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ANALYSIS

The value of ecosystem services provided by the U.S. National Wildlife Refuge System in the contiguous U.S.

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ABSTRACT

Studies that demonstrate the economic value of the ecosystem services provided by public conservation lands can contribute to a more accurate appraisal of the benefit of these lands. The objective of this study was to estimate the economic value, in real (2004) dollars, of the ecosystem services provided by the U.S. National Wildlife Refuge System (Refuge System) in the contiguous U.S. In order to estimate this value, we determined the ecosystems present on the Refuge System in the contiguous 48 states, the proportion in which they are represented, and the dollar value of services provided by each. We used land cover classes as an approximation of ecosystems present in the Refuge System. In a geographic information system (GIS), we combined land cover geospatial data with a map of the Refuge System boundaries to calculate the number of acres for each refuge and land cover class within the Refuge System. We transferred values for the following ecosystem services: climate and atmospheric gas regulation; disturbance prevention; freshwater regulation and supply; waste assimilation and nutrient regulation; and habitat provision. We conducted a central tendency value transfer by transferring averaged values taken from primarily original site studies to the Refuge System based on the ecoregion in which each study site and refuge was located and the ecoregion's relative net primary productivity (NPP). NPP is a parameter used to quantify the net carbon absorption rate by living plants, and has been shown to be correlated with spatially fungible ecosystem services. The methodologies used in the site studies included direct market valuation, indirect market valuation and contingent valuation. We estimated the total value of ecosystem services provided by the Refuge System in the contiguous U.S. to be approximately \$26.9 billion/year. This estimate is a first cut attempt to demonstrate that the value of the Refuge System likely exceeds the value derived purely from recreational activities. Due to limitations of current understanding, methods and data, there is a potentially large margin of error associated with the estimate.

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1. Introduction

The Refuge System consists of 545 National Wildlife Refuges, 37 Wetland Management Districts (comprised primarily of thousands of Waterfowl Production Areas), and 50 Coordination Areas that are managed by states. The Refuge System covers over 95 million acres in the U.S. and its possessions, including approximately 76 million acres in Alaska (Fig. 1). Its legal mandates make the Refuge System perhaps the premier system of U.S. public lands for purposes of biodiversity conservation and the maintenance of ecological integrity (Fischman, 2003). Most refuges were designated via legislation or executive order. The establishment of a refuge amounts to reserving lands from intensive economic production and recreational activity. Legislation and executive orders may likewise be used to withdraw conservation lands from conservation status. There is a tradition in the fish and wildlife conservation professions of demonstrating the economic values of wildlife-related outdoor activities. This tradition was developed largely for purposes of public education and government budget politics. For example, the Fish and Wildlife Service's *National Survey of Fishing, Hunting and Wildlife-Associated Recreation*, a 5-year report that evolved out of a report issued in 1955, has long been used to educate the public and policy makers on the economic importance of fish and wildlife, and therefore the economic importance of conserving fish and wildlife, and of funding fish and wildlife conservation programs.

In recent years studies have been conducted to demonstrate the value of various public conservation lands to the

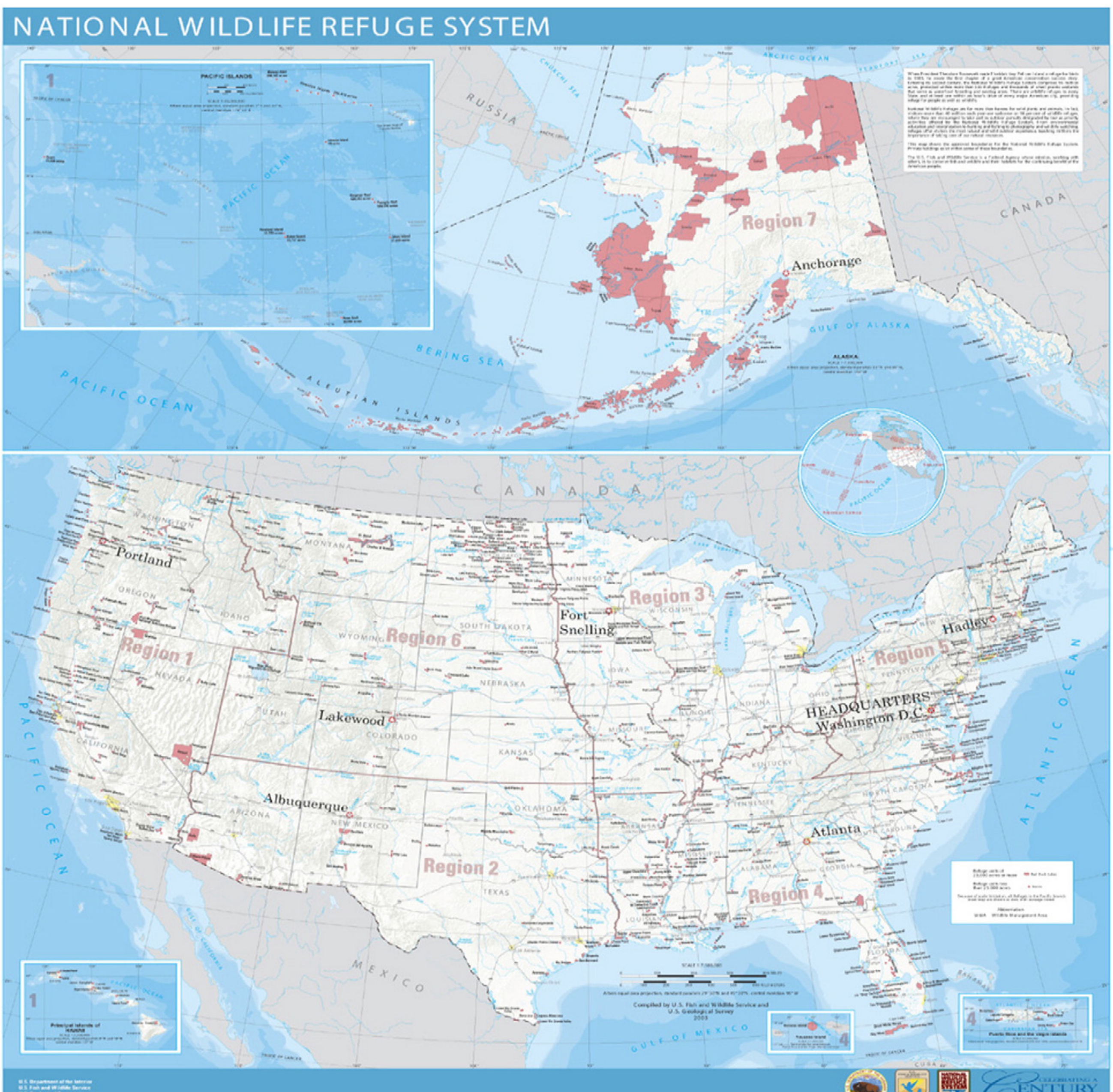

Fig. 1 – National Wildlife Refuge System.

American economy in monetary terms. The demonstration of such value helps to defend the political boundaries of such lands and the maintenance of ecological integrity within those boundaries. The example most relevant to the Refuge System is *Banking on Nature 2004: The Economic Benefits to Local Communities of National Wildlife Refuge Visitation* (Caudill and Henderson, 2005), in which it was reported that nearly 37 million people visited refuges in 2004. This visitation was instrumental in the demand for almost 24,000 private sector jobs and about $454 million of employment income.

Yet these direct use values, expressed in monetary quantities, have long been recognized as only a fraction, and perhaps a very small fraction, of the total economic value of public conservation lands. The development of ecological economics in academia was to some extent motivated out of this recognition (Daly and Farley, 2004). A large proportion of ecological economics studies are designed to estimate the value, in monetary terms, of ecosystem goods and services that are not subject to market transactions and are not, therefore, accounted for in standard measures of national income such as GDP. Our paper represents such a study as applied to the Refuge System. Our objective was to estimate the value, in real (2004) dollars, of the ecosystem services (also referred to as "ecological services") provided by the National Wildlife Refuge System, in a first cut effort to suggest that this value likely exceeds the value derived by studies focusing on recreational activity.

Ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well-being (Boyd and Banzhaf, 2006). Examples include water filtration, pollination, and decomposition of organic waste. A portion of the value of ecosystem services is typically reflected in the market, while another portion is taken for granted, as when payment is made for a harvest of fruit, with no payment made for the essential service provided by pollinators (Daily et al., 1997). This is a common type of scenario in which private goods and services are exchanged in the market while public goods and services are not and are especially subject to overuse or liquidation (Daly and Farley, 2004).

The total economic value of the Refuge System is a combination of direct use, indirect use, option, and nonuse values. Direct use value is benefit derived from direct interaction with the environment, such as the extraction of natural resources or recreation. Indirect use value is the benefit derived from indirect interaction with the environment (often an ecological process), such as water filtration. Option demand refers to a willingness to pay for potential benefits to present and future generations of resources that are nearly or completely irreplaceable, and for which a close substitute is not available (Krutilla, 1967). Nonuse values are benefits derived absent from any interaction with the resource: examples are intrinsic and existence values.

2. Methodology

The Refuge System is divided into seven regions (Fig. 1), with Region 7 encompassed by Alaska and portions of Regions 1 and 4 consisting of remote Pacific islands and Caribbean properties, respectively. We limited our analysis to the contiguous United States, in which 14% of the Refuge System exists.

We estimated values for ecosystem services provided by the Refuge System using benefit transfer, the practice of applying available estimates of the economic value of an ecosystem service to estimate values provided by the same or a "similar" resource in a different context (Smith et al., 1999). This methodology assumes that socioeconomic conditions in the "different context" are similar enough to the original study sites that the transfer will result in a reasonably accurate estimate. We used a value transfer approach, using single point estimates and average value estimates to summarize results of studies and apply them to our policy site, the Refuge System. Benefit value transfer is a common practice in environmental and ecological economics because it is the least time-intensive and data-intensive method for estimating economic values at large or discontinuous policy sites that are not conducive to site-specific revealed or stated preference approaches (Champ et al., 2003). Given that the Refuge System spans a large area, and is composed of relatively small land masses occurring in very different socioeconomic settings, we acknowledge the significant margin of error inherent in our value estimate. Nonetheless, the intent of our study is to demonstrate the likelihood that the total economic value of the Refuge System exceeds the value derived from recreational activity. Additional discussion of limitations to methodology are addressed in the Limitations section of this paper.

Benefit transfer can also be executed through benefit function transfers, or meta-analysis, based on the premise that the study site estimate is a function of characteristics of the study site context (e.g., location, physical features, and climate) and other explanatory variables (e.g., human demography and attitudes) (Champ et al., 2003). In other words, a function value transfer necessitates having access to datasets with a similar set of characters among the study and policy sites, and running regressional analyses to identify significant relationships. We were unable to collect sociodemographic, physical feature and other site-specific information necessary for a benefit function transfer. For this reason, we chose to conduct a benefit value transfer.

When possible, we conducted a central tendency transfer, as some studies have shown this method to perform better than single point transfers (Piper and Martin, 2001). However, we could not always find more than one study meeting our criteria for each ecosystem service valued, thus we did point-transfer some values. We used the following sequence in conducting our central tendency value transfer pursuant to Champ et al. (2003):

1. Define policy context. Definition should include various characteristics of the policy site, what information is needed and in what units.
2. Locate and gather original research outcomes. Conduct a literature review of potentially relevant studies.
3. Screen original research studies for relevance. (How well does original research context correspond to policy context? Are point estimates in the right units, or can be adjusted to right units? What is the quality of original research?)
4. Calculate a measure of central tendency for all of the estimates. Convert each estimate to a common metric. This

average value should be based on those estimates that have the best fit out of the candidate estimates.

5. Transfer the average value estimate. Aggregate the average value to the policy site context by multiplying it by the total number of units, providing a total value estimate for the good or service at the policy site.

2.1. Step 1. Define policy context

Our policy site is the portion of the Refuge System contained within the contiguous U.S. The site is large and discontinuous and there is no comprehensive collection of demographic information for surrounding communities.

In order to accomplish an economic valuation of the ecosystem services provided by the Refuge System, we determined the ecosystems present on the Refuge System, the proportion in which they are represented, and the services provided by each. We used land cover classes as an approximation of ecosystem types present in the Refuge System, and we combined land cover geospatial data with an interactive map of the Refuge System boundaries in a geographic information system (GIS) to calculate the number of acres for each land cover classification within the Refuge System (USFWS, 2001; Vogelmann et al., 2001; Dietz, 2003; USGS, 2003).

For the contiguous U.S., we used 1992 land cover data mapped at 120-meter resolution according to 21 classes based on the National Land Cover Dataset (NLCD). Because most valuation studies did not adhere to as rigorous a land cover classification, we merged these into nine distinct classes: (1) open water, (2) forest (deciduous, evergreen, and mixed forest), (3) shrubland, (4) grassland, (5) wetland (both woody and emergent herbaceous wetlands), (6) planted/cultivated (orchards/vineyards, pasture/hay, row crops, small grains, fallow, and urban/recreational grasses), (7) perennial ice/snow, (8) developed (low and high intensity residential and commercial/industrial/transportation land covers), and (9) barren (bare rock/sand/clay, quarries/strip mines/gravel pits, and transitional land cover) (USGS, 2003).

We calculated the area of each refuge by counting the number of 120 meter grid cells that overlapped between the Refuge System boundary layer and land cover layer (Beyer, 2004). We encountered two overestimation problems with this method. First, the entire area of each refuge border grid cell was counted regardless of whether the intersection of the refuge boundary layer and land cover layer encompassed the entire grid cell or just a small portion. Second, the Refuge System boundary layer included approved land acquisition boundaries for the Refuge System, thereby containing land not currently owned by USFWS. To correct for these overestimations, we calculated the percentage of total overestimated refuge area for each land cover class and then multiplied this land cover percentage by total refuge area reported by USFWS (2004), which resulted in a revised area for each refuge. In making this correction we assumed that each land cover class was represented among the border grid cells and approved land acquisition boundaries in a number equally proportional to its representation in the overestimated total refuge area. Not included in this study are those refuges that were not on the Refuge System boundary layer. These refuges were: Detroit River NWR, Green Bay NWR, Kirtland's Warbler NWR, Northern Tallgrass Prairie NWR, West Sister Island NWR, and Whittlesey Creek NWR in Region 3; Mountain Longleaf NWR and Red River NWR in Region 4; and Back NWR, Blackfoot Valley NWR, Colorado River NWR, Dakota Tallgrass Prairie NWR, Lost Trail NWR, and North Dakota NWR in Region 6. These omitted refuges total 138,936 acres, or roughly 1% of the Refuge System area in the lower 48.

We calculated revised land cover area for each of the six regions in the contiguous U.S. The refuges in the contiguous U.S. include 13.3 million acres, representing about 14% of the total Refuge System area. The land cover distribution was approximately 27% shrubland; 18% wetland; 17% open water; 13% planted/cultivated; 11% grassland; 10% forest; 4% barren; 1% developed; and $<$1% perennial ice/snow.

By assessing land cover at the region level, we were able to distinguish clear differences in the predominance of certain land cover classes in different parts of the country. The results indicated that in both Regions 1 (Pacific) and 2 (Southwest), shrubland accounted for more than half of the acres in each. Planted/cultivated land and forest (80% of which was deciduous) were both almost equally dominant in Region 3 (Midwest). Similarly, forest (76% of which was deciduous) was the dominant land cover in Region 5 (Northeast). Refuge land in Region 4 (Southeast) consisted mainly of wetlands, and Region 6 (Mountain-Prairie) was comprised mostly of grassland. Both total area and land cover composition for Regions 1 (Pacific) and 4 (Southeast) are not complete as the refuges located in Hawaii, Guam, the Pacific islands and the Caribbean islands were not considered in this study.

Once we determined the representation of different land cover classes within the Refuge System, in order to further define the policy context, we focused on these ecosystem services: carbon sequestration, disturbance prevention (e.g., flood control), freshwater regulation and supply, waste assimilation and nutrient regulation, and habitat provision. Because of the complex interdependence of ecosystems, categorization does not imply distinct boundaries. Land cover classes and ecosystem services often overlap and interact on temporal and spatial scales and cannot always be discretely separated from another, nor do all land cover classes provide all ecosystem services.

2.2. Step 2. Locate and gather original research outcomes

Our primary sources for identifying studies were the databases Environmental Valuation Reference Inventory (EVRI, 2004), the New South Wales Environmental Value database (ENVALUE, 2004), and the EcoValue Project of the Gund Institute for Ecological Economics (2004).

2.3. Step 3. Screen original research studies for relevance

We excluded the following categories of studies:

a) Extractive recreation-based studies, such as fishing and hunting
b) Studies focusing on intrinsic value, aesthetic value, existence value or option value
c) Values that could not be converted into $/acre/year
d) Studies that were not conducted in North America

e) Studies that were not specific to a land cover or ecosystem service
f) Studies that were not published
g) Studies that were not original. An exception was made to include a meta-analysis in which statistics were used to aggregate values from multiple studies (Woodward and Wui, 2001), and a study that was national in scope (Goodale et al., 2002).

The studies we included in our analysis used direct market valuation, indirect market valuation and contingent valuation. Direct market valuation relies on the exchange value reflected in our current market (e.g., water supply costs). Indirect valuation is used to reveal value when there is not an explicit market for the services. Factor income demonstrates indirect value by estimating the additional value ecological services provided to the income of particular market activities (e.g. estuaries as nurseries for commercial fish). We chose to include studies based on contingent valuation, which is used to obtain stated value (as opposed to revealed market value) for services by asking individuals a series of questions about willingness to pay or accept payment for changes in service quality (de Groot et al., 2002). Contingent valuation has been upheld by the U.S. Court of Appeals (Loomis and White, 1996), and a NOAA blue ribbon panel commissioned in 1993 found that this methodology can generate valid estimates if it follows best practice guidelines (Arrow et al., 1993). However, incorporation of contingent valuation studies remains highly controversial. While individuals may respond to a questionnaire positively, it has not been conclusively demonstrated that they would support their statements by adjusting behavior or diverting portions of their income. Without this demonstrated connection, the utility of contingent valuation will continue to be debated.

A common methodological concern with aggregation of ecosystem services for valuation is double counting, or capturing different aspects of the same service. We addressed this issue by breaking ecosystem services down into direct and indirect extractive and non-extractive benefits. Further, we only evaluated services that can be considered "joint" or "addable", and are therefore not different aspects of the same service (Brouwer, 2000).

2.4. Step 4. Calculate a measure of central tendency for all of the estimates

We categorized values according to ecosystem service and the associated land cover class (at the study site), and then sorted and averaged values according to ecoregion groupings based on net primary productivity (NPP) values. We included: five studies for disturbance prevention: four associated with wetlands and applying contingent valuation in South Louisiana (Farber and Costanza, 1987), estimating damages prevented in Minnesota and South Dakota (Roberts and Leitch, 1997), estimated avoidance cost in Massachussetts (Thibodeau and Ostro, 1981), and conducting a meta-analyses of studies across the continental United States (Woodward and Wui, 2001); and one with shrubland and grassland based on contingent valuation research in Colorado (Loomis et al., 2000). Two studies for freshwater regulation and supply were included: one for wetlands, applying contingent valuation in California (Pate and Loomis, 1997) and one for open water, which estimated the net operating income of local utilities in Minnesota and South Dakota (Roberts and Leitch, 1997). We included three studies for nutrient regulation and waste assimilation: two for wetlands, one which analyzed averting behavior in municipal wastewater treatment in Louisiana (Breaux et al., 1995) and one that estimated the construction cost of adding a tertiary treatment to an existing plant in Massachussetts (Thibodeau and Ostro, 1981); and one for shrubland and grassland which applied contingent valuation in Colorado (Loomis et al., 2000). Eight studies were included to determine habitat provision values: five within the wetland land cover class, one utilizing dose–response in Virginia (Batie and Wilson, 1978), two applying the production function to determine marginal value to commercial fisheries in Louisiana (Costanza et al., 1989; Farber and Costanza, 1987), one assessing the value of wildlife habitat in North Dakota (Hovde and Leitch, 1994), and one meta-analysis (Woodward and Wui, 2001); and one study each for: forest, valuing habitat provision for salmon (Knowler et al., 2003); open water, applying the production function to determine marginal value of habitat provision to commercial fisheries in Louisiana (Farber and Costanza, 1987); and, shrubland and grassland (Loomis et al., 2000). One study was included for carbon sequestration in the forest and shrubland land cover classes, respectively (Goodale et al., 2002). Note that the Loomis et al. (2000) study addressed multiple ecosystem services in the grassland and shrubland land cover classes. For this reason, the study is separated from the others in Table 1.

2.5. Step 5. Transfer the average value estimate

In Step 1, we determined the land cover composition for each refuge in the contiguous U.S. Because we recognize that ecosystem services are spatially variable, we attempted a means of extrapolation that would approximate the ecological aspect of this variation in value by using a net primary productivity (NPP)-based gradient. NPP is a parameter used to quantify the net carbon absorption rate by living plants (NRC, 2006), and has been shown to correlate with the value of some ecosystem services in populated areas with similar demographics (Costanza et al., 1998). This does not account for variation in value with a high degree of accuracy, as further addressed in the limitations section. In GIS, we determined which ecoregion each refuge was located within (Dietz, 2003; Olson and Dinerstein, 2005). The ecoregions were grouped into 11 categories according to their respective NPP values (Costanza et al., 2004). Each ecoregion group therefore contained several NPP values. Group 1 represents the ecoregions with the lowest mean NPP and Group 11 contains the ecoregions with the highest mean NPP. For example, ecoregion group 2 contains seven ecoregions, with NPP values ranging from 191.79 to 248.14. Within each group, these values were averaged in order to assign a single NPP value to each group (e.g., group 2 is 216.02). Valuation studies that were not national in scope or meta-analyses were then assigned to the ecoregion group in which they were conducted (WWF, 2005). One-hundred percent of a study value was transferred to the ecoregion group in which the study was conducted (Table 1).

Table 1 – Transfer values by land cover class and ecosystem service, according to NPP-gradient ($/year)

	Ecoregion group (average NPP of ecoregions in group)										
	1 (138.23)	2 (216.02)	3 (276.24)	4 (325.99)	5 (365.21)	6 (433.02)	7 (483.56)	8 (508.57)	9 (577.20)	10 (652.12)	11 (722.35)
Land cover class											
Wetland	$2,395.92	$3,723.46	$4,751.15	$5,600.17	$6,268.62	$7,426.34	$8,289.21	$8,716.20	$9,887.92	$11,167.03	$12,366.07
Open water	$82.23	$128.51	$164.33	$193.93	$217.26	$257.60	$287.67	$302.55	$343.37	$387.94	$429.72
Shrubland	$538.80	$551.63	$561.56	$569.77	$576.24	$587.42	$595.76	$599.88	$611.20	$623.56	$635.14
Grassland	$22.80	$35.63	$45.56	$53.77	$60.24	$71.42	$79.76	$83.88	$95.20	$107.56	$119.14
Forest	$845.23	$845.36	$845.46	$845.54	$845.60	$845.72	$845.80	$845.84	$845.95	$846.08	$846.19
Ecosystem service											
Carbon sequestration	$1,361.00	$1,361.00	$1,361.00	$1,361.00	$1,361.00	$1,361.00	$1,361.00	$1,361.00	$1,361.00	$1,361.00	$1,361.00
Disturbance prevention	$644.43	$1,002.84	$1,280.30	$1,509.52	$1,689.35	$2,002.28	$2,235.52	$2,350.93	$2,667.65	$3,013.39	$3,337.48
Freshwater regulation and supply	$696.59	$1,088.61	$1,392.08	$1,642.79	$1,840.43	$2,182.15	$2,436.84	$2,562.87	$2,908.73	$3,286.28	$3,640.19
Habitat provision	$82.82	$112.89	$136.16	$155.39	$170.54	$196.75	$216.28	$225.95	$252.47	$281.43	$308.57
Nutrient removal/waste assimilation	$1,054.54	$1,648.00	$2,107.41	$2,486.95	$2,786.15	$3,303.47	$3,689.03	$3,879.83	$4,403.40	$4,974.96	$5,510.74
Nutrient removal/waste assimilation; habitat provision; disturbance prevention	$22.80	$35.63	$45.56	$53.77	$60.24	$71.42	$79.76	$83.88	$95.20	$107.56	$119.14

In order to determine the value for the other ecoregion groups, the NPP of the site ecoregion was divided by the NPP value of the other ecoregion groups, resulting in a percentage that was then applied to the original value. For example, the Loomis et al. (2000) study valued wastewater dilution, purification, erosion control and habitat provision for shrub and grasslands. The study was conducted in Colorado, which is located within ecoregion group 6. Therefore, the full value of $71.42/acre/year was transferred to group 6. The NPP value of group 6 is 433.02. The following calculation demonstrates the derivation of the value for group 1, which has an NPP value of 138.23:

$$(138.23/433.02) \times 71.42 = 22.80.$$

Meta-analyses and studies that spanned the entire US, such as the carbon sequestration study (Goodale et al., 2002), were not adjusted for change in NPP value.

Carbon sequestration was applied to forests and shrublands, disturbance prevention was applied to wetlands, freshwater regulation and supply was applied to open water and wetlands, habitat provision was applied to wetlands, forest and open water, and nutrient removal and waste assimilation was applied to wetlands. One study addressed nutrient removal and waste assimilation, habitat provision, and disturbance prevention provided by grasslands and shrublands. As previously stated, this is by no means an exhaustive application of all relevant ecosystem services to their respective land covers. When more than one value existed for the same ecosystem service and land cover class (e.g. habitat provision provided by wetlands), we averaged these values prior to the actual transfer. While we were able to average 3 or more studies for most services and land cover classes, a few exceptions exist, for example: (1) We located two acceptable studies for waste assimilation and nutrient regulation in wetlands. 2) We included one study for freshwater regulation and supply provided by wetlands. (3) We included one study for climate and atmospheric gas regulation in temperate forests and other woodlands, and this study was transferred across all ecoregions for its respective land cover classes.

The study we used to transfer carbon sequestration values to the forest and shrubland land cover classes utilized national forest inventory data to calculate the net change of carbon stocks in live vegetation, dead organic matter, and forest products (Goodale et al., 2002). We multiplied these values by $11.30/ton, the mid-price value of Carbon Dioxide emissions on the European Union Emissions Trading Scheme (EU ETS), in order to calculate the transfer value for carbon sequestration per acre per year (The Katoomba Group, 2007).

3. Results

We calculated the total value of ecosystem services provided by the National Wildlife Refuge System in the contiguous U.S. to be $26.9 billion/year, or $2.4 thousand/acre/year. We separated the results by land cover classes and Refuge System Regions (Table 2).

Wetlands provided the largest portion of the calculated total ecosystem services value for the Refuge System, estimated at $22.9 billion annually or $8.8 thousand/acre/year. We included the most studies for wetland habitats, and therefore were able to attribute the most services to this land cover. Additionally, the values associated with the services in this land cover were disproportionately large. For example, one study estimated the value of nutrient removal/waste assimilation at $4529.26/acre/year, converted to 2004 dollars (Thibodeau and Ostro, 1981), while another valued freshwater regulation and supply at $2287.99/acre/year, converted to 2004 dollars (Pate and Loomis, 1997). Region 4 (Southeast) accounted for 73% of this wetland value. This is a highly productive region, and therefore has a high NPP value associated with it. The bulk of wetland studies were located here, and with 1,663,514 acres of wetland habitat,

Table 2 – Ecosystem service values by land cover class and region ($/year in thousands)

Land cover class	Region (acres)						Total
	1 Pacific (3,383,793.11 ac)	2 Southwest (2,413,706.05 ac)	3 Midwest (592,449.35 ac)	4 Southeast (2,930,741.25 ac)	5 Northeast (298,294.78 ac)	6 Mountain-Prairie (1,670,244.14 ac)	
Open water (1,616,085.34 ac)	$44,715	$41,078	$20,670	$309,024	$14,342	$37,625	$467,454
Forest (1,116,180.15 ac)	$123,964	$71,441	$192,728	$330,507	$117,317	$108,031	$943,988
Shrubland (4,575,874.67 ac)	$1,417,146	$958,823	$473	$2,094	$255	$139,944	$2,518,735
Grassland (1,385,381.63 ac)	$12,603	$11,688	$400	$1,403	$0.00	$45,148	$71,242
Wetlands (2,595,706.90 ac)	$1,176,292	$2,055,602	$1,668,501	$16,742,893	$619,927	$697,446	$22,960,661
Total (11,289,228.69 ac)	$2,774,720	$3,138,632	$1,882,772	$17,385,921	$751,841	$1,028,194	$26,962,080

this region has by far the most wetland acres of all regions, accounting for the significant percentage of total wetland value. Forest values across all regions totaled $94.4 million/year or $8.5 hundred/acre/year, with Regions 4 (Southeast) and 3 (Midwest) accounting for 55% of this value. Carbon sequestration and habitat provision were the only services valued for the forest land cover class. Open water provided a total of $467 million in ecosystem services annually, or $2.9 hundred/acre/year, with Region 4 (Southeast) accounting for 66% of this total value. Freshwater regulation and supply was the most highly valued service related to open water. Shrubland contributed $2.5 billion/year or $5.5 hundred/acre/year in ecosystem services. Regions 1 (Pacific) and 2 (Southwest) provided the most significant amount of value within this land cover class. The total value of services provided by grassland across all regions was $71.2 million/year or $51.40 acre/year. Region 6 (Mountain-Prairie) accounted for 62% of this value. Only one study (Loomis et al., 2000) was applied to this land cover class. In recent years significant research has been done to quantify the carbon sequestration value of grasslands, and therefore, the true value of services provided by this land cover class is likely much higher than our estimated value.

The estimated value of carbon sequestration services provided by the Refuge System within the contiguous United States was $3.3 billion/year. This service was applied to the forest and shrubland land cover classes. Disturbance prevention accounted for $6.2 billion/year, and was applied to the wetland land cover class. Freshwater regulation and supply was estimated at $6.5 billion/year, and was applied to open water and wetlands. Habitat provision accounted for $562.6 million/year of the estimated value, and was applied to wetlands and forests. Nutrient removal and waste assimilation was the highest valued service provided, accounting for $10.2 billion/year of the total estimate. This service was applied to wetlands only. One study that provided a value for wastewater dilution/purification, habitat provision and erosion control was applied only to shrubland and grasslands (Loomis et al., 2000). These three services were valued at $228.8 million/year.

Given that the application of net primary productivity is a first brush attempt to account for ecological variation, and does not have adequate precedent, total value for the Refuge System was also estimated without this variable. The estimated value of Refuge lands analyzed without NPP variation was $24.8 billion/year, or $2.2 thousand/acre/year.

4. Application of results

Our ecosystem service values may be used in tandem with direct use values, hedonic values, amenity values and passive use values toward estimating the total economic value of the Refuge System. Aiken and La Rouche (2003) attempted to quantify the direct use value of the Refuge System by reporting state estimates of net economic value of fishing, hunting and non-residential wildlife watching. Measured in annual value per participant, their data are not presented in a format that is readily compatible with ours. Caudill and Henderson (2003) also estimated recreation-related direct use values for the Refuge System, incorporating the income and employment effects recreational visitors have on the economies of local communities surrounding refuges. Fifteen sample refuges were considered with regard to hunting and fishing programs, along with the impact of "ecotourism," or non-consumptive use. Their results found $809.2 million in sales/year for over 35 million visitors from entrance fees, nearby lodging costs, and purchases from local businesses. This total figure was determined by extrapolating the data from the fifteen sample refuges to the entire nation.

While our nationwide ecosystem service values may be used in tandem with Caudill and Henderson's recreation-related direct use values toward a total valuation of the ecosystem services provided by the Refuge System, combination of these two studies would not lead to a total valuation of the Refuge System in the contiguous U.S. A total value would include the services omitted from our analysis, property value amenity premiums associated with the system, scenic amenities, the contribution of the refuges to the preservation of biodiversity and passive use values.

Ecosystem services are provided at different spatial scales, and questions remain about whether local or national (or the global economy) benefit the most from specific ecosystem services. Of particular interest are the values based on carbon sequestration. It can be argued that the value derived from the forest and other woodlands' ability to sequester carbon benefits the global economy to a greater extent than the U.S. economy. We do not offer an answer to this question, but it is clear that ecosystems and the services they provide do not adhere to regional and national boundaries.

5. Limitations and opportunities for future research

5.1. *Methodology*

Our methodology was based on creating a matrix of Refuge System land cover area and ecosystem service values. Consequently, we were limited to studies that provided values on a per-area basis, or that included enough information for us to calculate the per-area value. Therefore, we were unable to locate ecosystem service values for all services and land cover classes. We recognize that the number of studies used is small, and may therefore lead to large errors in our resulting value estimates. Arguably, less rigorous standards of acceptance may have lead to a more defensible estimate. In addition, with the exception of the meta-analysis (Woodward and Wui, 2001) and national study (Goodale et al., 2002), the scale of the site studies was one or two states. It is not likely that values derived at this scale would maintain the same value per acre when scaled up to the Refuge System in the coterminous United States. There is significant skepticism about the methodology in these types of studies, and issues of scale and spatial distribution are often at the heart of this concern. Site studies and meta-analyses alike will be most accurately applied when they give specific information about the scale, spatial distribution, and sociodemographic conditions of their study. Likewise, databases that serve as sources of values for benefit transfer studies would be improved by including this information, as well as clear statements as to how each study defines their respective ecosystem service.

Benefit transfer is the subject of substantial criticism (Brouwer, 2000), and there is high spatial variability of service values, thus, conducting benefit value transfers to a large and discontinuous site is certainly less accurate than a benefit function transfer or more rigorous modeling approach. The intent of the study was not to derive an inarguably accurate or precise value of the ecosystem services provided by the Refuge System, rather to offer a first approximation to be used as a reference point for policy and management decisions, and to demonstrate that the total value is likely much higher than values based solely on recreational use. Additionally, while there has been research conducted demonstrating some correlation between ecosystem service provision and NPP (Costanza et al., 1998), this link is not adequately developed or supported by the scientific community. A variation in NPP is more closely related to ecosystem functions than values, as the latter depends on sociodemographics and scarcity. Additional research is needed for more accurate and precise value estimates that apply specifically to the Refuge System.

Our estimated value may be biased downward because of the lack of original valuation studies or transferable values for many ecosystem services and for most land cover classes. Shrubland, wetland, and open water are the predominant land cover classes for the refuges in the 48 contiguous states with 27%, 18% and 17% coverage respectively. Therefore, these classes should receive priority for future valuation research. Wetland valuation studies were well represented in the literature relative to all other land cover classes. However, the wetland studies typically focused on habitat provision services with little attention given to other wetland ecosystem services. Also, the wetland valuation studies we reviewed often did not distinguish between open fresh water and open salt water and between saltmarsh and freshwater wetlands. Such distinction would increase the precision of the values transferred.

5.2. *Regions*

At the inception of this study, we intended to include a valuation of the Refuge System land in Alaska. Alaskan refuges account for 83% of total Refuge System area, and certainly provide a significant portion of the value of ecosystem services. We were unable to locate any original site studies conducted in Alaska, and due to the differences in land cover class, we chose not to transfer ecosystem service values to this region. The only values we deemed appropriate for transfer to Alaska were for climate and atmospheric gas regulation. Refuges in Alaska provide additional ecosystem services and the lack of transferable values almost surely resulted in a significantly underestimated value. We had to consider the possibility that a severely underestimated figure could be used in cost-benefit analyses and policy decision-making to the detriment of the Refuge System. Therefore, we chose not to include refuges in Alaska in our final analysis.

5.3. *Pollination*

Rigorous estimates of pollination values are rare, and we did not include pollination values in our study. Pollination services are important to ecological communities and economies, but ascertaining the value is fraught with numerous methodological difficulties. Pollination services are getting more attention, however, as invertebrate and vertebrate pollinators decline. Feral and managed honey bee colonies in North America have dropped by 25% since 1990 (Allen-Wardell et al., 1998). In order for pollen vector species to succeed at pollination, they require habitat in which to nest or roost and forage for alternate food sources.

The majority of pollination valuation studies focus on honey bee populations. Southwick and Southwick (1992) compared the yields of agricultural crops pollinated by bee colonies with the yields of those not pollinated by bees, taking into consideration the availability of alternate and wild pollinators in their estimate. While the value given was per acre of agricultural cropland, Southwick and Southwick (1992) measured the habitat provision value of habitat adjacent to the cropland. Therefore, to accurately transfer the value derived, we would have needed additional information: the number of bees needed to pollinate the acres of cropland adjacent to refuge land; and how many acres of refuge land is necessary to provide habitat for these bee populations. This remains one of the most significant pollination valuation studies, but it does not address the area requirements of crop pollination.

Since our study in 2004, there have been some advances in this area. Ricketts et al. (2004) took an innovative approach toward addressing this issue. They found that coffee yields were increased near patches of forest that provided habitat to wild bees. Ricketts et al. (2004) were also able to correlate the quality of coffee produced with proximity to forested areas. Their study took place in the tropics, so we did not transfer the values to any of the Refuge System. However, it stands out as a good example of how future pollination valuation studies may be conducted and applied. Additionally, Kremen et al. (2004) investigated variation in crop pollination services by unmanaged bee colonies along a gradient of access to natural habitat, and were able to predict the area necessary to provide varying levels of pollination services. The value of pollination services is immense, not only to the agricultural sector, but also to flora communities that do not fit into the standard definition of "economic species." Development of methodologies for quantifying the value of pollen vectors to non-market flora communities is necessary and will provide a valuable addition to market ecology discussions.

5.4. *Value at the margin*

A basic principle of economics is that rational people make decisions "at the margin." For example, the price a person will pay for a cone of ice cream generally diminishes with each cone eaten, because the marginal value diminishes. Many have argued that ecosystem service valuation studies do not always measure at the margin. A major criticism of Costanza et al's (1997) Nature article (considered a bellwether article on ecosystem services valuation) was that by valuing all of the world's ecosystems, they effectively removed any ability to make a decision at the margin and therefore the ability to assign a legitimate price. For example, if all of the world's ecosystems were to suddenly disappear at once, their value would be immeasurable. Our study avoids this issue, as the Refuge System comprises a small percentage of undeveloped land area in the coterminous U.S. The area of Refuge land we studied was 22.6 million acres or 1.4% of the 1.6 billion total acres of undeveloped (the sum of grasslands, shrubland, forest, wetlands, open water, barren, and perennial ice/snow) land in the contiguous U.S. However, the value estimated in this study is still a total value, not a true marginal value.

Another critique of similar valuation studies is the influence that spatial scale of measurement has on ecosystem service values. Konarska et al. (2002) compared two land cover datasets: one with 1-kilometer resolution and another with 30-meter resolution. They found that the total value of ecosystem services in the contiguous U.S. to be 200% greater using the finer resolution, mostly attributable to the increased capture of wetland area. We used 120-meter resolution land cover data and the majority of values transferred were to the wetland land cover class. Therefore, it is probable we would have derived a more accurate measure of ecosystem service value were we to have used the finer-resolution data. Ceteris paribus, the relatively coarse resolution of the land cover probably resulted in a conservative estimate of the value of ecosystem services provided by the Refuge System.

6. Conclusion

The Refuge System is perhaps the premier system of U.S. public lands for purposes of biodiversity conservation and the maintenance of ecological integrity (Fischman, 2003). Biodiversity conservation and ecological integrity are never guaranteed for perpetuity, however, and require continual attention to threats, as well as increased knowledge and understanding of the benefits that are provided by these lands. While economic valuation of the ecosystem services provided by public conservation lands is useful in protecting boundaries and maintaining conservation status, such valuation does not necessarily lead to protective actions. Getting the prices right requires increased knowledge about ecological processes and functions, and valuation methodologies that accurately reflect sound biological science and economics.

In this study, we estimated the total value of ecosystem services provided by the Refuge System in the contiguous U.S. to be approximately $26.9 billion/year. We have discussed several limitations of our methodology; however, the intent of the study was not to derive an inarguably accurate or precise value of the ecosystem services provided by the Refuge System, rather to offer a first approximation to be used as a reference point for policy and management decisions. Our hope is that this coarse approach may highlight an area that warrants further, more rigorous examination. Widespread knowledge of this value and the method by which it was estimated will help to protect the Refuge System, assist in management and policy decision-making by emphasizing that the total value of the Refuge System likely exceeds that of pure recreational value, and identify those areas in ecosystem service valuation research that could benefit from further study.

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