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Commodity Consistent Meta-Analysis of Wetland Values: An Illustration for Coastal Marsh Habitat

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Abstract
Prior meta-regression models (MRMs) of wetland values pool value estimates associated with diverse commodity types—for example recreation, flood control, nutrient cycling, habitat provision, nonuse value, and carbon sequestration. Neither theory nor economic intuition justify the inclusion of such dissimilar commodities within a single meta-analytic value function, leading to validity concerns. This article seeks to advance methods for commodity and welfare consistent MRMs, applied to a particular category of wetland values. We develop a wetland value MRM restricted to a specific wetland type (coastal marshes), general location (US and Canada), commodity type (habitat provision and services), and valuation approach (stated preference methods). Results indicate that willingness to pay per household for marsh habitat changes is responsive to scope, spatial scale, market extent, the type of habitat change, household characteristics, and other factors suggested by theory and intuition. Results supersede those of prior wetland value MRMs in terms of statistical performance, estimation of anticipated value surface patterns, and capacity to support conceptually valid benefit transfers. Comparison with an otherwise identical but less commodity consistent MRM demonstrates that commodity consistency leads to improved statistical and benefit transfer performance.

Keywords Benefit transfer · Meta-analysis · Salt marsh · Stated preference · Valuation · Wetland · Willingness to pay

1 Introduction

Meta-analyses are commonly used to estimate the systematic influences of study, economic, resource and population attributes on willingness to pay (WTP) for environmental quality or quantity improvements (Smith and Pattanayak 2002; Bergstrom and Taylor 2006; Moeltner et al. 2007; Nelson and Kennedy 2009; Johnston and Rosenberger 2010;

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Boyle et al. 2013, 2015; Rolfe et al. 2015; Boyle and Wooldridge 2018; Johnston et al. 2018b, 2019). Within meta-regression models (MRMs) used for this purpose, the dependent variable is often a comparable mean or median welfare measure drawn from extant primary valuation studies. Independent variables represent observable factors hypothesized to explain variation in this welfare measure across observations. Reduced-form MRMs of this type have been used to estimate benefit functions for changes in the quantity and quality of many different types of non-market goods, and benefit transfers from these functions are used increasingly within cost–benefit analysis (Bergstrom and Taylor 2006; Nelson and Kennedy 2009; Griffiths et al. 2012; Johnston et al. 2005a, 2018b, 2019; Newbold et al. 2018; US EPA 2009, 2010, 2012, 2015; Wheeler 2015).

Among the most commonly acknowledged requirements for valid valuation MRMs is at least a minimal degree of commodity consistency across metadata observations (Smith and Pattanayak 2002; Johnston et al. 2005a; Bergstrom and Taylor 2006; Loomis and Rosenberger 2006, Nelson and Kennedy 2009; Johnston and Rosenberger 2010; Boyle and Wooldridge 2018; Johnston et al. 2018b). Bergstrom and Taylor (2006, p. 353) characterize commodity consistency within MRMs as a situation in which "the commodity … being valued [is] approximately the same within and across studies." This implies that values for similar or broadly comparable goods or services are pooled within the MRM (i.e., so that apples are not compared to oranges or automobiles). Although recent studies have demonstrated that gains in benefit transfer reliability may be achieved by relaxing rigid, *ex ante* commodity groupings in favor of those supported by empirical analysis (e.g., Moeltner and Rosenberger 2014; Johnston and Moeltner 2014), the general relevance of commodity consistency for transfer validity is widely recognized.

While acknowledged as a requirement for validity, commodity consistency is frequently violated by valuation MRMs in the literature. For example, commodity inconsistency is almost universal in wetland value MRMs. Examples include Borisova-Kidder (2006), Brouwer et al. (1999, 2001), Woodward and Wui (2001), Brander et al. (2006, 2012a, b, 2013), Moeltner and Woodward (2009), Ghermandi et al. (2010), He et al. (2015), and Chaikumbung et al. (2016). Models such as these generally pool value estimates linked to many dissimilar goods and services—for example recreation (e.g., hunting and non-consumptive recreation), flood control, fisheries production, carbon sequestration, raw material provision, nutrient cycling, water supply, existence, aesthetics, or various combinations of these and other commodities. Although these values are sometimes aggregated into a single measure of value per unit area (e.g., wetland value per hectare), the underlying estimates are associated with many distinct commodity types across different studies. This heterogeneity is compounded by the frequent inclusion of primary studies implemented across a diverse set of developed and developing countries (i.e., across which the uses and values of wetland commodities may differ).

Wetland value MRMs also frequently pool observations on distinct welfare measures—a violation of welfare consistency (Bergstrom and Taylor 2006; Nelson and Kennedy 2009; Johnston and Moeltner 2014; Boyle and Wooldridge 2018). For example, some of these MRMs pool estimates of consumer value (e.g., from recreation demand or stated preference models), producer value (e.g., from factor input methods), and measures that, in general, do not reflect welfare-theoretic values (e.g., damage cost estimates).[1]

[1] Some of these welfare measures have theoretical and empirical properties that can support pooling in limited instances. For example, some evidence supports limited pooling of otherwise identical utility-held-constant (Hicksian) and income-held-constant (Marshallian) consumer welfare measures (Johnston and Moeltner 2014). However, pooling divergent consumer values, producer values, and non-welfare theoretic

The resulting MRMs are cited widely and provide insight into systematic value patterns across different types of wetland attributes and services. For example, many (unsurprisingly) find systematic differences in values across different types of wetland commodities (e.g., the value of recreational hunting differs from the value of flood protection; Ghermandi et al. 2010), and types of welfare estimates (e.g., producer net factor income differs from households' stated preference WTP; Brander et al. 2006). Nonetheless, the lack of metadata consistency within these models raises validity concerns—neither theory nor economic intuition appear to justify the inclusion of such dissimilar commodities and welfare measures within a single meta-analytic value function. At a minimum, such pooling implies strong preference restrictions that are unlikely to hold in most circumstances (Bergstrom and Taylor 2006).

As valuation MRMs are increasingly used for real-world benefit transfers, their validity has come under greater scrutiny (Smith and Pattanayak 2002; Bergstrom and Taylor 2006; Nelson and Kennedy 2009; Boyle et al. 2010, 2013, 2015; Boyle and Wooldridge 2018; Kling and Phaneuf 2018; Newbold et al. 2018; Moeltner 2019). The ability of an MRM to obtain statistically significant results does not ensure that the resulting estimates are suitable for use within applied welfare analysis. Of the threats to validity discussed by Nelson and Kennedy (2009), welfare and commodity consistency are the two primary issues emphasized in the closing paragraph (p. 373). Although challenges of this type within wetland value MRMs have been discussed for decades, they remain unresolved (Woodward and Wui 2001; Bergstrom and Taylor 2006; Smith and Pattanayak 2002; Johnston et al. 2018b).

At the same time, metadata consistency is neither rigid nor absolute (Bergstrom and Taylor 2006; Johnston and Moeltner 2014; Moeltner and Rosenberger 2014). All valuation MRMs admit *some* degree of inconsistency in the metadata to provide the sample sizes required for statistical analysis. The wetland MRM literature is a clear illustration of this tradeoff, with studies characterized by low metadata consistency and often-large sample sizes. The challenge is maintaining a minimal degree of consistency across observations required for validity and credibility, while maintaining sufficient sample sizes for meta-analysis.

Responding to this challenge, the present article seeks to advance methods for commodity and welfare consistent meta-analysis of wetland values. We develop methods to enable a wetland value MRM restricted to a specific wetland type (coastal/salt marshes[2] and associated wetland complexes), general location (US and Canada), broad commodity type (habitat provision and services), and comparable, welfare-theoretic value estimates from one valuation approach (stated preference methods). Findings of the model indicate that WTP per household for marsh habitat changes is responsive to scope, spatial scale, market extent, the type of habitat change considered, household characteristics, and other factors suggested by theory and intuition. Results supersede those of prior wetland value MRMs in terms of statistical performance, conformance with theoretical expectations, and an ability to support conceptually valid and credible benefit transfers. Comparison with an otherwise identical but less commodity consistent MRM demonstrates that commodity consistency leads to improved statistical and benefit transfer performance. These and other

Footnote 1 (continued)

measures such as damage costs within valuation metadata "is not consistent with an analysis and prediction of a well-defined economic value" (Boyle and Wooldridge 2018, p. 612).

[2] In the text that follows, we use the words "marsh" and "wetland" interchangeably.

results suggest the potential benefits of methods that promote greater commodity and welfare consistency within wetland value meta-analysis. At the same time, model development highlights challenges that may be encountered, even when reconciling welfare observations over seemingly similar commodity types.

2 Commodity Consistency in Wetland Value Meta-Analysis

There is no single, formal convention regarding the degree of commodity consistency required in MRMs. The underlying challenge is one of heterogeneity in effect sizes—an issue that pervades all economic meta-analysis (Stanley and Doucouliagos 2012). Bergstrom and Taylor (2006), Smith and Pattanayak (2002) and Boyle and Wooldridge (2018) all use wetland value MRMs as an archetypal illustration of the concern. The biophysical and ecological processes of wetlands (Mitsch and Gosselink 2000) generate many different outputs such as water supply, recreational opportunities and carbon sequestration that have few similarities, other than the fact that they are produced by different types of wetlands. Nonetheless, the origin of these goods and services in a similar ecosystem type (wetlands) is often used implicitly to justify the pooling of observations on otherwise dissimilar commodity types.

In support of these standard approaches for wetland value meta-analysis, one might argue that the wetland area itself (e.g., a wetland acre or hectare) is the "consistent commodity" under consideration. This argument, however, appears to conflict with (a) the type of studies included in wetland value metadata, and (b) the fact that wetlands are often not the final commodity valued by these studies. Most primary studies in wetland value metadata are *not* designed to estimate total or marginal values per unit area of wetland, but instead to estimate marginal values for the commodities *produced* by wetlands—the final valued outputs, attributes, or services of these ecosystems. The fact that these derive from a single source does not obviate the dissimilarities in the commodities that are valued by each primary study.

In cases such as this—in which welfare estimates for dissimilar commodities are pooled within metadata—the theoretical validity and econometric unbiasedness of the resulting MRM require a specification able to control for all relevant aspects of commodity inconsistency using right-hand-side (RHS) variables (Bergstrom and Taylor 2006). Approaches such as this may be feasible for relatively similar types of commodities—such as values per day for different types of outdoor recreation (Bergstrom and Taylor 2006; Londoño and Johnston 2012; Moeltner and Rosenberger 2014) or values per fish for different types of recreational angling (Johnston et al. 2006b). Here, "recreation days" and "fish" represent broadly similar classes of commodities. However, RHS corrections are problematic for less similar commodities, such as flood control, fisheries production and endangered species survival. The reason is that these RHS adjustments introduce implied preference restrictions that are implausible for dissimilar commodities (Smith and Pattanayak 2002; Bergstrom and Taylor 2006).

For illustration, consider a traditional MRM specification such as

$$y_{js} = \alpha + \mathbf{x_{js}}\boldsymbol{\beta} + \varepsilon_{js}, \tag{1}$$

where y_{js} is a welfare measure such as mean WTP (or the natural log of WTP) for observation s in study j, and $\mathbf{x_{js}}$ is a vector of independent variables that explains systematic variations in the welfare measure across studies and observations. The coefficient α is the equation intercept, and $\boldsymbol{\beta}$ represents a conforming parameter vector. A simple model of this type may be readily adapted to incorporate such common features as random- or fixed-effects or non-linear transformations of independent variables (Nelson and Kennedy 2009; Boyle and Wooldridge 2018).

The ability of a specification such as (1) to provide valid inferences and predictions depends on the capacity of the RHS variables ($\mathbf{x_{js}}$) to capture systematic variations in y_{js} due to the inclusion of dissimilar commodities in the metadata. For example, an MRM of WTP for water quality changes might include variables characterizing the scope and geographical scale of quality changes valued within different observations, among other features (Johnston et al. 2019). However, the way in which this is done—particularly for dissimilar commodity types—can impose implausible restrictions, even for a reduced form MRM.

For example, wetland value MRMs typically account for commodity differences primarily if not solely using dummy variables for each broad commodity type.[3] Assume, for illustration, that there are $c = 1 \ldots C$ different commodity types included within the metadata (e.g., recreation, water supply, carbon sequestration, flood control, etc.), in addition to a default commodity type defined as the baseline.[4] Equation (1) is then typically adapted to a form such as

$$y_{js} = \alpha + \boldsymbol{\gamma}_{\mathbf{c}} + \mathbf{x_{js}}\boldsymbol{\beta} + \varepsilon_{js}, \tag{2}$$

where $\boldsymbol{\gamma}_{\mathbf{c}}$ is a vector of dummy variables that allow different equation intercepts for each commodity type. As noted by Bergstrom and Taylor (2006), equations such as (2) impose strong linearity restrictions. If the y_{js} are non-transformed WTP measures, (2) implies that WTP for distinct commodities differs only by an additive scalar—that is the element of $\boldsymbol{\gamma}_{\mathbf{c}}$ associated with the particular commodity. For illustration, assume that flood control is the default commodity for a wetland value MRM. If predicted WTP for flood control assuming wetland and population characteristics $\mathbf{x_{js}}$ is given by $\widehat{WTP}_{flood}$, then WTP for any other specific commodity $c = c_1$ is given by $\widehat{WTP}_{flood} + \gamma_{c_1}$, or the WTP for flood control plus a linear, additive scalar. If y_{js} is log-transformed, then the relationship between these WTP estimates is multiplicative rather than additive, but the difference is still a fixed scalar transformation.

The plausibility of implied restrictions such as these within an MRM depends on theoretical and empirical considerations (Smith and Pattanayak 2002; Bergstrom and Taylor 2006). However, it seems implausible that WTP for diverse wetland commodity types will differ by only a fixed scalar, even as a linear approximation. At a minimum, one might expect that other elements of the equation such as vector $\mathbf{x_{js}}$ (e.g., capturing effects of scope, scale or market extent) might vary across commodities such as flood control, fish production and carbon storage. That is, theory and intuition suggest that each of these commodities should have fundamentally different demand (and hence value) functions. Similar arguments apply to welfare consistency (Smith and Pattanayak 2002; Bergstrom and Taylor 2006; Nelson and Kennedy 2009).

A related consideration for MRM specification is the effect of commodity consistency on the set of RHS variables that can be included in the model. As discussed by Moeltner

[3] For examples, see Brouwer et al. (1999, 2001), Woodward and Wui (2001), Brander et al. (2006, 2012a, b, 2013), Ghermandi et al. (2010), and Chaikumbung et al. (2016).

[4] Hence, there are C + 1 total wetland commodities.

et al. (2007), explanatory variables can only be included in a meta-regression if they are common to all studies in the metadata. However, as the similarity of commodities in the metadata declines, the set of common variables also declines. For example, many variables that are relevant when meta-analyzing WTP for wetland habitat (e.g., affected species), are likely irrelevant for flood control or carbon sequestration. Past wetland value MRMs tend to include few core variables characterizing specific attributes of the commodities under study, because few common variables are relevant to the diverse variety of wetland commodities considered.

These arguments imply that—all else equal and notwithstanding some contrary evidence (e.g., Johnston and Moeltner 2014; Moeltner and Rosenberger 2014)—commodity and welfare consistency are desirable attributes of valuation MRMs. This goal, however, comes at the cost of reduced sample size. As one restricts the set of allowable commodity types and welfare measures, the number of candidate studies for inclusion in the metadata declines. Given this tradeoff, the practical feasibility of enhanced commodity and welfare consistency within MRMs is not immediately evident. Can sufficient metadata sample sizes be developed for narrower classes of commodities? Can the resulting model specifications be developed in ways that correspond more closely to theoretical expectations—for example by including commodity-specific scope and scale measures that are infeasible within multi-commodity MRMs? And, will the empirical properties and benefit transfer performance of these models justify the development of more commodity- and welfare-consistent approaches?

3 Enhancing Commodity Consistency—A Meta-Analysis of Salt Marsh Habitat Values

The goal of this article is to illustrate and evaluate a wetland value meta-analysis that maintains greater commodity and welfare consistency. We illustrate the approach using an MRM of WTP for changes to coastal wetland wildlife habitat commodities. We include in this category both changes to habitats themselves (when they are valued directly) and to the wildlife (fauna) outputs of those habitats. The latter include fish, shellfish, birds and other species explicitly produced or supported by specified wetland habitats, in particular locations. The metadata are restricted to a specific wetland type (coastal/salt marshes and associated wetland complexes), general location (US and Canada), broad commodity type (habitat provision and services), and type of welfare estimate (per household WTP from stated preference methods). Remaining commodity differences are accommodated via discrete and continuous RHS variables in the MRM. Although the resulting commodity consistency is not perfect (there are no perfectly commodity consistent MRMs in the valuation literature), the goal is an MRM that is designed to be *more commodity consistent* than those in the prior wetland valuation literature.

We evaluate the model in terms of statistical performance, conformance of results to theoretical expectations and benefit transfer accuracy (via a leave-one-out convergent validity test of benefit transfer error). We further compare the results of this commodity consistent "habitat-only" model to an alternative, otherwise identical MRM specification that expands metadata sample size (*N*) by relaxing commodity consistency restrictions to a modest degree. We begin by describing the commodity consistent metadata and MRM specification. This is followed by a description of the parallel, less commodity consistent alternative (see *An Alternative Model—Increasing Sample Size* via *Relaxed Commodity Consistency*). We then contrast the results of the two alternative MRM specifications.

3.1 The Coastal Marsh Habitat Metadata

Metadata observations are drawn from primary studies that estimate total (use and nonuse) WTP for changes in the quantity or quality of coastal marsh wildlife habitats or their services (e.g., changes in fish, shellfish, birds, or other marsh fauna), in particular locations.[5] Habitat types are restricted to coastal marshes and related aquatic habitat complexes, as identified by each study. These primarily include salt marshes, but also include habitats such as coastal riparian marshes, combined salt and fresh water marsh complexes, everglades, and other coastal marsh types. Studies of wetlands not linked to coastal areas or saltwater systems in any way were excluded.

Studies are further restricted to those that estimate total WTP using generally accepted stated preference methods, report theoretically comparable and quantifiable Hicksian welfare measures, and provide sufficient information on valued commodities to enable inclusion in the metadata. Required information included key details such as the continuous, quantitative scope (or magnitude) of the specific habitat-related good or service for which values were estimated, the wetland providing the good or service (and its location), and the population and/or area sampled by the primary stated preference study. We further restrict observations to studies conducted in the US or Canada, and published between 1990 and 2016, inclusive. Studies were excluded if they did not provide sufficient methodological detail to identify valuation methods or ensure that these methods met minimum standards (Boyle et al. 2013).

Observations were identified and added to the metadata following the guidelines of Stanley et al. (2013) for research identification and coding. This included documentation of protocols used to identify and screen studies, including (a) the databases and other sources searched, (b) keywords used, and (c) dates completed.[6] Data were double-coded by the two authors. The data combine information provided by primary studies with external data from geographic information system (GIS) data layers and other sources such as the US Census, US National Historical GIS (https://www.nhgis.org/), and US Fish and Wildlife Service National Wetlands Inventory (https://www.fws.gov/wetlands/Data/Mapper.html).

The resulting metadata include 139 observations of willingness to pay (WTP) per household from 23 studies published from 1990 to 2016, with all values adjusted to 2016 USD. Multiple WTP estimates from some studies are available due to in-study variations in such factors as the type of habitat improvement, the scope of change, WTP elicitation methods, region or type of population sampled (e.g., users versus nonusers), and affected

[5] Salt marshes are wetlands that are found along coastlines, with extent determined by factors such as tidal range, sediment supply and slope (Kirwan and Megonigal 2013).

[6] Sources included: (1) databases and search engines (EBSCO, Google Scholar, Google), (2) online reference and abstract databases (Environmental Valuation Resource Inventory), Benefits Use Valuation Database (BUVD), AgEcon Search, RePEc/IDEAs), (3) webpages of authors and programs known to publish stated preference studies or wetland value research, (4) web sites of organizations known to conduct valuation (e.g., Resource for the Future), (5) websites of key resource economics journals (*Land Economics*, *Environmental and Resource Economics*, *Marine Resource Economics*, *Journal of Environmental Economics and Management*, *Water Resources Research*, and *Ecological Economics*). For all papers identified, citation lists were reviewed. Requests for studies were also made to individual researchers known to work in the field, and posted on the RESECON online discussion forum.

uses. The inclusion of multiple observations per study is common in valuation metadata (Nelson and Kennedy 2009). Table 1 summarizes the marsh habitat studies included in the metadata; these studies are identified using the term "Habitat" in the Valued Commodity column.

The dependent variable for all MRMs is the natural log of WTP, per household, for the specified improvement. Methods used to reconcile these improvements across studies are described below. Independent (RHS) variables characterize features hypothesized to influence WTP for habitat improvements in coastal marshes, based on theory, intuition and findings of the prior literature. These characterize (1) the scope [size] of the valued habitat change and the spatial scale of the wetland area affected by the change, (2) the type of habitat, marsh and uses affected, (3) regions and populations sampled by the primary study, and (4) study methodology, sample size and year. Emphasis was given to core economic and resource variables directly relevant to benefit transfer. Methodological variables were included to avoid potential omitted variables bias in the MRM (for example of the type that would occur if economic and resource variables were correlated with omitted methodological variables). Variables were also included to test for value patterns associated with different publication types (Rosenberger and Johnston 2009). Additional details on variables and model specification are provided below.

3.2 Reconciling and Contrasting Habitat Changes

One of the challenges faced within valuation meta-analysis is the reconciliation of valued commodity changes across studies and observations, allowing these changes to be compared within an MRM (Smith and Pattanayak 2002; Bergstrom and Taylor 2006). A primary limitation of prior wetland value MRMs in the literature is an inability to quantify and compare the scope of change in individual wetland commodities (e.g., storm surge protection versus fisheries production). A corresponding contribution of the present study is a potential means to quantify and compare one category of wetland commodities—those related to wetland habitat changes—across diverse studies in the literature. Although the present metadata are restricted to enhance commodity consistency, some differences in valued commodities are unavoidable. Hence, multiple steps and assumptions are required to allow pooling of commodity changes within the metadata. For example, we include a set of variables to distinguish the scope, geospatial scale and type of habitat changes included in the metadata.

Among the core variables within the MRM are those quantifying the *scope or magnitude* of commodity change. The metadata include multiple different sub-types of coastal marsh habitat improvements. These include changes in (1) habitat size, (2) habitat quality, (3) harvest [e.g., of fish or shellfish] due to habitat change, (4) species populations affected by habitat changes,[7] and (5) habitat-dependent species survival likelihood. Species affected by habitat changes of these types include bird, fish, shellfish and other wildlife.[8] To provide a comparable measure of scope across these wetland habitat-related commodities, all improvements within these five categories are quantified as *percentage gains or losses in quantity or quality, compared to either relative or absolute baselines*. For example, a 2% increase in a specified habitat measure is reported as 2.0. All included studies provided

[7] These changes include exposures of wetland habitats to contaminants or pollutants.

[8] Changes in these species were only included if related to a specified coastal wetland habitat improvement.

Table 1 Primary studies in the metadata

References	State	Coastal marsh type(s)	Valued commodity	# of obs. in meta-data	Mean WTP per hh in $2016	Min. WTP per hh in $2016	Max. WTP per hh in $2016
Bauer et al. (2004)	RI	Salt or estuarine marsh	Habitat and area	2	19.33	0.73	37.94
Bergstrom et al. (1990)	LA	Combined salt marsh and freshwater complex	Habitat	5	0.21	−0.21	0.56
Eastern Research Group (2016)	NJ	Salt or estuarine marsh	Area	2	9.03	8.94	9.12
Hanemann et al. (1991)	CA	Combined salt marsh and freshwater complex	Habitat	8	463.81	291.02	589.7
He et al. (2017)	Canada	Riparian or forested wetland	Habitat	4	1.82	1.51	2.09
Hoehn and Loomis (1993)	CA	Combined salt marsh and freshwater complex	Habitat	8	254.57	188.97	352.29
Hwang et al. (2014)	LA	Coastal marsh and other habitat	Habitat	2	127.85	82.38	173.31
Interis and Petrolia (2014)	LA	Coastal marsh and other habitat	Habitat	12	238.75	74.89	565.94
Interis and Petrolia (2016)	LA/AL	Salt or estuarine marsh/Other coastal wetlands	Habitat	20	52.78	5.18	126.39
Johnston and Abdulrahman (2017)	CT	Salt or estuarine marsh	Area	3	5.80	4.96	7.09
Johnston et al. (2001)	NY	Coastal marsh and other habitat	Habitat	3	0.15	0.12	0.19
Johnston et al. (2002a, b)	RI	Salt or estuarine marsh	Habitat and area	4	22.79	9.56	30.36
Johnston et al. (2002a, b)	NY	Coastal marsh and other habitat	Habitat	6	0.12	0.06	0.17
Johnston et al. (2005b)	RI	Salt or estuarine marsh	Habitat and area	12	21.80	1.67	36.95
Johnston et al. (2015)	ME	Riparian or forested wetland	Habitat	2	1.26	1.19	1.33
Johnston et al. (2016)	ME	Riparian or forested wetland	Habitat	4	0.82	0.71	0.95
Johnston et al. (2018a)	CT	Salt or estuarine marsh	Area	2	8.12	6.46	9.78
Kaoru (1993)	MA	Coastal marsh and other habitat	Habitat	3	167.03	101.67	250.87
Loomis (1991)	CA	Combined salt marsh and freshwater complex	Habitat	8	458.31	291.02	689.26
Makriyannis et al. (2018)	CT	Salt or estuarine marsh	Area	2	5.62	4.49	6.76
Milon and Scrogin (2006)	FL	Everglades	Habitat	2	33.72	25.79	41.64
Milon et al. (1999)	FL	Everglades	Habitat	2	26.43	13.64	39.22
Newell and Swallow (2013)	RI	Riparian or forested wetland	Habitat and area	8	0.99	0.84	1.10
Petrolia et al. (2014)	LA	Salt or estuarine marsh	Habitat	8	173.98	98.42	253.55
Seeteram (2014)	FL	Everglades	Habitat	18	0.22	0.07	0.32

Table 1 (continued)

References	State	Coastal marsh type(s)	Valued commodity	# of obs. in meta-data	Mean WTP per hh in $2016	Min. WTP per hh in $2016	Max. WTP per hh in $2016
Udziela and Bennett (1997)	CT	Salt or estuarine marsh	Habitat	1	93.48	93.48	93.48
Whitehead (1993)	NC	Coastal marsh and other habitat	Habitat	2	22.52	19.22	25.81

information sufficient to quantify and compare habitat improvements in this manner.[9] The result is a directly comparable quantitative measure of habitat change across all studies.[10]

From here, two additional steps are required to enable meaningful economic comparisons.

First, these percentage changes reflect improvements to potentially different types of habitat (e.g., fish, birds, shellfish), in different types of coastal wetlands (e.g., salt marshes, wooded or riparian coastal marshes, combined fresh/salt wetland complexes), affecting different types of services or outcomes (e.g., habitat size, habitat quality, population size, harvest quantity). Hence, even within the category of habitat improvements, differences are possible. To accommodate these differences within the MRM, we include RHS variables that identify distinct categories of habitats (by species type), coastal wetlands (by ecosystem type), and outcomes (by commodity type), together with variables characterizing the scope and spatial scale of changes. Assignments for these categorical variables were made based on information presented in each primary valuation study. These variables are outlined in Table 2, and accommodate systematic variation in WTP associated with differences in wetland habitat improvements across primary studies.

Second, two distinct interpretations of percentage improvements are possible, depending on the ways that percentages are calculated. These differences depend on how changes are quantified in each primary stated preference study. Many studies in the metadata calculate percentages as a *relative change*, interpreted as a proportional change relative to a known baseline. For example, if the bag limit increases from 10 to 15 fish, the resulting change of 5 fish is a 50% improvement relative to the baseline of 10 fish. This would enter the metadata as 50.0.

Other studies calculate percentages as *absolute changes* on an external (e.g., 0–100) scale, sometimes without quantitative information on the baseline. For example, habitat quality changes are often measured relative to an external benchmark scale, such as an Index of Biotic Integrity (Boyd et al. 2016), where the scale is anchored on the top end by a locally relevant reference condition defined as the "best possible" habitat in a particular area. For example, if policy would improve fish habitat by 10 points on a 100-point external scale or index, this would reflect a 10% improvement on an absolute scale. This would enter the metadata as 10.0. That is, the difference between relative and absolute percentage changes relates to whether they are calculated relative to the current baseline (relative) or as percentage points on an external scale (absolute).

Because these two types of changes—relative versus absolute percentages—have different interpretations, we follow Ojea and Loureiro (2011) and include two mutually exclusive scope variables within the MRM. Both of these enter the model as natural logs. The variable *ln_absolute_change* is the natural log of the percentage point commodity change, for changes measured in absolute terms (and zero otherwise). The variable *ln_relative_change* is the natural log of percentage point commodity change, for changes measured in relative terms (and zero otherwise). In each case, we expect a positive influence of scope on WTP.

[9] In many cases, percentage measures were provided directly by primary studies—for example choice experiments in which habitat attributes were quantified using percentages. In other cases, the studies provided sufficient information on habitat baselines and changes to enable percentages to be calculated.

[10] Given the different types of habitat change commodities in the metadata, there is no consistent way to reconcile commodity measurements using a single, cardinal, non-proportional unit (e.g., number of fish, change in survival probability, etc.).

Table 2 Meta-analysis variables and summary statistics

Variable	Definition	Habitat metadata Mean (SD)	Habitat and area metadata Mean (SD)
ln_wtp	Natural log of willingness to pay (WTP) per household, adjusted to 2016 US dollars. Range in habitat metadata: − 2.81 to 2.94	2.74 (2.94)	2.57 (2.81)
ln_absolute_change	Natural log of percentage point habitat commodity change, if measured in absolute terms—change on external 0–100 scale—(zero otherwise). Range in habitat metadata: 0 to 4.61	0.87 (1.43)	0.77 (1.37)
ln_relative_change	Natural log of percentage point habitat commodity change, if measured in relative terms—change as a proportion of baseline—(zero otherwise). Range in habitat metadata: − 5.56 to − .70	1.04 (2.38)	1.03 (2.27)
ln_affected_area	Natural log of the size of the resource (or marsh) area affected by change. Unit: acres. Range in habitat metadata: 1.59–16.65	10.37 (4.30)	9.73 (4.50)
ln_income	Natural log of median household income of the US places sampled by the stated preference study (e.g., states, counties, etc.), based on the historical U.S Census data. Where the sample covers multiple US places for which an aggregate median income is not provided by the Census (e.g., multiple counties), population-weighted averages over these places are used. Unit: US dollars. Range in habitat metadata: 9.99–11.15	10.67 (0.24)	10.70 (0.26)
ln_sampled_area	Natural log of the area in which respondents for each study were sampled (the sampled market area). Unit: acres. Range in habitat metadata: 9.39 to 21.56.	16.69 (3.31)	16.10 (3.58)
peer_review	Binary variable indicating that the study is from a peer reviewed source (1 = peer reviewed source). Range: 0 or 1	0.83 (0.37)	0.84 (0.36)
annual_wtp	Binary variable indicating that WTP payment would be paid annually, and zero otherwise (1 = annual payment). Range: 0 or 1	0.68 (0.47)	0.72 (0.45)
yearindex	Variable indicating the year in which the survey was conducted (converted to an index by subtracting 1985). Range in habitat metadata: 2–28	18.24 (10.19)	18.71 (9.95)
dichotomous	Binary variable indicating that the type of elicitation method is dichotomous. (1 = dichotomous elicitation method; 0 = other elicitation types). Range: 0 or 1	0.32 (0.46)	0.28 (0.45)
habitat_fish	Binary variable indicating that the survey scenario addressed fish habitat or services of these habitats (1 = fish habitat; 0 = habitat for multiple species, shellfish, bird, wildlife, or endangered species). Range: 0 or 1	0.17 (0.38)	0.15 (0.36)
habitat_multiple	Binary variable indicating that the survey scenario addressed combined fish, shellfish and wildlife habitats or services of these habitats (1 = multiple species habitat; 0 = habitat for fish, shellfish, bird, wildlife, or endangered species). Range: 0 or 1	0.57 (0.50)	0.50 (0.50)

Table 2 (continued)

Variable	Definition	Habitat metadata Mean (SD)	Habitat and area metadata Mean (SD)
salt_other_habitat	Binary variable indicating that the type of marsh described in the survey is a combination of salt marsh and other habitat (1 = combined salt marsh and other habitat; 0 = all other coastal marsh types, see Table 1). Range: 0 or 1	0.38 (0.49)	0.33 (0.47)
riparian_marsh	Binary variable indicating that the type of marsh used in the survey is riparian or forested coastal marsh (1 = riparian or forested coastal marsh; 0 = all other coastal marsh types, see Table 1). Range: 0 or 1	0.10 (0.31)	0.12 (0.32)
change_harvest	Binary variable indicating that the valued commodity is a change in harvest or harvest potential (1 = change in harvest; 0 = all other types of change, see main text). Range: 0 or 1	0.22 (0.41)	0.19 (0.39)
change_population	Binary variable indicating that the valued commodity is a change in marsh species population size (1 = change in population size; 0 = all other types of change, see main text). Range: 0 or 1	0.19 (0.40)	0.17 (0.38)
change_survival	Binary variable indicating that the valued commodity is a change in population or survival for threatened or endangered species (1 = change in survival probability; 0 = all other types of change, see main text). Range: 0 or 1	0.13 (0.33)	0.11 (0.32)
change_size	Binary variable identifying observations for which the valued commodity is defined as a raw change in wetland area or size rather than a change in a specified wetland service or commodity. (1 = change in area; 0 = change in specific habitat or habitat service, see main text). Range: 0 or 1	–	0.12 (0.32)

WTP is also frequently influenced by geospatial scale. For example, WTP for a given change in environmental quality is often greater, *ceteris paribus*, if that quality change occurs over a larger area (Schaafsma 2015; Johnston et al. 2017; De Valck and Rolfe 2018; Glenk et al. 2019). To accommodate such scale effects, we adapt the approach of Johnston et al. (2017) and define *ln_affected_area* as the natural log of the wetland area, in acres, affected by the habitat change.[11]

This combined set of independent variables provides a means to compare changes in different types of habitat commodities across studies in the literature, with scope and scale quantified in directly comparable units. At the same time, the model allows for systematic differences in WTP associated with different types of wetland, habitat and sub-commodity types.

3.3 The Meta-Regression Model

We estimate two main specifications of the commodity consistent, "habitat-only" model using unweighted OLS with cluster robust standard errors.[12] These models allow for cross-sectional correlation among observations from the same study. If left unaddressed, such correlation can lead to heteroskedastic errors and inefficient, inconsistent parameter estimates (Rosenberger and Loomis 2000; Nelson and Kennedy 2009; Boyle and Wooldridge 2018). Formally, for each observation, the natural log of mean WTP for the representative individual is given by $\bar{y}_{js}$, which is the measured effect size in the MRM,

$$\bar{y}_{js} = \alpha + \bar{\mathbf{x}}_{\mathbf{js}}\boldsymbol{\beta} + \varepsilon_{js}. \tag{3}$$

Here $\bar{y}_{js}$ is the log WTP measure for observation s in study j, and $\bar{\mathbf{x}}_{\mathbf{js}}$ is the vector of independent variables. $\boldsymbol{\beta}$ represents a conforming vector of coefficients to be estimated, and α is the equation intercept. Other aspects of the model follow standard conventions.

Model variables were selected and specified based on preliminary models, guidance from theory and the prior literature. In addition to RHS variables described above that characterize the commodity change, we include variables to characterize sampled markets, respondents and valuation methodology. These include variables characterizing the (natural logs of) the sampled area size over which respondents were surveyed by each study and the median household income in those areas (*ln_sampled_area* and *ln_income*), with the latter calculated using US Census data. We also include a set of variables to capture effects of valuation methodology on WTP (Johnston et al. 2006a; Moeltner et al. 2007; Stapler and Johnston 2009; Boyle and Wooldridge 2018), including dummy variables identifying peer-reviewed studies (*peer review*), WTP measured as an annual rather than lump sum value (*annual WTP*), and dichotomous choice elicitation methods (*dichotomous*). We include an index of the study year (*yearindex*) to capture temporal trends in WTP (Rosenberger and Johnston 2009).

In summary, the MRM specifies the natural log of WTP as a function of independent (RHS) variables that include the natural logs of relative (*ln_relative_change*) and absolute (*ln_absolute_change*) habitat changes, sampled area size (*ln_sampled_area*), affected marsh size (*ln_affected_area*), and median income within the sampled area (*ln_income*).

[11] This variable was calculated using information provided by each primary study, combined with GIS data layers from the US Fish and Wildlife Service National Wetlands Inventory.

[12] Similar results are obtained when using random effects estimation.

Discrete independent variables and the index of survey year (*yearindex*) are included in linear form. Additional details of model variables are found in Table 2. This log specification implies that the percentage point change in marsh habitat influences (linear) WTP multiplicatively with other independent variables, including affected marsh size. Hence, WTP for each percentage point habitat change depends, implicitly, on the size of the affected marsh and other marsh characteristics.

The resulting MRM is a weak structural utility theoretic specification (Bergstrom and Taylor 2006). That is, the model is specified based on expectations from theory, but is not formally derived from an assumed underlying indirect utility function (Smith et al. 2002; Newbold et al. 2018).[13]

3.4 An Alternative Model—Increasing Sample Size Via Relaxed Commodity Consistency

To evaluate the influence of commodity consistency on MRM performance, we compare results of the primary coastal marsh habitat-only model described above to an alternative specification that enables a larger sample size by relaxing commodity consistency to a modest degree. When developing this alternative MRM, care is taken to avoid a "straw man" model—a *purposefully* inferior specification designed solely to illustrate the superiority of the commodity consistent model. Hence, we design the model following the same rigorous standards and practices applied to the original MRM, but apply a somewhat less restrictive screen for commodity consistency.

To ensure an alternative model of comparable quality (but with lower commodity consistency), we begin with the metadata and model structure described above for the commodity consistent habitat-only model. We supplement these original metadata with a set of additional observations identified using the same search and coding procedure. The new observations, however, are drawn from primary stated preference studies that estimate total (use and nonuse) WTP for changes in *coastal marsh area (or size)*, where these area increases *provide habitat combined with other wetland services* such as flood control, water filtration, aesthetics, recreation, and habitat.[14] At least superficially, the raw "commodity" valued by these new studies is similar—a change in coastal marsh area (e.g., acres, hectares, etc.). However, underlying this superficial consistency are differences in the specific set of wetland commodities provided by marsh area changes across different studies and sites.

These differences can be seen by reviewing the stated preference scenarios that underlie each of the added WTP estimates. In all cases: (a) the commodity that is directly valued is a change in marsh area, (b) this area change is described as providing multiple wetland services including but not limited to habitat, and (c) the specific services provided per unit of additional marsh area remain unquantified. For example, the valuation scenarios in Makriyannis et al. (2018) list (but do not quantify) potential benefits of additional marsh acres that include habitat, flood control, aesthetics and water filtration. As another example,

[13] It is also possible to impose an explicit multiplicative relationship between proportional habitat change and affected area, by including these variables as interactions within the model (i.e., the natural log of the product of each proportional habitat measure and affected marsh area). Although most model results are robust to this alternative specification, the statistical fit of the model declines.

[14] These studies are identified using the same search protocol as above, with habitat keywords replaced with keywords associated with marsh size, such as "area," "size," "acres," "hectares," etc.

Bauer et al. (2004) state that new marsh area will provide habitat in addition to other unquantified "environmental and ecological services." These and other new observations are broadly similar to the original metadata observations, in that all incorporate (in some way) WTP for marsh habitat change. However, the WTP estimates from the newly added studies also include, implicitly, the value of a diverse set of other wetland services that are provided by each unit of marsh area, and that vary across studies. As a result, the commodity consistency of the combined metadata is reduced, relative to the original habitat-only metadata.[15] However, the added studies have a degree of internal consistency, in that all are based on stated preference studies that directly report WTP for coastal marsh area change.

With the exception of this commodity difference, the added studies are screened using the same protocols described above for the habitat-only metadata. As implied by the selection criteria described above, the new observations are restricted to those for which WTP estimates can be linked to a quantified change in coastal wetland area, compared to a baseline affected marsh area identified by the study. To enable pooling with the original habitat metadata observations, these area (scope) changes are expressed as a relative proportion of the affected baseline marsh area. For example, an increase of 1000 acres relative to a status quo marsh area of 36,660 acres (as in Eastern Research Group 2016) would reflect a 2.73 percentage point relative change. To mirror the treatment of similar proportional changes within the habitat-only metadata, these changes are quantified in log form using the same *ln_relative_change* variable. We also introduce a new binary (dummy) variable *change_size* that identifies these new wetland area observations—following standard approaches in the literature that accommodate wetland commodity differences using similar dummy variables.

The resulting new metadata studies are identified using the identifier "Area" within the Valued Commodity column of Table 1. In some cases, the same studies that provide WTP estimates for quantified changes in coastal marsh habitat also provide separate WTP estimates for changes in marsh area or size—so that the same studies provide observations in both categories. The resulting expanded metadata include 151 total observations—including the 133 original habitat observations and an additional 18 marsh area observations. The final column of Table 2 presents summary statistics for the new, expanded metadata including both marsh habitat and area observations. As shown by Table 2, summary statistics of the original and expanded (less commodity consistent) metadata are similar, although not identical.

The MRM for the less commodity consistent metadata is estimated using an identical specification to that described above for the habitat metadata model, with area changes quantified as described above and the new variable *change_size* allowing for systematic variation in WTP associated with the added marsh area observations. All other aspects of the model are identical to those described above for the habitat-only MRM.

[15] We emphasize, however, that even these less commodity consistent metadata are more consistent than the metadata in most published wetland value MRMs.

4 Results—Commodity Consistent Marsh Habitat MRM

We first present results for the commodity consistent, habitat-only MRM. The second and third columns of Table 3 illustrate results for the two main versions of this model. The first is an unrestricted habitat-only MRM including all variables described above. The second is a restricted habitat-only MRM limited to a small set of core variables on scope, scale, sampled area, income, and methodological variables identifying study year and annual WTP measures. The number of observations for both models is 133 (6 observations are dropped due to missing values for one or more variables).

Measures of model performance for the two primary marsh habitat value MRMs compare favorably to prior wetland value MRMs in the literature. Even with a relatively small set of $K=16$ non-intercept RHS variables, we find $R^2=0.956$ for the unrestricted model, with model variables jointly significant at $p<0.0001$ ($F=1119.72$; $df=16, 22$). We obtain a similar $R^2=0.908$ for a restricted MRM with $K=7$. Similar results were found across a wide range of preliminary models.[16] Of 16 independent variables in the unrestricted variable, 13 are statistically significant at $p<0.10$ or better; 9 of these are significant at $p<0.01$. Signs of all statistically significant parameter estimates comport with prior expectations, where clear and unambiguous expectations exist.

Estimates are largely robust across the restricted and unrestricted model, although two parameter estimates that are significant in the unrestricted model are insignificant in the restricted model. Both of these relate to geospatial scale (*ln_sampled_area* and *ln_affected_area*). Variations of this type are not surprising, given the potential for omitted variables bias in a highly restricted MRM with only 7 non-intercept RHS variables. Nonetheless, core effects such as those of scope (*ln_absolute_change*, *ln_relative_change*), income (*ln_income*), and annual versus lump-sum payments (*annual_wtp*) are virtually identical across the two models. Unless otherwise noted, discussions of habitat-only model results below rely on the unrestricted model.

Among the main findings of the MRM is the systematic sensitivity of per household WTP to variables suggested by theory and intuition to be relevant to the demand for coastal wetland habitat improvements. The focus of the model on habitat commodities alone enables these variables to be included and associated value surface patterns to be estimated.

4.1 Evaluating Publication Bias

Before discussing additional findings of the habitat-only MRM, we briefly present a third specification of the habitat-only MRM that is designed to test for publication bias. As described by Nelson and Kennedy (2009, p. 347), "publication bias (aka "file-drawer problem") is a form of sample selection bias that arises if primary studies with statistically weak, insignificant, or unusual results tend not to be submitted for publication or are less likely to be published." Stanley (2005, 2008) and Stanley and Doucouliagos (2012) discuss the impact, detection and correction of publication bias in the economic literature. Rosenberger and Johnston (2009) discuss parallel issues with respect to valuation and benefit transfer applications. In the presence of (uncorrected) publication bias, estimates of typical empirical findings or "true effect sizes" drawn from the literature (such as estimates of

[16] Alternative models were tested, and none led to unambiguous improvements over the illustrated specifications.

Table 3 MRM estimation results—cluster robust OLS

	Unrestricted model: habitat	Restricted model: habitat	Unrestricted model: habitat and area
ln_absolute_change	0.811***	0. 698***	0.859***
	(0.117)	(0.152)	(0.0893)
ln_relative_change	1.231***	0.964***	1.258***
	(0.108)	(0.135)	(0.0746)
ln_sampled_area	− 0.158*	0.116	− 0.203***
	(0.083)	(0.123)	(0.0623)
ln_income	4.385***	3.553***	4.989***
	(1.109)	(1.082)	(0.778)
ln_affected_area	0.138**	− 0.0967	0.164***
	(0.0564)	(0.059)	(0.0503)
change_harvest	− 1.354***		− 1.307***
	(0.339)		(0.312)
change_population	− 1.244***		− 1.387***
	(0.276)		(0.270)
change_survival	− 0.701*		− 0.903**
	(0.343)		(0.350)
riparian_marsh	− 1.146***		− 0.0502
	(0.396)		(0.282)
annual_wtp	− 2.284***	− 2.046***	− 0.879***
	(0.580)	(0.446)	(0.263)
habitat_fish	− 0.280		− 2.559***
	(0.263)		(0.519)
habitat_multiple	− 1.502***		− 0.466*
	(0.282)		(0.251)
dichotomous	− 0.318*		− 1.688***
	(0.177)		(0.263)
peer_review	0.716		− 0.0831
	(0.607)		(0.284)
yearindex	− 0.124***	− 0.153***	0.457
	(0.0292)	(0.0192)	(0.439)
salt_other_habitat	− 0.0733		− 0.128***
	(0.280)		(0.0267)
change_size			− 2.137***
			(0.418)
intercept	− 39.87***	− 33.56***	− 45.35***
	(11.33)	(10.77)	(7.634)
N	133	133	151
R-sq	0.956	0.908	0.948
Adj. R-sq	0.950	0.902	0.941
RMSE	0.656	0.917	0.680

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

mean WTP) become distorted, leading to biased conclusions. Among the primary goals of meta-analysis in the economics literature is to identify and correct this type of bias, thereby providing unbiased estimates of true effect sizes.

To conduct an evaluation of this type for the present study, we estimate a third unrestricted habitat-only MRM. This model is estimated in addition to the two habitat-only models introduced above (Table 3), and is presented in Appendix 1. Standard approaches to identify potential publication bias in MRMs rely on the observation that these biases tend to cause an (otherwise absent) relationship between effect size estimates and the precision of these estimates, where the latter is typically quantified using the standard error (Stanley 2005). Hence, following standard approaches, the illustrated model in Appendix 1 incorporates the inverse of the square root of sample size (n) as an independent variable; this serves as an instrumental variable (IV) for the standard error (SE) of the welfare estimate (Stanley 2005, 2008). SEs are frequently omitted when reporting welfare estimates in the valuation literature, and hence cannot usually be included in valuation MRMs (Johnston et al. 2018b). Moreover, Stanley and Rosenberger (2009) argue that MRMs including inverse root n should outperform those including SEs in many valuation applications. The model is estimated using WLS with observations weighted by n (Stanley and Rosenberger 2009). Statistical significance of the IV in this model would suggest the presence of publication bias. As this model shows no evidence of statistically significant publication bias ($p > 0.56$), we continue the discussion of the habitat-only MRM based on the primary results shown in Table 3.

4.2 Scope, Scale and Market Extent

Unrestricted and restricted model results in Table 3 show robust responsiveness of WTP to variations in the scope of habitat improvements across studies. Indeed, the majority of explanatory power within the model is derived from the two scope variables alone (*ln_absolute_change* and *ln_relative_change*).[17] WTP per household varies depending on whether scope is quantified as an absolute or relative percentage (*ln_absolute_change* versus *ln_relative_change*), with both estimates significant at $p < 0.01$. Given the log form of these variables, parameter estimates may be interpreted as the elasticity of WTP with respect to the proportional (percentage point) change in each habitat commodity.[18] Results find elastic sensitivity of WTP to scope when changes are quantified as percentages relative to extant baselines (*ln_relative_change*). We find inelastic scope sensitivity when changes are quantified as percentages on an absolute or external scale (*ln_absolute_change*).[19] Although there is no necessary theoretical expectation for which of these effects should be larger, variations in WTP scope sensitivity associated with different types of absolute versus relative scope have been found in MRMs for other resources (Ojea and Loureiro 2011).

[17] An alternative MRM containing only these two variables ($K = 2$) explains over 70% of the variation in the dependent variable.

[18] This reflects the effect of a percentage change relative to a baseline percentage point level for each scope variable.

[19] An F-test rejects the null hypothesis that *ln_relative_change* = 1 (unit elasticity) at $p < 0.05$. A parallel test fails to reject the same null hypothesis for *ln_absolute_change* ($p = 0.12$).

Unrestricted model results also indicate that WTP per household is sensitive to the geospatial scale of habitat improvements (*ln_affected_area*, $p<0.05$), with an intuitive finding that improvements to larger spatial areas are associated with larger values. Similar to the findings of Johnston et al. (2017) for the spatial scale of water quality improvements (in rivers, lakes and bays), we find a relatively small (inelastic) magnitude for this effect.[20] The negative and statistically significant ($p<0.10$) parameter estimate for *ln_sampled_area* further suggests that per household WTP decreases with the spatial size of the surveyed market area (the area sampled for the stated preference survey in each primary study). When viewed across and within different studies from the literature, studies over larger market areas are associated with lower per household WTP, *ceteris paribus*. This is also intuitive, because larger sampled market areas imply greater mean distances between households and improved marshes. Hence, findings of this type imply distance decay (Bateman et al. 2006; Johnston et al. 2017, 2019).

4.3 Income and Payment Duration

Results from both models show that WTP is positively related to household income (*ln_income*) and negatively related to annual (versus lump sum) payments (*annual_wtp*).[21] These results are consistent with theoretical expectations of positive income elasticity of demand for wetland habitat commodities, and that households are willing to pay less on a recurring annual basis than they would be in a single lump sum. The implied elasticity of these effects, and particularly that associated with household income, is larger than that for all other RHS variables. The implied income elasticity of WTP for habitat improvements is also larger than those typically estimated in the literature for environmental improvements; past studies have often found inelastic WTP with respect to income (Barbier et al. 2017). These results suggest strong responsiveness of WTP for wetland habitat services to income (particularly) and payment schedules. The former finding is consistent with the intuitive idea that habitat commodities and services are luxury goods when viewed across primary studies.

The large size of the income effect might also suggest that this estimate captures effects of other variations that are correlated with income and unobserved (and hence omitted from the MRM). For example, low-income areas might be associated with difficult-to-observe cultural, educational or other regional differences that depress WTP for marsh habitat changes, the effects of which could be captured by the *ln_income* parameter (cf. Johnston and Ramachandran 2014, p. 381).[22] If such effects occur, the parameter cannot

[20] This finding is not equivalent to those from wetland value MRMs in the literature that aggregate values (a) over many or all different wetland-related commodities, and (b) over all households and firms in an assumed market, to generate a "total" average value estimate per area of wetland (e.g., value per hectare). Here, we meta-analyze *per household* WTP for changes in a single type of wetland commodity—coastal marsh habitat—as a function of the size of marsh over which the habitat improvements occur.

[21] Following common approaches in the literature (e.g., Johnston et al. 2017, 2019; Moeltner 2019; Newbold et al. 2018), we account for this payment duration effect using a dummy variable identifying studies that report annual rather than lump sum WTP. Some other wetland value MRMs have transformed WTP estimates into a standardized annual value for all studies (e.g., Woodward and Wui 2001; Brander et al. 2006). We do not apply such a standardization here, as it requires additional assumptions to be made regarding discount rates for each study.

[22] The large magnitude of the income effect could also imply that median regional income is not a good proxy for the true income of survey respondents from each region.

be viewed as an unbiased estimate of an income effect alone. The focus of benefit transfer MRMs on welfare prediction (i.e., $\hat{y}_{js}$) rather than hypothesis testing (i.e., $\hat{\boldsymbol{\beta}}$) implies less inherent concern with the magnitude of individual parameters such as these (Boyle and Wooldridge 2018). Nonetheless, the magnitude of this estimate suggests that it should be interpreted with caution.

4.4 Marsh and Habitat Type

Results also identify variations in per household WTP associated with different categories of habitat types, coastal wetlands, and habitat-related outcomes (or commodities), as described by the survey instruments used to elicit WTP within each primary study. Regarding habitat (species) types, patterns across studies suggest that improvements described by the primary stated preference survey as affecting multiple species types (*habitat_multiple*; $p<0.01$) are associated with the lowest per household WTP, compared to other species categories, including individual improvements to shellfish, bird, wildlife, and endangered species habitats. The intution behind this finding is not clear, but similar findings have been obtained by MRMs studying other resource types.[23] One potential explanation is that stated preference studies that elicit WTP for individual species improvements may tend to focus on iconic species of particularly high value, whereas studies elicitiong WTP for multiple-species improvements may tend to focus on more general improvements to many, less-recognized species. We find no significant difference associated with studies focused on fish habitat in the main model specifications (*habitat_fish*; $p > 0.10$).

For coastal wetland types, results suggest that riparian and forested coastal marshes (*riparian_marsh*), are associated with lower WTP than other marsh types ($p<0.01$), *ceteris paribus*. The parameter associated with salt marsh combined with other wetland types (*salt_other_habitat*) is negative but insignificant. These values are estimated relative to an omitted default category, which groups salt marshes, estuarine wetlands and complexes, and other coastal marsh types (including everglades).

Finally, regarding commodity types, negative coefficient signs for all the included commodity-type variables implies that the highest WTP is assocated with general (combined) wetland habitat improvements. One possible explanation for this pattern is that general marsh habitat improvements can support many types of habitat "outputs" (e.g., changes in fish harvest, improvements in species survival probability, etc.), and are hence valued more highly than each output in isolation. The lowest WTP, *ceteris paribus*, is placed on improvements in harvest (*change_harvest*) and species population size (*change_population*). Higher WTP is placed on improvements that affect the survival of threatened or endangered species (*change_survival*).

4.5 Methodological Effects

The model includes a small set of methodological variables, primarily to attenuate any potential omitted variable bias (Boyle and Wooldridge 2018). Among these is the year in which the study was conducted. Results for the coefficient on *yearindex* suggest a negative time trend—estimated WTP declines over time, *ceteris paribus*. Similar results have been found in MRMs addressing other types of aquatic improvements (Johnston et al. 2017, 2019), and for wetland values by Chaikumbung et al. (2016). We also find lower WTP

[23] For example, Johnston et al. (2019) find lower WTP for water quality improvements that affect multiple water bodies, compared to otherwise identical policies that affect individual water bodies.

associated with the dichotomous choice elicitation (*dichotomous*). No significant difference is found between peer-reviewed and non-reviewed publications (*peer_review*)—this is consistent with results of the model in Appendix 1, which show no sign of statistically significant publication bias.

5 Comparison to Less Commodity Consistent MRM

Results for the less commodity consistent (habitat and area) but larger sample size ($N=151$) model are shown in the final column of Table 3. Most results discussed above are robust across the two unrestricted MRM specifications (habitat-only vs. habitat and area), and the overall statistical fit of the less commodity consistent MRM remains very good. However, despite the larger sample size, measures of overall fit decline in the less commodity consistent MRM (e.g., R^2, adjusted R^2, RMSE). Although these declines are small, they nonetheless suggest reduced statistical performance of the less commodity consistent MRM, compared to the original commodity consistent specification. Hence, the larger sample size in the less commodity consistent model does not improve performance.

Results also suggest large and statistically significant differences in WTP across the habitat and area observations. The coefficient on *change_size* (-2.137, $p<0.01$) implies that WTP is 88.2% smaller ($=(e^{-2.137}-1)*100$) for changes in marsh area commodities than for changes in marsh habitat commodities, *ceteris paribus*. Other aspects of the less commodity consistent model lead to possible validity concerns. For example, coefficients on habitat-type dummy variables such as *habitat_fish* increase to a substantial degree—with the less commodity consistent MRM results implying that WTP for fish habitat improvements is 92.3% smaller than WTP for other types of improvements, holding all else constant. Although (arguably) implausible magnitudes such as these must be viewed in the context of other model coefficient estimates, they do suggest at least the potential for misspecification within the less commodity consistent MRM.

These findings are not surprising. Although the less commodity consistent MRM still displays good overall performance, it relies on a single dummy variable (*change_size*) to capture all possible systematic differences between WTP surface patterns for marsh habitat and area change. This is done purposefully, to mirror common practice in the wetland value MRM literature. The (slightly) reduced statistical performance of this model—combined with the large magnitudes of certain estimated coefficients—suggest that this specification was not able to fully capture the heterogeneity between these two types of marsh commodities. Implications for benefit transfer performance are discussed below.

6 Implications for Benefit Transfer

The results described above provide insight into systematic value patterns associated with coastal marsh habitat changes. Although value surface patterns such as these may be of interest to researchers and decision-makers, a primary goal for MRMs of this type is often to support WTP predictions for benefit transfer (Smith and Pattanayak 2002; Bergstrom and Taylor 2006; Johnston and Rosenberger 2010; Boyle and Wooldridge 2018). To evaluate and compare the benefit transfer accuracy of the two unrestricted MRM specifications (habitat-only versus habitat and area), we apply a standard, iterative leave-one-out convergent validity test (Brander et al. 2006; Stapler and Johnston 2009; Londoño and Johnston 2012; Boyle et al. 2015).[24]

Results are illustrated by Table 4. For the commodity consistent MRM, we find a mean (out-of-sample) absolute value error of 72.02% and a median value of 41.84%. Differences between the mean and median imply a positively skewed error distribution, with a two relatively large errors influencing the mean. Hence, we also present a 5% trimmed mean (50.98%), following Stapler and Johnston (2009). Combined, these results suggest out-of-sample benefit transfer performance similar to means and medians found in prior benefit function transfers evaluated across the literature (Rosenberger 2015), and also similar to those found by Johnston et al. (2017, 2019) for MRMs of water quality improvement values. Hence, while the in-sample fit of the habitat-only model is superior to that found in most published valuation MRMs in the literature, out-of-sample transfer error is in the same general range as prior high-quality MRMs. The suitability of results of this type for benefit transfer depends on degree of accuracy required within different decision contexts (Navrud and Pruckner 1997).

Benefit transfer errors increase (worsen) in the parallel test of the less commodity consistent (habitat and area) MRM. Mean absolute value errors increase to 78.78% and median errors increase to 44.47%, reflecting an accuracy loss of 6.76 percentage points (mean) and 2.63 percentage points (median). These results are consistent with the somewhat reduced statistical performance of the less commodity consistent MRM.

Errors in all cases are similar to those reported by the prior wetland value meta-analysis of Brander et al. (2006), and higher than errors reported by Chaikumbung et al. (2016). However, review of these prior wetland value MRMs suggests that their presented "transfer error" estimates may have been calculated relative to the natural log of WTP rather than WTP itself.[25] Hence, direct comparisons of this type are likely not meaningful. Neither of these prior papers states whether errors are calculated relative to WTP or the natural log.

7 Conclusions

This article develops methods that enable greater commodity and welfare consistency within wetland value meta-analyses. The MRM quantifies systematic WTP variation associated with specific types of habitat improvements in US and Canadian coastal marshes. Model results supersede those of prior wetland value MRMs in terms of commodity and welfare consistency, statistical fit, and the capacity to estimate theoretically anticipated value surface patterns. Results indicate that WTP per household for coastal marsh habitat

[24] We begin with $n=1\ldots N$ metadata observations. The first step is the omission of the nth observation. The model is estimated using the original model specification for the remaining $N-1$ observations. This is iterated for each $n=1\ldots N$ observation, resulting in a vector of N unique MRM parameter estimates, each corresponding to the omission of the n^{th} observation. For each of these model runs, the nth observation represents an out-of-sample observation corresponding to the vector of parameter estimates from that iteration. Parameter estimates for the nth iteration are combined with independent variable values for the nth observation to generate a WTP forecast for the omitted observation. The result is N out-of-sample WTP forecasts, each drawn from a unique model estimation. Transfer error is assessed through comparisons of predicted and actual WTP for each observation, and is reported as absolute value percentages. Following Stapler and Johnston (2009), these predictions do not include the intercept adjustment ($\sigma_e^2/2$) prior to the exponential transformation.

[25] For example, Figure 5 in Brander et al. (2006) and Figures 3 and 4 in Chaikumbung et al. (2016) imply that errors may have been calculated relative to the natural log of WTP.

Table 4 Convergent validity results: absolute value percentage transfer errors

	Mean absolute percent WTP error	Mean absolute percent WTP error (5% trimmed)	Median absolute percent WTP error
Unrestricted mode1: habitat (N = 133)	72.02	50.98	41.84
Unrestricted model: habitat and area (N = 151)	78.78	52.13	44.47

changes is responsive to dimensions such as scope, spatial scale, the extent of the sampled market, the type of habitat and wetland change considered, and other factors suggested by theory and intuition. Out-of-sample transfer errors are similar to those found in prior MRMs in the valuation literature. These results suggest the potential viability of wetland value MRMs with a greater degree of commodity and welfare consistency than those common in the literature. Comparison to a similar but less commodity consistent MRM suggests that the advantages of added sample size do not offset the disadvantages due to reduced commodity consistency in the metadata.

Results of this analysis must be interpreted within the context of our case study application. The illustrated MRM specification was chosen after preliminary modeling to evaluate alternative means to model wetland habitat value surface patterns, and implies a particular set of assumptions about the comparability of WTP for proportional habitat changes across studies and observations. These assumptions lead to a model with good empirical performance. However, other specifications and assumptions are possible, and additional model enhancements might be possible in other valuation contexts. For example, information available with the coastal marsh metadata prevented the inclusion of a consistent variable that quantified current habitat baselines (other than the current size of the marsh). Limitations such as this could be potentially addressed by future research in other valuation contexts. It is also unclear whether the methods used here to reconcile coastal marsh habitat changes are similarly applicable to other types of wetland or environmental commodities, and to what extent models of this type can enhance benefit transfer reliability in applied settings. Finally, some results—such as the large implied income elasticity of WTP—warrant further study to evaluate validity and generalizability. Hence, additional work is required to evaluate whether and how the presented methods apply to other resource types and valuation contexts.

We also emphasize that the presented model reflects a reduced-form, MRM specification. Following guidance of Kling and Phaneuf (2018), we do not restrict the specification to ensure properties such as "adding-up"[26] or impose other structural restrictions on preferences, as such approaches typically detract from the empirical fit of the model (Newbold

[26] The adding-up property in MRMs relates to sequential use of the model to predict WTP for additive improvements. Assume that WTP_A is predicted WTP for a quality improvement from A to B, WTP_B is predicted WTP for a quality improvement from B to C, and WTP_C is predicted WTP for a combined improvement from A to C. The adding-up property implies that $WTP_A + WTP_B = WTP_C$, when each is predicted separately by the MRM. This property holds trivially in simple linear (in the variables and parameters) MRMs. Otherwise, a structural specification is required to impose the adding-up property on WTP predictions (Newbold et al. 2018).

et al. 2018; Moeltner 2019). Moeltner et al. (2019) illustrate the use of such a model to meta-analyze WTP for changes in freshwater wetland size (acres). As shown by Moeltner (2019), however, models that roughly approximate the adding-up property can be obtained without strong structural restrictions by transforming the dependent variable from the natural log of WTP to the natural log of WTP per unit change (here, WTP per percentage point change in habitat). Appendix 2 presents the specification and results of this alternative MRM for the present marsh habitat value application—denoted MRM2. All properties of the original MRM (Table 3) continue to hold for MRM2.

In summary, results of the analysis suggest that wetland value MRMs can potentially accommodate greater degrees of commodity and welfare consistency. The presented approach provides an alternative to standard methods for wetland value meta-analysis that pool data over diverse commodity groups. Such analyses can serve multiple purposes. For example, in addition to supporting more valid benefit transfers, these models can reveal systematic welfare patterns that are obscured by meta-analyses addressing more diffuse commodity types. Models of this type can also engender greater credibility for MRMs and benefit transfers, by reducing uncertainty regarding the validity of pooling data over dissimilar commodities.

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Appendix 1: Results for Model Testing Publication Bias

This appendix illustrates results of the WLS MRM developed to test for publication bias in the metadata, as described in the main text. Observations are weighted by original study sample size (n). Insignificance of the coefficient on the inverse root sample size ($1/\sqrt{n}$) implies that we fail to reject the null hypothesis of zero publication bias in the sample (Appendix Table 5).

Appendix 2: Commodity Consistent MRM for WTP Per Unit Change (MRM2)

This appendix illustrates results of an alternative commodity consistent MRM (Table 3), with the dependent variable redefined as the natural log of WTP per percentage point change in habitat. That is, the dependent variable is redefined as WTP/unit rather than WTP following the example of Moeltner (2019). Other aspects of the model are unchanged. For conciseness, we denote this new model MRM2, with the original unrestricted model (in Table 3) denoted MRM1. The mathematical (structural) relationship between MRM1 and MRM2 implies—necessarily—that only the coefficient estimates related to the percentage point changes in habitat *(ln_absolute_change*, *ln_relative_change*) should vary between the two specifications. More precisely, the coefficients on both *ln_absolute_change* and *ln_relative_change* should decline by exactly 1.0 between MRM1 and MRM2.[27] Measures of

[27] To illustrate this relationship, assume a simple case in which $\ln(WTP)=\beta_1{*}\ln(Units)+\varepsilon$, where *Units* is the measure of commodity change. Because $\ln(WTP/Units)=\ln(WTP)-\ln(Units)$, it follows that $\ln(WTP/Units)=\beta_1{*}\ln(Units)-\ln(Units)+\varepsilon=(\beta_1-1){*}\ln(Units)+\varepsilon$.

Table 5 MRM estimation results—cluster robust WLS with publication bias test using inverse root sample size ($1/\sqrt{n}$)

	Unrestricted model: habitat
$1/\sqrt{n}$	9.474
	(16.018)
ln_absolute_change	0.675***
	(0.170)
ln_relative_change	1.178***
	(0.127)
ln_sampled_area	− 0.094
	(0.136)
ln_income	3.996***
	(1.274)
ln_affected_area	0.078
	(0.088)
change_harvest	− 1.782***
	(0.259)
change_population	− 1.220***
	(0.260)
change_survival	− 0.582
	(0.368)
riparian_marsh	− 0.914**
	(0.404)
annual_wtp	− 2.746***
	(0.417)
habitat_fish	− 0.073
	(0.267)
habitat_multiple	− 1.294***
	(0.311)
dichotomous	− 0.312**
	(0.141)
peer_review	0.453
	(0.649)
yearindex	− 0.131***
	(0.027)
salt_other_habitat	− 0.003
	(0.233)
intercept	− 35.808***
	(12.070)
N	133
R-sq	0.953
RMSE	0.618

Observations are weighted by sample size (n)

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

Table 6 MRM2 estimation results—dependent variable defined as the natural log of WTP per percentage point habitat change

	Unrestricted model: habitat
ln_absolute_change	−0.189
	(0.117)
ln_relative_change	0.231**
	(0.108)
ln_sampled_area	−0.158*
	(0.083)
ln_income	4.385***
	(1.109)
ln_affected_area	0.138**
	(0.0564)
change_harvest	−1.354***
	(0.339)
change_population	−1.244***
	(0.276)
change_survival	−0.701*
	(0.343)
riparian_marsh	−1.146***
	(0.396)
annual_wtp	−2.284***
	(0.580)
habitat_fish	−0.280
	(0.263)
habitat_multiple	−1.502***
	(0.282)
dichotomous	−0.318*
	(0.177)
peer_review	0.716
	(0.607)
yearindex	−0.124***
	(0.0292)
salt_other_habitat	−0.0733
	(0.280)
intercept	−39.87***
	(11.33)
N	133
R-sq	0.851
RMSE	0.656

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

overall model fit should also vary (e.g., R^2, RMSE). Other coefficient estimates should be identical to those in Table 3.

Results of MRM2 are shown in Appendix Table 6, and are as expected. All results in Table 3 continue to hold precisely, except for the coefficients on *ln_absolute_change* and *ln_relative_change*, each of which decline by 1.0. Given that MRM2 now meta-analyzes WTP *per unit* change, these two coefficients now indicate the type of curvature in the value function—specifically whether predicted WTP/unit increases or decreases with scope. However, the underlying properties of the value surface remain unchanged. As shown by Moeltner (2019), functional forms of this type have desirable properties when analyzing WTP for successive environmental improvements. Factors such as these should be considered when choosing between MRM1 and MRM2 for benefit transfer applications. However, with regard to the role and impact of commodity consistency, all properties of MRM1 continue to hold for MRM2.

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