higher economic value than natural wetlands (Ghermandi et al. 2010).
- Ecosystem services that are the highest valued are water quality improvements, non-consumptive recreation, and provision of natural habitat and biodiversity (Brander, Florax, and Vermaat 2006; Ghermandi et al. 2010).
- Wetland abundance (-): The abundance of neighbouring wetlands has a negative impact on wetland values (Ghermandi et al. 2010).
- Population density (+): Urban wetlands are more valuable (Brander, Florax, and Vermaat 2006) and wetland values are positively related to local population levels (Ghermandi et al. 2010).

More recent meta-analyses have advanced implemented state-of-the-art frameworks to address some of these limitations (Moeltner et al. 2019). These models use dollars per household as the dependent variable to better reflect the fact that it is people that benefit from wetlands. Furthermore, there is emphasis on ensuring the value estimates are commensurable by using only estimates from a single valuation method and representing a specified region. For example, Moeltner et al. (2019) only includes stated preference studies that were conducted within the United States. These more recent meta-analyses have also done a better job at using the functional form of the meta-regression function is consistent with economic theory.

The meta-analytical function in Moeltner et al., (2019) models wetland value estimates as a function of the change in wetland acreage, the location of the wetland within one of 4 US regions, whether the wetlands provide provisioning, regulating, and/or cultural ecosystem services, whether the wetland is forested, and the income level of the local population.

This meta-analysis allows the user to generate new predictions of the economic value of wetland conservation and is useful for generating regional scale wetland value estimates. The user still needs to determine the appropriate 'extent of the market' and how many people these values should be applied to (e.g. people within 5 kilometres of the wetland? The whole province?). Furthermore, the limited and coarse set of variables may miss important differences in more local applications. For example, the ecosystem services are included as indicator variables masking the intensity or levels of these different services.

All four approaches have their strengths and limitations. Table 5 provides a brief overview

TABLE 5 SUMMARY TABLE OF WETLAND BENEFIT VALUATION APPROACHES

Method	Strengths	Limitations	Examples
Per hectare transfer	Simple to implement	Limited ability to account for site specific characteristics Difficult to find suitable studies to transfer	Pattison, Anielski, Thompson papers…
Bottom-up approach	Unique characteristics of wetland and people can be explicitly taken into account.	Each ecosystem service can require extensive research efforts to quantify and value.	Jenkins et al. (2010)
Holistic Stated Preference Approach	Flexible approach to capture full set of economic values (i.e. use and non-use values) Avoids double counting of benefits	Resource costs of undertaking a study, Challenges with survey research, Validity of survey responses	Pattison et al. (2011) Dias and Belcher (2015)
Meta-analysis	Uses value information from many studies.	Limited by number of appropriate studies to transfer	Brander et al. (2006), Moeltner et al. (2019)

Conclusions

Ancient Greek society utilized a form of discourse, termed rhetoric, as an art of *persuasion* in influencing public participation in influencing politics. Since that time this art of persuasion has permeated many areas beyond politics. For example, McCloskey employs the term rhetoric to describe how economists persuade themselves and others through the "aptness of metaphors", "relevance of historical precedence", "charm of symmetry" in their research activity (McCloskey 1983: 482). We believe to a certain extent that rhetoric pervades many discussions around wetland conservation - "wetlands are incredibly valuable hence deserve protection and conservation".

This rhetoric, along with the immediacy of the concern for arresting wetland loss, has led to simplicity in terms of wetland economic thinking and the inappropriate application of translation/transfer of values to services from functions in applications of both local, regional and national concern. As reviewed in this paper, the translational applications ignore the large degree of heterogeneity in ecosystem service provision, valuation, and costs of conversion. Not all wetlands are the same, and thus neither are their functions, services and values. In fact it is somewhat instructive that some of the meta-analyses of wetland values and services identify this considerable variation (e.g. Ghermandi et al. 2010; Brander et al. 2006), despite potential for some inappropriate methods being employed. This considerable degree of variation has been recognized by wetland scientists, but does not seem to have been recognized by wetland conservation advocates. It does not show up in the rhetoric.

More specifically, an important finding of this review is the importance of cost heterogeneity across the landscape. Studies that have used detailed farm-specific information or reverse auction methods uncover 'hockey stick' shapes to the cost curves (Figures 1 and 2). Opportunity cost heterogeneity is driven by the nature of the farm's production system (rotations, crop choice, etc), the land's productivity including soil class. Nuisance cost heterogeneity is driven by technology, location of wetland within field. Drainage cost heterogeneity is driven by distance to adequate outflow channel, characteristics of wetland basin and wetland complex, hydrological position of the wetland.

Another key finding is that wetland costs are dynamic and are likely to change quickly over time due to changing crop production practices, crop prices, drainage costs, and the evolving role of technology. For example, the increasing size of modern farm equipment can increase the nuisance costs of operating around wetlands but the development of precision farming technology such as automatic switch input off for overlapped areas might decrease these nuisance costs. Technological change is also decreasing costs of drainage with improved GPS technology and specialized equipment that can more effectively contour fields. There are also developments in the installation of tile drainage resulting in more effective and permanent drainage of depressions on agricultural landscapes. The implication of this dynamism is that older cost estimates are likely inappropriate proxies for current wetland costs and that projections into the future should account for these changing cost drivers.

From the demand side we found that there is a paucity of primary empirical studies on both specific ecosystem service provision and valuation in the Canadian prairies. This information gap is surprising given the claim of the economic significance of their ecosystem service provision. However, rarely are the ecosystem services quantified in terms of measureable benefits that could be converted to economic values. Yet there are numerous studies of the ecological functions associated with wetlands – the economic literature needs to catch up.

There is a clear need for additional research on linking ecological functions to ecosystem services that people care about. However, translational studies that transfer values and benefits across many landscapes (e.g. Thompson and Young 1992, Pattison-William et al. 2017) are much more common. These kinds of studies would not incorporate the degree of heterogeneity that we believe exists on the demand side as well as the supply of ecosystem services by different wetlands; something that is suggested by meta analyses of wetland benefit estimates (e.g. Ghermandi et al. 2010). This would provide fertile ground for future research, particularly because of recent policies that require compensatory restoration to mitigate wetland loss (e.g. Alberta Wetland Policy).[6]

Whether the economic benefits of retaining and conserving wetlands are larger than the costs of maintaining them in original states is likely site specific as there is no average wetland. While the heterogeneity in costs and benefits raising economic measurement and management challenges, there are also opportunities for targeting. Focusing policies on high benefit, low cost wetlands can

[6] What we mean here is that a storm water retention pond that was used to compensate for wetlands lost as a result of urban expansion may provide ecosystem services that could be more valuable than the services provided by the original wetlands.

improve the economic and environmental effectiveness of wetland conservation efforts. Similarly, allowing flexibility for wetlands that impose large costs to producers and have little ecosystem service values to society. The challenge is in finding these wetlands on the landscape and the methods reviewed in this paper can be employed for this task.

Over time and space a wide range of policy instruments have been tailored to wetland conservation including regulatory approaches (Rubec and Hanson 2009) conservation easements (Nature Conservancy), payment programs (e.g. payment for ecosystem services (PES) from both government and private organizations (e.g. Ducks Unlimited)) (Hill et al. 2011) as well as information-based and extension initiatives. Unlike other natural resources such as forests or marine environments, private property is prevalent in agricultural landscapes making the use of market-based approaches to land management appealing. Will decision makers be willing to consider the economic values of wetlands in policy and program developments, particularly the non-market values? Even if net benefits are positive, the distribution of the costs and benefits are particularly important and the asymmetrical impacts to private landowners and society from wetland conservation efforts will be a challenge.

References

Alberta Government. 2018. "Alberta Wetland Mitigation Directive." https://open.alberta.ca/dataset/2e6ebc5f-3172-4920-9cd5-0c472a22f0e8/resource/dfbea0b8-df23-4ddd-8038-a51f69fbfff7/download/albertawetlandmitigationdirective-june-2018.pdf.

Anielski, Mark, John Thompson, and Sara Wilson. 2014. "A Genuine Return on Investment: The Economic and Societal Well-Being Value of Land Conservation in Canada." http://www.anielski.com/wp-content/uploads/2014/07/14-03-31-DUC-A-Genuine-Return-on-Investment-Exec-Summ1.pdf.

Asare, Eric, Ken Belcher, and Patrick Lloyd-Smith. 2020. "Spatially Explicit Modeling of Wetland Conservation Costs in Canadian Agricultural Landscapes."

Boxall, Peter C., and Anna Kauffman. 2018. "Information Rent Seeking in Conservation Auctions Using Uniform and Discriminatory Pricing: Field Experiments in Wetland Restoration." Presented at the World Congress on Environmental and Resource Economics, Gothenburg, Sweden, June 25.

Boxall, Peter C., K Packman, Marian Weber, A Samarawickrema, and W Yang. 2009. "Price Discovery Mechanisms for Providing Ecological Goods & Services from Wetland Restoration: An Examination of Reverse Auctions." In *Proceedings of the Ecological Goods and Services Technical Meeting*, 191–208. Prairie Habitat Joint Venture. Ottawa, Canada.

Boxall, Peter C., Orsolya Perger, and Marian Weber. 2013. "Reverse Auctions for Agri-Environmental Improvements: Bid-Selection Rules and Pricing for Beneficial Management Practice Adoption." *Canadian Public Policy*, September. https://doi.org/10.3138/CPP.39.Supplement2.S23.

Boyd, James, and Alan Krupnick. 2013. "Using Ecological Production Theory to Define and Select Environmental Commodities for Nonmarket Valuation." *Agricultural and Resource Economics Review* 42 (1): 1–32. https://doi.org/10.1017/S1068280500007590.

Brander, Luke M., Raymond J. G. M. Florax, and Jan E. Vermaat. 2006. "The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-Analysis of the Literature." *Environmental and Resource Economics* 33 (2): 223–50. https://doi.org/10.1007/s10640-005-3104-4.

Brouwer, R., I. H. Langford, I. J. Bateman, and R. K. Turner. 1999. "A Meta-Analysis of Wetland Contingent Valuation Studies." *Regional Environmental Change* 1 (1): 47–57. https://doi.org/10.1007/s101130050007.

Brown, Laura K., Elizabeth Troutt, Cynthia Edwards, Brian Gray, and Wanjing Hu. 2011. "A Uniform Price Auction for Conservation Easements in the Canadian Prairies." *Environmental and Resource Economics* 50 (1): 49–60. https://doi.org/10.1007/s10640-011-9461-2.

Champ, Patricia A., Kevin Boyle, and Thomas C. Brown, eds. 2017. *A Primer on Nonmarket Valuation*. 2nd ed. The Economics of Non-Market Goods and Resources. Springer Netherlands. https://www.springer.com/gp/book/9789400771031.

Cohen, Matthew J., Irena F. Creed, Laurie Alexander, Nandita B. Basu, Aram J. K. Calhoun, Christopher Craft, Ellen D'Amico, et al. 2016. "Do Geographically Isolated Wetlands Influence Landscape Functions?" *Proceedings of the National Academy of Sciences* 113 (8): 1978–86. https://doi.org/10.1073/pnas.1512650113.

Cortus, Brett G., Scott R. Jeffrey, James R. Unterschultz, and Peter C. Boxall. 2011. "The Economics of Wetland Drainage and Retention in Saskatchewan." *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie* 59 (1): 109–26. https://doi.org/10.1111/j.1744-7976.2010.01193.x.

Cortus, Brett G., James R. Unterschultz, Scott R. Jeffrey, and Peter C. Boxall. 2009. "The Impacts of Agriculture Support Programs on Wetland Retention on Grain Farms in the Prairie Pothole Region." *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques* 34 (3): 245–54. https://doi.org/10.4296/cwrj3403245.

Creed, Irena F., Charles R. Lane, Jacqueline N. Serran, Laurie C. Alexander, Nandita B. Basu, Aram J. K. Calhoun, Jay R. Christensen, et al. 2017. "Enhancing Protection for Vulnerable Waters." *Nature Geoscience* 10 (11): 809–15. https://doi.org/10.1038/ngeo3041.

Dias, Vitor, and Ken Belcher. 2015. "Value and Provision of Ecosystem Services from Prairie Wetlands: A Choice Experiment Approach." *Ecosystem Services* 15 (October): 35–44. https://doi.org/10.1016/j.ecoser.2015.07.004.

EPA Science Advisory Board (SAB). 2009. "Valuing the Protection of Ecological Systems and Services." EPA-SAB-09-012. https://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/ValProtEcolSys%26Serv.

Federal, Provincial and Territorial Governments of Canada. 2010. "Canadian Biodiversity: Ecosystem Status and Trends 2010." http://www.biodivcanada.ca/default.asp?lang=En&n=83A35E06-1&pedisable=true.

Fisher, Brendan, Ian Bateman, and R. Kerry Turner. 2013. "Valuing Ecosystem Services: Benefits, Values, Space and Time." In *Chapters*, 58–69. Edward Elgar Publishing. https://ideas.repec.org/h/elg/eechap/15127_3.html.

Ghermandi, Andrea, Jeroen C. J. M. van den Bergh, Luke M. Brander, Henri L. F. de Groot, and Paulo A. L. D. Nunes. 2010. "Values of Natural and Human-Made Wetlands: A Meta-Analysis." *Water Resources Research* 46 (12). https://doi.org/10.1029/2010WR009071.

Government of Canada. 1991. "The Federal Policy on Wetland Conservation."

Gustavson, Kent, and Elizabeth Kennedy. 2010. "Approaching Wetland Valuation in Canada." *Wetlands* 30 (December): 1065–76. https://doi.org/10.1007/s13157-010-0112-0.

Hansen, LeRoy, Daniel Hellerstein, Marc Ribaudo, James Williamson, David Nulph, Charles Loesch, and William Crumpton. 2015. "Targeting Investments To Cost Effectively Restore and Protect Wetland Ecosystems: Some Economic Insights." 199283. Economic Research Report. United States Department of Agriculture, Economic Research Service. https://ideas.repec.org/p/ags/uersrr/199283.html.

Hill, Michael R. J., D. Glen McMaster, Tom Harrison, Aron Hershmiller, and Trevor Plews. 2011. "A Reverse Auction for Wetland Restoration in the Assiniboine River Watershed, Saskatchewan." *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie* 59 (2): 245–58. https://doi.org/10.1111/j.1744-7976.2010.01215.x.

Jeffrey, Scott R., Dawn E. Trautman, and James R. Unterschultz. 2017. "Canadian Agricultural Business Risk Management Programs: Implications for Farm Wealth and Environmental Stewardship." *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie* 65 (4): 543–65. https://doi.org/10.1111/cjag.12145.

Jenkins, W. Aaron, Brian C. Murray, Randall A. Kramer, and Stephen P. Faulkner. 2010. "Valuing Ecosystem Services from Wetlands Restoration in the Mississippi Alluvial Valley." *Ecological Economics* 69 (5): 1051–61. https://doi.org/10.1016/j.ecolecon.2009.11.022.

Jensen, Anne Kejser, Robert J. Johnston, and Søren B. Olsen. 2019. "Does One Size Really Fit All? Ecological Endpoint Heterogeneity in Stated Preference Welfare Analysis." *Land Economics* 95 (3): 307–32. https://doi.org/10.3368/le.95.3.307.

Johnston, Robert J., Kevin J. Boyle, Wiktor (Vic) Adamowicz, Jeff Bennett, Roy Brouwer, Trudy Ann Cameron, W. Michael Hanemann, et al. 2017. "Contemporary Guidance for Stated Preference Studies." *Journal of the Association of Environmental and Resource Economists* 4 (2): 319–405. https://doi.org/10.1086/691697.

Kanjilal, Manikarnika. 2015. "Costs of Wetland Restoration in the Canadian Prairies: Comparison of Simulated Opportunity Costs and Farmers' WTA." University of Alberta; Department of Resource Economics and Environmental Sociology.

King, D, and C Bohlen. 1994. "Making Sense of Wetland Restoration Costs." University of Maryland Center for Environmental and Estuarine Studies Technical Report UMCEES-CBL-94-045.

Kooten, G. C. van, and Andrew Schmitz. 1992. "Preserving Waterfowl Habitat on the Canadian Prairies: Economic Incentives versus Moral Suasion." *American Journal of Agricultural Economics* 74 (1): 79–89. https://doi.org/10.2307/1242992.

Kooten, G. Cornelis van. 1993. "Bioeconomic Evaluation of Government Agricultural Programs on Wetlands Conversion." *Land Economics* 69 (1): 27–38. https://doi.org/10.2307/3146276.

Laporte, Aaron De. 2014. "Effects of Crop Prices, Nuisance Costs, and Wetland Regulation on Saskatchewan NAWMP Implementation Goals." *Canadian Journal of Agricultural*

Economics/Revue canadienne d'agroeconomie 62 (1): 47–67. https://doi.org/10.1111/cjag.12020.

Latacz-Lohmann, Uwe, and Steve Schiizzi. 2005. "Auctions for Conservation Contracts: A Review of the Theoretical and Empirical Literature (Project No: UKL/001/05)." Report to the Scottish Executive Environment and Rural Affairs Department: Project No: UKL/001/05. http://www.gov.scot/Publications/2006/02/21152441/0.

Lawley, Chad. 2014. "Changes in Implicit Prices of Prairie Pothole Habitat." *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie* 62 (2): 171–90. https://doi.org/10.1111/cjag.12022.

Lawley, Chad, and Charles Towe. 2014. "Capitalized Costs of Habitat Conservation Easements." *American Journal of Agricultural Economics* 96 (3): 657–72. https://doi.org/10.1093/ajae/aau012.

Leitch, J. 1983. "Economics of Prairie Wetland Drainage," Transactions of the American Society of Agricultural Engineers, 26 (2): 1465–70.

Manitoba Habitat Heritage. n.d. "Wetland Resotoration Incentive Program." https://www.gov.mb.ca/sd/waterstewardship/water_info/riparian/waterrestore_factsheet.pdf.

Minnesota Board of Water and Soil Resources. 1992. "Minnesota Wetland Restoration Guide." St. Paul, MN.

Moeltner, Klaus, Jessica A. Balukas, Elena Besedin, and Ben Holland. 2019. "Waters of the United States: Upgrading Wetland Valuation via Benefit Transfer." *Ecological Economics* 164 (October): 106336. https://doi.org/10.1016/j.ecolecon.2019.05.016.

Norton, Nancy Anders, Tim T. Phipps, and Jerald J. Fletcher. 1994. "Role of Voluntary Programs in Agricultural Nonpoint Pollution Policy." *Contemporary Economic Policy* 12 (1): 113–21. https://doi.org/10.1111/j.1465-7287.1994.tb00417.x.

Novitski, R.P, R. D. Smith, and J.D Fretwell. 1996. "Wetland Functions, Values, and Assessment." In *National Water Summary on Wetland Resources*, 79–86. Washington, DC: USGS Water-Supply Paper 2425. U.S. Department of the Interior,.

Pattison, John, Peter C. Boxall, and Wiktor L. Adamowicz. 2011. "The Economic Benefits of Wetland Retention and Restoration in Manitoba." *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie* 59 (2): 223–44. https://doi.org/10.1111/j.1744-7976.2010.01217.x.

Pattison-Williams, John K., John W. Pomeroy, Pascal Badiou, and Shane Gabor. 2018. "Wetlands, Flood Control and Ecosystem Services in the Smith Creek Drainage Basin: A Case Study in Saskatchewan, Canada." *Ecological Economics* 147 (C): 36–47.

Pattison-Williams, John K., Wanhong Yang, Yongbo Liu, and Shane Gabor. 2017. "Riparian Wetland Conservation: A Case Study of Phosphorous and Social Return on Investment in the Black River Watershed." *Ecosystem Services*, Putting ES into practice, 26 (August): 400–410. https://doi.org/10.1016/j.ecoser.2016.10.005.

Renner, R. 1999. "Wetland Projects Help Reduce Flooding in North Dakota." Waterfowl 2000.

Rolfe, John, Steve Schilizzi, Peter Boxall, Uwe Latacz-Lohmann, Sayed Iftekhar, Megan Star, and Patrick O'Connor. 2018. "Identifying the Causes of Low Participation Rates in Conservation Tenders." *International Review of Environmental and Resource Economics* 12 (1): 1–45. https://doi.org/10.1561/101.00000098.

Rosenberger, Randall S., and John B. Loomis. 2001. "Benefit Transfer of Outdoor Recreation Use Values: A Technical Document Supporting the Forest Service Strategic Plan (2000

Revision).” *Gen. Tech. Rep. RMRS-GTR-72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.* 72. https://doi.org/10.2737/RMRS-GTR-72.

Rubec, Clayton D. A., and Alan R. Hanson. 2009. “Wetland Mitigation and Compensation: Canadian Experience.” *Wetlands Ecology and Management* 17 (1): 3–14. https://doi.org/10.1007/s11273-008-9078-6.

Saskatchewan Assessment Management Agency. 2015. “Saskatchewan Assessment Manual (2015 Base Year).” https://www.sama.sk.ca/document-library-news/manuals-handbooks-guides.

Schultz, Eric T., Robert J. Johnston, Kathleen Segerson, and Elena Y. Besedin. 2012. “Integrating Ecology and Economics for Restoration: Using Ecological Indicators in Valuation of Ecosystem Services.” *Restoration Ecology* 20 (3): 304–10. https://doi.org/10.1111/j.1526-100X.2011.00854.x.

Shultz, S. D., and J. A. Leitch. 2003. “The Feasibility of Restoring Previously Drained Wetlands to Reduce Flood Damage.” *Journal of Soil and Water Conservation* 58 (1): 21–29.

Smith, R. D., Alan Ammann, Candy Bartoldus, and Mark M. Brinson. 1995. “An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices.” WES/TR/WRP-DE-9. ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS. https://apps.dtic.mil/docs/citations/ADA307121.

Stoneham, Gary, Vivek Chaudhri, Arthur Ha, and Loris Strappazzon. 2003. “Auctions for Conservation Contracts: An Empirical Examination of Victoria’s BushTender Trial.” *Australian Journal of Agricultural and Resource Economics* 47 (4): 477–500. https://doi.org/10.1111/j.1467-8489.2003.t01-1-00224.x.

Thompson, John, and Don A. Young. 1992. “The Optimal Use of Prairie Pothole Wetlands: An Economic Perspective.” *Canadian Water Resources Journal / Revue Canadienne Des Ressources Hydriques* 17 (4): 365–72. https://doi.org/10.4296/cwrj1704365.

Wang, Yihong, Anish Neupane, Angele Vickers, Tom Klavins, and Rob Bewer. 2011. “Ecosystem Services Approach Pilot on Wetlands: Economic Valuation Technical Report.”

Woodward, Richard T., and Yong-Suhk Wui. 2001. “The Economic Value of Wetland Services: A Meta-Analysis.” *Ecological Economics* 37 (2): 257–70. https://doi.org/10.1016/S0921-8009(00)00276-7.

Yang, Wanhong, Yongbo Liu, Marius Cutlac, Peter Boxall, Marian Weber, Adam Bonnycastle, and Shane Gabor. 2016. “Integrated Economic-Hydrologic Modeling for Examining Cost-Effectiveness of Wetland Restoration Scenarios in a Canadian Prairie Watershed.” *Wetlands* 36 (3): 577–89. https://doi.org/10.1007/s13157-016-0768-1.

Yu, Jia, and Ken Belcher. 2011. “An Economic Analysis of Landowners’ Willingness to Adopt Wetland and Riparian Conservation Management.” *Canadian Journal of Agricultural Economics/Revue Canadienne d’agroeconomie* 59 (2): 207–22. https://doi.org/10.1111/j.1744-7976.2011.01219.x.