

ANALYSIS

The economic value of wetland services: a meta-analysis

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Abstract

The number of studies quantify the value of wetlands and the services provided by these ecosystems is rapidly expanding. The time is ripe for an assessment of what has been learned from this literature. Using results from 39 studies, we evaluate the relative value of different wetland services, the sources of bias in wetland valuation and the returns to scale exhibited in wetland values. While some general trends are beginning to emerge, the prediction of a wetland's value based on previous studies remains highly uncertain and the need for site-specific valuation efforts remains large. © 2001 Elsevier Science B.V. All rights reserved.

1. Introduction

The valuation of wetlands' ecological services is a relatively recent phenomenon. Historically, wetlands were viewed as a waste of valuable land that could only be 'improved' through drainage and destruction of the wetland (Mitsch and Gosselink, 1986). Today, while there is now widespread recognition that wetlands provide valuable ecological services, there remain substantial debates over whether particular areas are in their highest economic use as wetlands, and to what extent public and private resources should be used for their protection and restoration. Hence, there is a

growing need to quantify the value of wetland services.

The services provided by wetlands include habitat for species, protection against floods, water purification, amenities and recreational opportunities. Because these services typically have no market price, a measure of their values can only be obtained through non-market valuation techniques. Many wetland valuation studies have been conducted and the range of the estimates is remarkable. A recent review by Heimlich et al. (1998) lists 33 studies over the last 26 years with per acre values ranging from US\$0.06 to US\$22050. Even within the same study looking at a single ecosystem function, Batie and Wilson (1978) find values per acre that differ by two orders of magnitude from one site to another.

The purpose of this paper is to assess whether any systematic trends can be distilled from the

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breadth of wetland valuation studies conducted to date, and to shed light on what factors determine a wetland's value. We maintain an assumption that there exists an unobserved valuation function that determines a wetland's value given its physical, economic and geographic characteristics. After reviewing 46 studies, data from 39 wetland valuation studies were identified that had sufficient commonalities to allow inter-study comparisons. We used two techniques to learn about the valuation function, both of which can be broadly described as meta-analysis since many studies are used to identify general relationships. The first method that we employ uses bivariate graphical and standard techniques. This gives us both an indication of the extent to which particular characteristics influence wetland values while also portraying the full distribution of the data. The second technique is more standard, using a multivariate regression of wetland values on the characteristics of both the wetlands and the studies. Together, these two techniques provide a richer basis from which we can draw lessons on the factors determining wetland value.

There are numerous reasons why understanding the value of wetland services might be useful. The most obvious is that if the value of these services were known, benefits transfer efforts could be substantially improved. As Deck and Chestnut (1993) point out, benefits transfer may play a variety of different roles, ranging from an attempt to place a precise value on a particular resource to providing information that feeds into the process of building support for projects already implemented. While benefits transfer is rarely suitable for the former case, it might often be appropriate for the latter. Another form of benefits transfer is the use of estimated values to predict the aggregate value of similar systems nationally or globally. Such estimates can be useful in setting national priorities or the evaluation of policies with impacts that are national or global. Costanza et al. (1997), for example, placed a value on the entire globe's ecosystems. While such expansive efforts may be overambitious, the aggregate numbers do help to get the attention of policy makers and the public.

Estimates of the value of a wetland can also influence site-specific valuation efforts in two ways. First, they might provide Bayesian priors that might be formally incorporated into the valuation exercise. Secondly, they may give researchers a sense of where the values at stake are likely to be of greatest social importance and might, therefore, influence where detailed studies are carried out.

The paper is organized as follows. In the next section we provide a brief overview of the economics of wetland valuation. We survey the ecological functions and economic services provided by these areas, the basis for their valuation and the techniques that are used to place an economic value on wetlands. Section 3 provides a brief summary of meta-analysis as a tool. In Sections 5 and 6 we explore the trends in the data, identifying the sources of variability in wetland values. We conclude by reflecting on the implications of our analysis both for our understanding of wetland values and for future research.

2. The value of wetland functions

2.1. *Wetland functions and services*

While an inclusive definition of wetlands is difficult to state, they are generally characterized as being moist during an extended period each year with soils, plants and animals that are distinct from their aquatic and terrestrial neighbors. These transition areas are highly diverse, ranging from coastal mangroves that are inundated with water most of the year to areas that are moist for only a few months during the year. Partly because they share features of both terrestrial and aquatic systems, wetlands are remarkably productive.

In assessing the value of wetlands, it is useful to distinguish the systems' ecological functions from the associated services that are directly valued by humans (Costanza et al., 1997). Larson et al. (1989) list 17 services and functions provided by the world's ecosystems (Table 1). In our data set, the services were grouped into ten categories as indicated in the table. The measurement of the value of these services varies substantially both in

Table 1

Wetland functions, the associated economically valuable goods and services and the names of variables that capture the presence of these in the data^a

Function	Economically valuable good(s) and/or service(s) (variable names)	Technique(s) typically used to quantify the value of the service(s)
Recharge of ground water	Increased water quantity (quantity)	Net factor income or replacement cost
Discharge of ground water	Increased productivity of downstream fisheries (com.fish)	Net factor income, replacement cost or travel cost
Water quality control	Reduced costs of water purification (quality)	Net factor income or replacement cost
Retention, removal and transformation of nutrients	Reduced costs of water purification (quality)	Net factor income or replacement cost
Habitat for aquatic species	Improvements in commercial and/or recreational fisheries either on or offsite (com.fish and rec.fish). Nonuse appreciation of the species (habitat)	Net factor income, replacement cost, travel cost or contingent valuation
Habitat for terrestrial and avian species	Recreational observation and hunting of wildlife (birdwatch & birdhunt). Nonuse appreciation of the species (habitat)	Travel cost or contingent valuation
Biomass production and export (both plant and animal)	Production of valuable food and fiber for harvest (birdhunt & com. fish)	Net factor income
Flood control and storm buffering	Reduced damage due to flooding and severe storms (flood)	Net factor income or replacement cost
Stabilization of sediment	Erosion reduction (storm)	Net factor income or replacement cost
Overall environment	Amenity values provided by proximity to the environment (amenity)	Hedonic pricing

^a The first two columns are adapted from Larson et al. (1989).

the methods that are used and the economic theory that underlies the valuation exercise. The most common methods for measuring the economic value of these services are also presented in the table. Though not indicated in the table, the contingent valuation method can, in principle, be used to measure the value of all these services.

2.2. *The valuation of wetland services*

The economic value of resources such as wetlands is equal to the benefits (net of costs) that these systems provide to humans (Freeman, 1993). Four methods are listed in Table 1 as commonly used to place a value on wetlands. The net factor income (NFI) method is most appropriate when the wetland provides a service that leads to an increase in producer surplus. In the NFI method the physical relationship between wetland area and the economic activity is estimated. It is then possible to identify the increase in producer surplus associated with the wetland's area. In prac-

tice, it is often assumed that demand is perfectly elastic so that the impact of the wetland on consumer surplus can be ignored. Other times the producer surplus that is generated by a wetland is estimated using the replacement cost (RC) method. This approach values the wetland's service based on the price of the cheapest alternative way of obtaining that service. For example, the value of a wetland in the treatment of wastewater might be estimated using the cost of chemical or mechanical alternatives. As noted by Anderson and Rockel (1991), the replacement cost method is actually an upper bound on the true value since the producer may not choose to actually use that alternative considered.

Non-market values can be measured using travel cost (TC), contingent valuation (CV), or hedonic pricing (HP) methods. There is, however, substantial variability within each of these approaches, much more than can be discussed here (Freeman, 1993), and the literature is filled with reasons why results might be biased or otherwise

deficient. While in principle each method can give a correct estimate of economic value, it is easy to misuse the method and obtain results that may have little relation to the true value.

Some wetland values are obtained using methods that do not estimate economic surplus and, therefore, lack a foundation in standard economic theory. Of the studies identified in our review of the literature, two values were estimated using energy analysis in which the value is based on the gross primary production of the ecosystem, and five values were obtained using the market value of the products extracted. These methods have been strongly criticized (Anderson and Rockel, 1991). Energy analysis equates the energy embodied in a wetland's biota with the energy purchased in fossil fuels. Since the correlation between energy content and consumer preferences is quite weak, the technique is a poor predictor of economic value. The market value technique is also flawed since it cannot capture consumer surplus and can lead to over-estimate producer surplus if cost of extracting the valued products is not subtracted.

3. Meta-analysis as a tool in understanding non-market valuation

First used by psychologists (Glass, 1976; Schmidt and Hunter, 1977), meta-analysis has proved to be a useful tool for synthesizing the results of numerous studies. The method has recently gained attention in economics as a way to appreciate numerous studies that have placed economic values on environmental goods and services (see Brouwer (2000) for a review). The central advantage of meta-analysis is that it provides a rigorous statistical synthesis of the literature that cannot be achieved using more qualitative analysis.

There are two main types of meta-analyses: those that use the actual data from multiple studies, and those that use the results of multiple studies. It is the later method that has been applied to interpret valuation studies. Brouwer lists ten studies that have used meta-analysis to study valuation efforts. Smith and Kaoru (1990) were

the first to use meta-analysis in the context of nonmarket valuation, looking at values placed on outdoor recreation. Since then, meta-analysis has been used to study air pollution, recreational fishing, visibility, health risks, endangered species and wetlands.¹

The basic approach used in most valuation meta-analyses is the same. A set of studies is selected yielding a number of values that become the dependent variable. The independent variables are the characteristics of each study and study site. If a single study reports numerous values, then several data points are obtained. Meta-analysis allows the evaluation of the effect of changes in the underlying environmental attribute on value. Such analysis is usually not possible in the context of a single study since most such attributes are held constant.

A good example of the benefits of meta-analysis is seen in Smith and Osborne's (1996) analysis of the value of improvements in visibility. Since visibility varies continuously from zero to one, the authors are able to estimate the marginal benefit of improvements in visibility. One of the most significant limitations of meta-analysis, however, is the lack of comparability across studies (van den Bergh and Button, 1997). Characteristics of the resource being valued are often presented in such diverse fashion that the best that the analyst can do is to use a binary variable to indicate whether an attribute is reflected in each value. Boyle et al. (1994), for example, have no data on the level of cancer risk in each of their eight studies, only an indication of whether such a risk was mentioned in the study. Similarly, in this study wetland services are captured using qualitative variables.

Brouwer et al. (1997) is, to our knowledge, the only other attempt to carry out meta-analysis of wetland valuation studies. In their work, only contingent valuation studies are considered. This narrow focus allowed the authors to develop a

¹ The analysis of wetlands by Brouwer et al. (1997) looked at WTP estimates from CV studies and used a more expansive interpretation of 'wetlands' than we retain in this paper. Hence, their results are not directly comparable to the results here.

rich set of variables characterizing the qualities of the studies. However, this is also a limitation in that it eliminates any variability associated with valuation method and reduces the variability in services that can be considered. In the next section we discuss how we attempted to overcome these limitations in our data.

4. The wetland valuation data

After a lengthy review of the literature, we identified 39 studies that contained sufficient data to allow inter-study comparisons. Many other studies were identified but could not be used. The values are taken from published reports, 'gray' literature, and theses.² Because of our desire to synthesize wetland values from all different services, we use annual value per acre in 1990 US dollars. This distinguishes our work from other meta-analyses which typically use willingness to pay (WTP) per person (e.g. Brouwer et al., 1997). WTP per person is not applicable here because some methods (e.g. NFI) do not lead to a WTP per person measure. On the other hand, if WTP per person is available, then value per acre can be calculated with knowledge of the relevant population and the wetland's size. When capitalized values were reported, they were annualized assuming constant value per year and using discount factors provided in the studies or a 6% rate in the two studies that did not state a discount rate.

In our analysis we assume that a wetland's value is a function of the system's ecological characteristics and its socio-economic environment. Each wetland in our data is interpreted as a (not necessarily random) draw from the population of all wetlands. We assume that there exists a true public WTP at a given moment for a particular wetland. While this true WTP cannot be observed directly, it can be estimated using the methods discussed above. Seen in this way, there are two sources of variability in the wetland val-

ues: variation due to differing characteristics of the wetlands, i.e. along the function; and variation due to error in the estimation of the true value, i.e. deviations from the function.

Of course, the wetlands that have been valued were almost certainly not chosen at random from the total population. First there is the problem of selection bias. It seems likely that wetlands that are considered valuable a priori are much more likely to be studied and valued. This need not lead to errors in our estimation of the valuation function if all important variables are accurately measured, but given the limitations in the available data, the likelihood of such bias should be taken into account in benefits transfer exercises or any other attempt to extrapolate estimated values. Similarly, the fact that many of the studies have been filtered by the peer review process might have excluded some estimates. Good estimates that are either not statistically different from zero or are much higher than anticipated may not be published.

The values in our data are also not independent draws. Numerous studies generate multiple measures of wetland value, so that, as pointed out by Smith and Kaoru (1990), the data have panel characteristics. Furthermore, researchers who work closely together are likely to share practices that differ in important ways from others. Finally, since there has no doubt been learning over time, both in terms of methodology and the values that are reasonable, the data also probably suffer from some autocorrelation.

5. Bivariate meta-analysis

Using the available data, we now evaluate the sources of variation in estimates of wetland value. Two complementary techniques are used. In this section we explore some of the relationships in the data using graphical presentation and bivariate statistics. The advantage of this analysis is that it allows us to present the full data set graphically, making possible a richer appreciation of the data. However, the bivariate analysis ignores interactions between explanatory variables. Hence, a second and more standard technique is also used,

² The complete data set, including a description of each study and an explanation of the interpretations of the data that were made is available from the authors on request or via the internet at <http://ageco.tamu.edu/faculty/woodward/>.

that of estimating a valuation function using multivariate regression techniques.

5.1. Variation due to measurement error or bias

As noted above, there are two types of variation with which we are concerned, deviations from the valuation function due to bias or errors in estimation, and variations along the valuation function attributable to different wetland characteristics. We begin by looking at sources of systematic error because of study weaknesses and bias because of the valuation method used.

One might expect study quality to affect estimates of wetland value. Attention to this issue is potentially important because there is substantial variability in the quality of wetland valuation studies. While some studies are characterized by sound theoretical foundations and state-of-the-art econometric methods, others are crippled by faulty logic, poor data or incorrect economic analysis.

The weakness of many wetland valuation efforts is widely recognized. In their review of wetland valuation studies, Anderson and Rockel (1991) found only five studies that they deemed credible enough to list in their summary table. However, while it may appear obvious that only high quality analyses should be used in meta-analysis, it is also clear that the evaluation of quality is likely to be quite subjective. The problem of subjectivity is particularly problematic in wetland valuation studies because few efforts satisfy the highest standards of quality, in large part because of data limitations. In CV studies, for example, strict adherence to the guidelines of the NOAA panel (Arrow et al., 1993) is often impossible because of budgetary restrictions. Hence, there is a great deal of subjectivity in assessing how good is good enough.

As Cooper (1989, p. 67) points out, “The decision to include or exclude studies on an a priori basis requires the reviewer to make an overall judgment of quality that is often too subjective to be credible.” He argues that it makes more sense to enumerate characteristics of each study and then evaluate whether ‘good’ methods lead to different results than ‘bad’ methods. “When no

difference is found it is sensible to retain the ‘bad’ studies because they contain other variation in methods (such as different samples and locations) that, by their inclusion, will help answer many other questions surrounding the problem area.”

Following Cooper’s advice, some meta-analyses include objective indicators of study quality such as response rate or study format (Brouwer et al., 1997; Loomis and White, 1996). Given the diversity of studies considered in our analysis, no standard objective indicator of quality was available; only a subjective assessments of study quality could be used. Each study was ranked on a scale of 1–3 in four categories: the apparent quality of the data, the theoretical consistency of the methodology, econometric techniques and statistical certainty. A study was given a rank of 1 if we felt that this feature of the study made the results highly questionable. Studies with a 1 in any of the quality categories are called ‘weak’ in the figures and econometric analysis below.³ A ‘weakness’ in a study should not be interpreted as a condemnation since valuation may not have been the authors’ primary objective or data limitations may have been prohibitive.

On average, the weak and strong studies do not yield statistically different values. Excluding the highest value in our data set, the average of the weak studies is US\$986 per acre versus US\$915 for the strong studies.⁴ When looking at the complete distribution of these studies however, there do appear to be some systematic differences two sets of values. Fig. 1 plots the rank of both the weak and the strong studies in their respective

³ For studies that are also evaluated by Anderson and Rockel (1991) our critique was generally consistent. Some studies which we ranked as a 2 were questioned, but did not appear to be completely rejected by Anderson and Rockel.

⁴ The highest value from the Amacher et al. (1989) study is excluded as it is over 60 times the second largest value. After excluding this value, the mean of the weak studies is not significantly different from the mean of the strong studies at the 10% level. This value, one other value estimated using energy analysis and five values estimated using the market value of the output are excluded from the econometric analysis below.

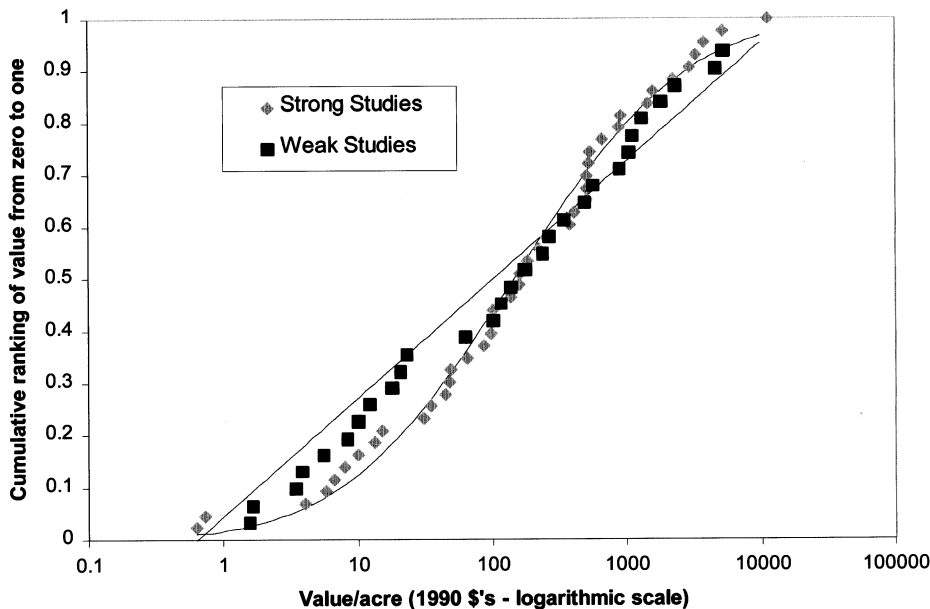


Fig. 1. Cumulative distributions of wetland values broken down by study quality.

categories on the vertical axis, against the estimated values per acre on the horizontal axis. The solid lines in the figure represent cumulative distribution functions (cdfs) of distributions from which the data appear to be drawn. While the distribution of the strong data closely resembles a log normal distribution, the weak data seem to be drawn from a uniform distribution. There is also slightly less variance in the strong studies, indicating that the lack of quality may not bias the estimated value, but it might have implications for the accuracy of the predictions. This result is confirmed in the multivariate analysis below. Nonetheless, we do not find the kind of dramatic difference between the two groups that would justify discarding the weak studies from the data set.

Another potential reason that the estimated value may deviate from the valuation function might be bias due to the method that was used in the study. In principle, if two methods seek to estimate consumer surplus from the same wetland then they should yield similar values. If there is no systematic difference between two techniques, then they are said to satisfy the criterion of convergent validity. Numerous studies have tested the

convergent validity of CV analysis relative to other methods (e.g. Carson et al., 1996).

Fig. 2 presents the distributions of the values taken from the four primary methods used to measure wetland values. The means of the values from these methods vary from a low of US\$198 for the travel cost method to a high of US\$1555 for the replacement cost method. However, because of the substantial variability in the data, none of the means are statistically different from each other. Still, some patterns are evident. At one extreme, the net-factor input method is a lower bound on the distribution of values. At the other extreme, the distribution of values obtained using CV nearly stochastically dominates the distributions of values from the other three methods. These findings do not necessarily indicate biases in these techniques. Because of the small sample size we cannot statistically reject the hypothesis that the distributions are the same. Moreover, different methods are used to value different services. It may be that CV is used for high-value services while the NFI method is used for low-value services. Hence, the question of whether the method itself is a source of bias can only be explored using multivariate analysis.

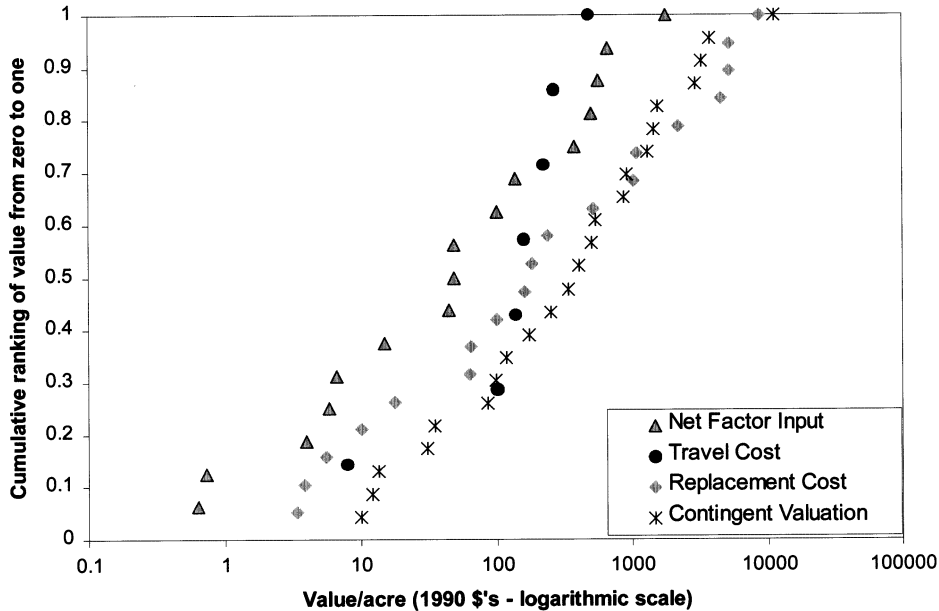


Fig. 2. Cumulative distributions of wetland values broken down by valuation method.

5.2. Variation in value due to wetland characteristics

We now turn an initial analysis of the sources of variation in the valuation function. Ten variables were defined indicating whether a particular wetland service was reflected in each study. These are listed in Table 1. Identifying the services reflected in a study often involves some subjectivity, particularly in CV studies since respondents might be aware of services other than those about which they had been explicitly asked in the survey.⁵

A relatively weak hypothesis would be that increasing the number of services considered in a valuation exercise would tend to increase a wetland's estimated value. This relationship is presented in Fig. 3. While almost two-thirds of the studies measured the value of only one wetland service, more than 30% of the studies measured three or more services. Contrary to our hypothesis, there is no noticeable relationship between the value of a wetland and the number of services

valued. The correlation between estimated value per acre and the number of services is only 0.10 and, based on the Spearman rank criterion, the hypothesis of no correlation cannot be rejected at the 10% level.

In addition to being affected by wetland services, one might also expect the value per acre to be a function of the wetland's area. In this case there is no clear a priori expectation as to the form that such a relationship might take. Economic intuition would suggest that the marginal value of each acre would tend to decline. On the other hand, based on ecological principles of functional interdependence, one might expect that larger wetlands would provide a richer and more valuable set of services. This relationship is plotted in Fig. 4. There is no apparent relationship between wetland area and value in the figure and, once again, the hypothesis of no significant correlation cannot be rejected at the 10% level.

Our analysis to this point is quite inconclusive. There is some evidence that CV studies tend to yield greater values than any other method, but no visible relationship between value per acre and either the number of services or the size of the wetland. However, while we find the bivariate

⁵ In a few instances authors were contacted to assist us in obtaining the most accurate interpretation possible.

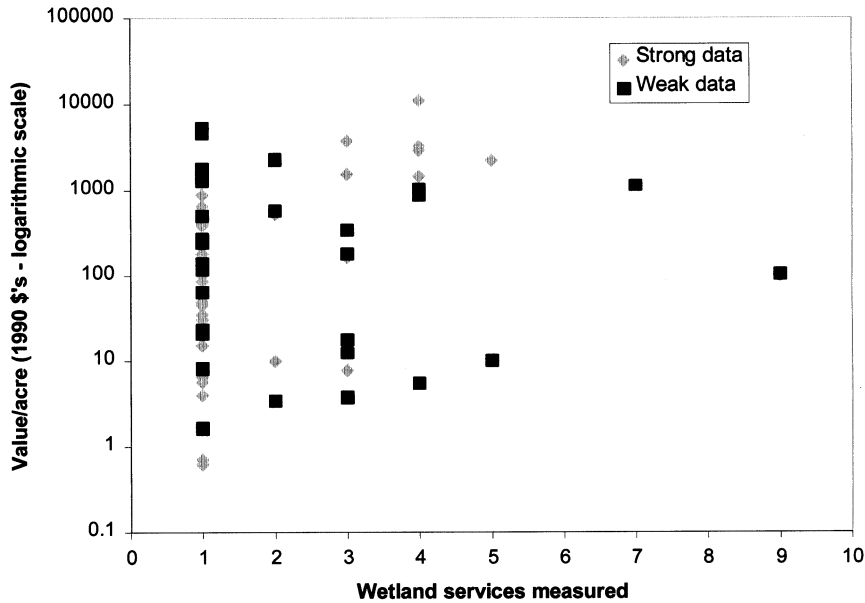


Fig. 3. Wetland values and the number services present.

analysis useful, it cannot distinguish how multiple factors might be interacting to influence wetland value. In the next section we attempt to tease out more understanding of the wetland valuation function using multivariate regression analysis.

6. Multivariate meta-analysis of wetland values

In this section we estimate a parametric specification of the valuation function using the data discussed above. After excluding incomplete observations and values based on either energy analysis or the market value methods, the 65 observations of wetland values were obtained.

6.1. The estimated model and results

The dependent variable in all regressions is the natural log of the value per acre of wetland converted to 1990 dollars, the mean of which is 4.92. In addition to the variables discussed above representing services, area and study quality, we included variables indicating date of the study (1960 = 0), year; whether the wetland was a coastal wetland, coastal; whether the value was an

estimate of producer's surplus, PS; and whether the results had been published, published. The variables *data0*, *theory0* and *metric0*, are dummy variables set at one if the data, theory or econometrics used in the study were deemed highly questionable.⁶

We should recognize that there are certainly important variables that determine a wetland's value that are omitted from our model. Characteristics of the population near a wetland are particularly likely to influence the value placed on the area. However, such data could not be identified in most of the studies; we were unable to include any such variables in our model. While the absence of these variables no doubt greatly diminishes the explanatory power of our analysis, it need not bias the estimated coefficients if these variables are uncorrelated with the included set (Kennedy, 1986).

Our econometric model is based on a maintained hypothesis that measured wetland value

⁶ Since only two studies were deemed weak based on statistical significance, and many studies did not report sufficient information to gauge the statistical accuracy of their estimates, this variable was excluded from the econometric analysis.

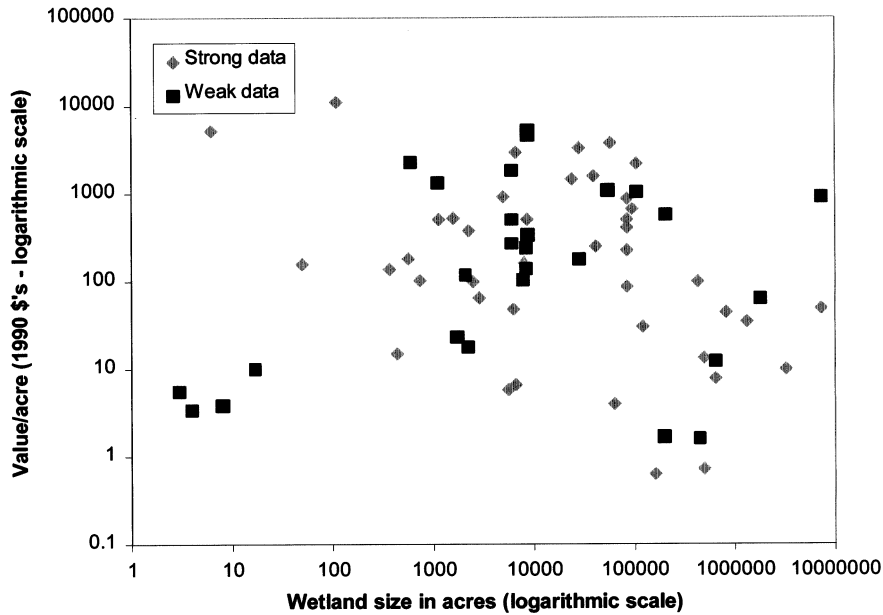


Fig. 4. Wetland area and values.

per acre, y , is a function of the services provided, \mathbf{x}_s , the methodology used, \mathbf{x}_m , the acres of the wetland x_a , other variables describing the study including year and location, \mathbf{x}_0 , and a constant term. The fit was substantially improved by using the logs of both the per-acre value and the acres. Hence, the estimated linear model is

$$\ln(y) = a + b_a \ln(x_a) + \mathbf{b}'_s \mathbf{x}_s + \mathbf{b}'_m \mathbf{x}_m + \mathbf{b}'_0 \mathbf{x}_0 \quad (1)$$

where a is the constant term and the b 's are the estimated coefficients on the respective explanatory variables.

The results of several regressions are presented in Table 2. In each case the hypothesis of homoskedasticity was rejected at the 5% significance level using the BPG test. Accordingly, the standard errors were estimated using White's (1980) correction. Model A presents the estimated coefficients of a model in which it is assumed that the variability in the values is solely a function of the physical characteristics of the wetland systems, ignoring any systematic variation due to the way that the values were estimated. Model B takes the opposite approach, explaining the values based solely on the methods used to measure those

values and the quality of the studies. Model C combines both the characteristics of the sites and variables related to how the values were estimated.

6.2. Do the study quality or valuation method affect the value obtained?

In our discussion of Fig. 1 we argued that there was little evidence of bias as a result of the quality of the studies, and our regression results largely confirm that conclusion. The coefficients on the variables indicating poor quality theory and data are both statistically insignificant, as is the coefficient indicating whether the study was published. However, the variable indicating econometric quality was strongly significant in both regressions B and C. Holding all else constant, the values from studies with poor quality econometrics average 24–50 times greater than those from those with comparatively strong econometric foundations.

Study quality also has important consequences for the confidence we place on predicted values. Using the results from model C evaluated at the

Table 2

Estimated models of the wetland valuation function^a (log of value per acre dependent variable, standard errors in parentheses)

Variable	Mean	A	B	C
Intercept		7.945 ^b (1.07)	6.641 ^b (1.31)	7.872 ^b (1.74)
Year	14.908	−0.052 (0.03)	−0.004 (0.04)	0.016 (0.04)
Ln acres	9.281	−0.168 ^c (0.10)		−0.286 ^b (0.11)
Coastal	0.431	−0.523 (0.71)		−0.117 (0.68)
Flood	0.138	−0.358 (1.03)		0.678 (0.77)
Quality	0.200	1.494 ^c (0.78)		0.737 (0.75)
Quantity	0.062	0.514 (1.60)		−0.452 (1.54)
Rec. Fish	0.354	0.395 (0.55)		0.582 (0.56)
Com. Fish	0.277	0.669 (0.79)		1.360 (1.01)
Birdhunt	0.400	−1.311 ^b (0.49)		−1.055 ^b (0.52)
Birdwatch	0.277	1.704 ^b (0.52)		1.804 ^b (0.59)
Amenity	0.154	−3.352 ^b (0.93)		−4.303 ^b (0.95)
Habitat	0.308	0.577 (0.56)		0.427 (0.59)
Storm	0.031	0.310 (2.37)		0.173 (1.66)
Publish	0.769		−0.669 (0.72)	−0.154 (0.71)
Data0	0.246		0.302 (0.56)	0.000 (0.60)
Theory0	0.215		−1.020 (0.84)	−1.045 (0.84)
Metric0	0.123		−4.030 ^b (1.21)	−3.186 ^b (1.22)
PS	0.277	−2.416 ^b (0.83)	−2.034 ^b (0.72)	−3.140 ^b (0.86)
HP	0.031		0.441 (1.02)	5.043 ^b (1.12)
NFI	0.246		−0.724 (0.82)	0.273 (0.90)
RC	0.277		1.376 (0.86)	2.232 ^b (0.89)
TC	0.108		−1.196 ^c (0.64)	−0.341 (1.05)
<i>n</i>	65	65	65	65
<i>R</i> ²		0.373	0.364	0.582

^a Standard errors were calculated using White's (1980) correction for heteroskedasticity. All results were obtained using Shazam version 8.0 (White, 1997).

^b Significantly different from zero at the 5% level.

^c Significantly different from zero at the 10% level.

means of the variables the log of the wetland value predicted for a high-quality unpublished study is 5.68 with a standard error around the prediction (σ_p) of 0.61. If it is assumed that the study is published, however, σ_p falls to only 46% of the original value. For studies that are weak in the areas of theory or econometrics, σ_p increases by 1.9 or 2.1-fold, respectively. On the other hand, the impact of study's data being of poor quality is slight, leading to a 4% decline in σ_p .⁷ Study quality is important not so much because it might bias results, but because high quality studies lead to a much more precise basis for prediction.

There is some evidence that the method used has a statistically significant effect on the value obtained. As in Fig. 2, in model B we find that CV tends to dominate other methods as the signs on their coefficients are either negative or statistically insignificant. However, when variables indicating the wetland services are introduced in model C, the dominance of CV disappears and the sign on HP and RC methods becomes significantly positive. Hence, relative to these methods, CV studies tend to find a lower value per acre and we cannot conclude that this method is biased relative to the TC or NFI method.⁸

6.3. Do wetlands values exhibit returns to scale?

The coefficient on LnAcres is consistently negative and statistically significant across the models reported in Table 2, indicating significant decreasing returns to scale. However, because of the double-log functional form, the scale effect is extremely small for large wetlands. From Eq. (1), the marginal effect of an increase in the size of a wetland is

$$\partial y / \partial x_a = a_a x_a^{(a_a - 1)} e^{(a_0 + a_s x_s + a_m x_m + a_0 x_0)}$$

⁷ The predicted values and standard errors around the predictor were calculated following Goldberger (1991, p.175).

⁸ The coefficient on the HP method should be interpreted with extra caution since it reflects only two studies in the data set that used this method.

While a negative value for a_a means that an increase in the size of a wetland pushes down the value per acre, this effect diminishes rapidly as wetland size increases. Using the coefficient from model C, a 1% increase in area leads to a 2.9% fall in value for a ten-acre wetland. This effect declines geometrically, and for a wetland of 1000 acres the elasticity is only -0.029 . This confirms what we see in Fig. 4 where wetland area appears to have little impact on value per acre.

6.4. How do wetland services affect wetland value?

The final and central question that we seek to answer is how wetland services influence wetland value. The coefficients on the wetland service variables are estimates of the extent to which the presence of each service changes the value per acre. A very small coefficient on the habitat variable, for example, does not mean that this service has no value, but that the value of wetlands that provide this service are very close to the average value for all wetlands.

Most of the wetland service variables are not statistically significant. In models A and C, only the coefficient on the birdwatch variable is significant and greater than zero while those on the birdhunt and amenity variables are significant and less than zero. Hence, the data indicate that a wetland that provides bird watching opportunities is more valuable than the average wetland, while those that offer bird hunting or amenity services are less valuable.

As one would expect, based on the explanatory variables in the model, only very imprecise predictions of wetland values are possible. Using the estimates from model C, Table 3 presents the predicted values per acre for each possible single-service wetland and 90% confidence intervals around those estimates.⁹ Some strong conclusions can be drawn from the results. Looking not only at the mean, but at the upper and lower bounds of the confidence interval, bird watching and com-

Table 3
Predicted values per acre of single-service wetlands^a

Service	$E[\ln y]$	90% confidence interval around \hat{y} (1990 US\$'s per acre)		
		Lower	Mean	Upper
Flood	5.97	89	393	1747
Quality	6.03	126	417	1378
Quantity	4.84	6	127	2571
Rec.fish	5.88	95	357	1342
Com.fish	6.66	108	778	5618
Birdhunt	4.24	25	70	197
Birdwatch	7.10	528	1212	2782
Amenity	0.99	1	3	14
Habitat	5.72	95	306	981
Storm	5.47	11	237	5142

^a The results presented in Table 3 are obtained from model C. The predicted values are obtained at the means of year and acre variables. Except for the variables indicating the respective services, all other binary variables are set to zero so that the prediction reflects a high-quality CV study estimating consumer surplus.

mercial fishing services are among the highest three valued services while amenity services are the least valued among all wetland services. The confidence intervals are extraordinary, spanning thousands of dollars. Clearly it would be highly speculative to use of a single point from this distribution in a benefits transfer exercise.

7. Conclusions

We have seen that wetland valuation studies are remarkably diverse in terms of the values obtained, the wetlands evaluated, and the characteristics of the studies. Our goal in this study was to isolate the sources of the variability in the wetland value.

There is some evidence that the method employed affects the value obtained. Relative to the HP or RC methods, using the CV method tends to yield a lower estimated value while there is no statistically significant difference between the CV and the TC or NFI methods. While it is perhaps comforting that the method that is used does not appear to be a primary determinant of value, the unimportance of study quality is not so reassuring.

⁹ We emphasize that the values in Table 3 do not represent marginal values and cannot be summed to obtain the value of multiple function wetlands.

ing. As we saw in Fig. 1, the distribution of weak studies is quite similar to that of the values from strong studies. However, econometric quality was found to be statistically significant in Table 2, and studies with weak econometrics tended to yield higher values. Study quality also has a substantial impact on the standard error around our prediction, suggesting that quality is important for the precision of our results.

This leads us to our final point: the use of benefits transfer to estimate wetland values faces substantial challenges. From our analysis it is clear that the prediction of a wetland's value based on previous studies is, at best, an imprecise science. The need for site-specific studies remains. Part of the problem lies in the lack of uniformity across studies. A better understanding of wetland values might be achieved if future researchers follow the suggestions of David (1993) in providing more information about their studies and centralizing the supporting documentation. Until an improved foundation can be established, it is important to emphasize the enormous uncertainties that are present in benefits transfer exercises applied to wetlands. In the interim, our analysis provides some guidance as to the wetland services that are most valuable, and the potential biases of some of the valuation methods.

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