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METHODS

Deriving values for the ecological support function of wildlife: An indirect valuation approach

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Abstract

We describe a method that combines economic willingness-to-pay estimates for higher trophic-level species with basic information available about ecosystem relationships to derive estimates of partial willingness-to-pay for lower level species that might be of direct policy interest. This method is intended as a quasi-benefit transfer method for use in benefit–cost analysis. Our method makes it possible to establish partial willingness-to-pay estimates for the large number of species of immediate or potential policy interest using only data available in non-market valuation and biology and ecology literature. We provide a partial estimation of indirect values for the predator–prey relationships that support golden eagles in the Snake River Bird of Prey area as an example of how to operationalize our approach.

Keywords: Valuation; Eagles; Ecosystem services; Predator–prey

1. Introduction

Valuation of wildlife–particularly estimation of non-use and non-consumptive use values for wildlife–is an important input into various policy decisions. Willingness-to-pay estimates for wildlife form inputs to many policy analyses in areas such as National Park and Forest planning, waterway projects and recreation policy. In these areas and others, understanding societal willingness-to-pay for wildlife is essential to fully understanding the benefits and costs of policy options under consideration.

In addition to the areas in which wildlife valuation currently plays a role, there has been recent interest in expanding the use of information regarding willingness-to-pay for wildlife to other areas. The U.S. EPA (2003) recently announced its interest in better understanding the benefits of its environmental protection policies on ecosystems. One component of this understanding, and an important but rarely quantified element of the benefits of environmental regulations, is an understanding of willingness-to-pay for wildlife preservation. When linked to an understanding of how reductions in emissions to air, land and water

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will help reduce damage to wildlife, this valuation information will allow direct consideration of benefits in terms of wildlife preservation in the benefit–cost analysis of environmental regulations.

Another area in which willingness-to-pay estimates for wildlife could be important is direct protection of endangered species. Although current listings and species recovery plans under the Endangered Species Act (ESA) rarely contain direct consideration of benefits and costs, some proposals for reauthorization of the ESA have included provisions calling for some examination of benefits and costs in future ESA decision making. In addition, decisions regarding the extent of designation of critical habitat currently allow for balancing of benefits of cost–an opportunity that could be used more often were willingness-to-pay estimates available for more species of policy interest. Given these considerations, willingness-to-pay for wildlife may become increasingly relevant to endangered species policy.

While we provide several reasons above for desiring willingness-to-pay estimates as policy-making inputs, there are important limitations that make it difficult to use common methods for estimating such values to produce all of the estimates needed. In general, the contingent valuation method (CVM) is used to estimate non-market values for recreational use and direct use as well as non-use values, while the travel-cost method can also be employed to estimate recreation use values. Contingent valuation is generally the method used to estimate willingness-to-pay for protection of well-known wildlife species. The contingent valuation method requires a significant expenditure of both time and money in order to estimate willingness-to-pay for a single species of wildlife. There are approximately 22,000 species of plants and animals currently in the U.S. (Heinz Center, 2002), each is of potential policy interest, and 1265 species are currently considered endangered or threatened (USFWS, 2004) and thus of identified policy interest. Arrayed to estimate values for this large number of species is a handful of contingent valuation practitioners and a limited pool of time and financial resources.

CVM may allow us to estimate these values for the ecosystem support function of wildlife along with other direct use and non-use values. In some cases, particularly where the relationships in the ecosystem are well understood by the general public, the willingness-to-pay estimate yielded by CVM research would include such support functions. Where the relationships are relatively simple, the CVM survey could include discussion of the relationships as part of the description of the good being valued. However, many of these support relationships are not widely understood and are often too complex to describe to survey respondents. In these cases, it cannot be assumed that the CVM-derived willingness-to-pay will include such values. At the same time, adding sufficient information to the CVM survey to allow for the inclusion of these values in the willingness-to-pay estimate would, in many cases, make the instrument so long and difficult to understand that it would significantly increase non-response to the survey.

Given these resource constraints and the large number of species of potential or immediate policy interest, it is useful to devise a method to utilize currently available information to estimate at least partial willingness-to-pay for a large number of wildlife species. One approach to doing this was proposed by Goulder and Kennedy (1997), who argued that we can use ecological models to map changes in lower trophic level species to effects in terms of change in populations of higher trophic-level species for which we have willingness-to-pay estimates. In this way, we might analyze all effects on ecosystems in terms of species for which we have already established willingness-to-pay estimates. This approach is probably the best way to assess ecosystem benefits and costs.

Unfortunately, we do not presently have sufficient understanding of most ecosystems in which we might be interested to allow for directly modeling changes in prey species in terms of effects on predator species. The costs in time and money of gaining a full understanding of a particular ecosystem and the constraints on both of these resources that usually face a policy maker trying to assess a particular decision make it necessary to investigate alternative approaches that use information currently available to estimate willingness-to-pay for the support roles of wildlife. As we show below, however, we do have enough information to reverse this process and derive values for the lower level species from knowledge about the top-level species for which willingness-to-pay estimates already exist.

In this paper, we describe a method that combines economic willingness-to-pay estimates for higher level species with basic information available about ecosystem relationships to derive estimates of partial willingness-to-pay for lower level species that might be of direct policy interest. In so doing, we provide a benefit-transfer method to establish partial willingness-to-pay estimates for the large number of species of immediate or potential policy interest for which direct contingent valuation method estimates are not available. Our method allows us to estimate willingness-to-pay with a level of ecosystem function information far less than what would be required to fully model the effects of changes in one species in the system on other species.

2. Theoretical approach

Considering any ecosystem, the change in a predator species' population in response to a change in its prey is defined by a function known as a numerical response function (Begon et al., 1990). The most common such functions used in ecology are either linear functions or a functional form called a ring function. In a numerical response function, for a change in prey x, the change in predator population y is defined by the current populations of x and y—in other words, the response to a change in prey populations is a function of all relevant populations including the number of members of the predator population of interest (Abrams and Ginzburg, 2000), so that:

$$\frac{\mathrm{d}y}{\mathrm{d}x}=f(y,x). \tag{1}$$

Whichever form the particular numerical response takes, the full response of an hypothetical ecosystem containing prey a, b and c and predator y can therefore be described by a system of equations:

$$\begin{aligned}\frac{\mathrm{d}y}{\mathrm{d}a}&=f(y,a)\\ \frac{\mathrm{d}b}{\mathrm{d}a}&=f(b,a)\\ \frac{\mathrm{d}c}{\mathrm{d}a}&=f(c,a)\\ \frac{\mathrm{d}y}{\mathrm{d}b}&=f(y,b)\\ \frac{\mathrm{d}y}{\mathrm{d}c}&=f(y,b).\end{aligned} \tag{2}$$

In other words, the system would respond to a change in any prey item through a dynamic system of adjustments through which both predator and other prey populations would react until a new equilibrium state was reached. The key point in this discussion is that the complete relationship set can be complex, thus, the difficulty in modeling ecosystem responses in each new system of policy interest and the need for an alternative indirect value estimation procedure such as the one proposed in this paper.

Unfortunately, for almost all ecosystems that might be of interest to us for policy purposes, we do not currently have enough information to define the system of response equations and, thus, the dynamic adjustment process that would occur when our actions affected a particular species in the system. If we did have sufficient information to model the system to this extent, we could simply estimate the changes in populations of known value species caused by the effects of policies on unknown value species and arrive at a reasonably complete estimate of society's willingness-to-pay based on willingness-to-pay for the anticipated effects on known value species. As we stated earlier, this mapping of effects into previously estimated species could be seen as the preferred approach but because it is not possible in the vast majority of policy relevant systems at this time, an alternative estimator is necessary.

Our approach is the reverse of what we would contemplate if we could fully model the ecosystem. That is to say that rather than map all changes in the unknown value species populations to effects on known value populations, our method allows us to transfer a portion of the willingness-to-pay for the known value wildlife to each of the species that supports it and, thus, to define partial willingness-to-pay estimates for wildlife of policy interest without conducting a full contingent valuation method study to estimate the values of each prey species.

We begin by considering three types of value that would create societal willingness-to-pay for a species. Consumptive use values (Goulder and Kennedy, 1997) would include the harvesting of fish and game for either recreation or food supply. Many of these consumptive uses have associated market prices; others may require valuation studies using either travel cost or contingent valuation methods. Non-consumptive use (Goulder and Kennedy, 1997) and non-use values (Champ et al., 2003) might include bird watching as an example of the former and the value of bequeathing the availability of the species to the next generation as an example of the later (i.e., "non-use" value includes what are may be thought of as intrinsic or existence value). The former type of value might be estimated using the travel cost method while the latter is a common target for contingent valuation method estimation. A final category of value is indirect value—that is, value derived from a species' function in providing food or other support for one or more other species for which society holds direct use or non-use value (Goulder and Kennedy, 1997).

It is at this third type of value, indirect value in support of other species that our technique is aimed. Our technique is similar to a production function approach to hedonic price estimation; we are using a known full value and characteristics to estimate part-worths. Our technique allows the estimation of part-worths from known data in order to arrive at a partial estimate of the total willingness-to-pay for the species of interest. Obviously, our estimated partial value excludes potentially important use and non-use components of value from the prey species itself. However, our estimate has the dual advantages of being possible for many species using existing data and–we expect–capturing much of the value of a number of species that do not have significant direct use or non-use values themselves, thus making our technique a useful tool to estimate willingness-to-pay for policy analysis purposes.

3. A stylized example

The fundamental argument of this paper is that we can examine the willingness-to-pay for a predator in the same way that we would for any good, that is, that the willingness-to-pay must be a statement of value for the entire system that results in the production of the final good. The crucial point is that for a market good, the individual does not need to understand the production process that leads to the final good she simply pays a price for the good which then is then used to pay for all of the inputs and prior processes. Similarly, an individual does not need to understand the complete ecological system supporting a given predator—her statement of value regarding that predator is a statement of value regarding the entire supporting system.

To examine the question in a way that allows us to begin to discuss the technique for actual calculation of the partial values, let us examine predator A. Predator A's value may be attributed to a group of species that support it. This is to say that a person's willingness-to-pay for a particular species must, by the very nature of the predator species' complete dependence upon prey species for its existence, be a willingness-to-pay for the system that supports it. We may therefore "move" that value down a trophic level and use these the direct willingness-to-pay for the predator to estimate the indirect value that society holds for each of the prey species of predator A for their role in supporting predator A. Supposing, to simplify matters, that species A relies on three species x, y, and z and defining term s to mean indirect value (as described above), we define Eq. (3):

$$\text{WTP for A} = (sx + sy + sz). \tag{3}$$

The partitioning of the directly estimated (either from CVM or market prices) willingness-to-pay for a predator into indirect values for its supporting prey begins by defining an energy relationship between predator and prey. We can do this by using the biology and ecology literature to establish both the energy requirements of the predator population and the portions of that energy provided on average by members of each of its direct prey species. It is important to use an average energy contribution in order to control for seasonal, annual and multiyear cycles in the predator–prey relationships. Our technique aims specifically at informing policy decisions that will alter–in a long-term manner–the energy available in the system (in the form of numbers of one or more species of interest). If we use only point estimates of energy relationships, we risk mischaracterizing the relationships as they exist the in time periods in which the policies will affect them.

In the same manner, using long-term energy relationships allows us to examine the effects of policies in what is effectively a comparative-statics framework. This is to say, we examine the pre- and post-policy states based on the relationships that exist before any action is taken. This approach makes our estimation procedure analogous to those used for estimating the other benefits and costs in most policy analyses. While we know that the adjustment of an ecosystem to perturbations will be dynamic, if we know that the final result of a policy is the long-term loss (or gain) of energy in support of predators for which willingness-to-pay has been directly estimated, we may proceed to use this information to estimate willingness-to-pay for those gains or to avoid the losses. The only case in which this does not hold is when the impact of the actions under consideration is so severe that it causes a fundamental reordering of the ecosystem (e.g., transformation of a forest to grassland or restoration of a wetland). In those cases, the data available (observations on existing relationships) would not provide a useful approximation of the relationships (indeed for the species present) in the new ecosystem.

We can define the current energy relationship in terms of a simple linear function where the energy required to sustain a predator is equal to the sum of the products of the net energy gained from consuming a prey item (itself a function of prey energy content and energy required to find, capture and consume the prey) and the quantity of that prey item consumed. Eq. (4) is an example of the functional form in question:

$$\text{Predator energy} = aX + bY + cZ \tag{4}$$

where a is the energy contribution of X, b is the energy contribution of Y, and c is the energy contribution of Z.

The specification presented may be used for either a single predator or a predator population. Other considerations discussed later, most particularly that willingness-to-pay estimates in the existing literature are most often found for a population rather than a marginal individual, will cause us to look at this problem at the predator population level. As will be seen in the next paragraph, however, the ratios of the energy contributions are the important information in Eq. (4) and these ratios are constant between single predator and predator population sizes (though the magnitude of both of the two terms forming the ratio is obviously much larger for the entire predator population).

We now assume that, over the long term, predator populations tend to maximize their size relative to the energy available to them. This is somewhat similar to the ecological concept of optimal foraging (see Begon et al., 1990 for more on optimal foraging), but rather than attempt to explain the behavior of a particular predator, we are invoking a similar concept to describe the long-term behavior of an entire population—that the population tends toward an energy-maximizing prey mix. We can combine this assumption about the natural system under examination with a constraint from the nature of indirect values. The indirect values of all of the prey items used to support an individual predator must equal our willingness-to-pay for that predator (they cannot exceed the predator value and since the value is assigned to the system cannot be more than our value for the predator).

Combining the maximization of predator energy maximization problem with the willingness-to-pay constraint on indirect values, we arrive at the problem specified in Eq. (5).

$$\max\ aX + bY + cZ \ \text{s.t.}\ \text{WTP}_{\text{predator}} = I_aX + I_bY + I_cZ \tag{5}$$

where a, b, and c are net energy terms for each prey item; X, Y, and Z are the three prey; I_x is the indirect value calculated for each prey species.

Setting up the appropriate Lagrangian equation, taking its first-order conditions and doing some simple algebraic rearrangement of terms leads us to the set of equalities described in Eq. (6).

$$I_A/I_B = a/b$$

$$I_B/I_C = b/c. \tag{6}$$

In this equation, the I values are the indirect values of each prey species of interest—these are the values that we are attempting to estimate with our technique.

If we examine the price-ratio to productivity ratios derived in Eq. (6) we have the foundation of a derived set of indirect values that we are seeking in this analysis. All that is left is for us to reintroduce the concept behind the constraint in Eq. (6) and the basic concept behind our search for indirect values in total—that the indirect values for the prey of a particular predator must sum to the willingness-to-pay for that predator. We thus have the system of equations shown in Eq. (7).

$$I_A/I_B = a/b$$

$$I_B/I_C = b/c$$

$$\mathrm{WTP}_{\mathrm{predator}} = A^*I_A + B^*I_B + C^*I_C \tag{7}$$

where I_X is the indirect value assigned to prey species X; a, b, and c are the net energy terms for each prey item; and A, B, and C are the annual consumption by the predator population of each prey item.

We have now derived a system of equations of number exactly equal to the number of I_X indirect values in which we are interested. This system may be solved to identify the indirect values for all of the prey species supporting our known-value predator.

Attention should be paid to the fact that, for a particular prey species of policy interest, the indirect value thus derived from a single predator–prey interaction will represent only a fraction of even the total indirect value of each prey species. When using our method for estimating partial willingness-to-pay via indirect values, it is important that the analyst repeat the process discussed above for all of the known-value predators that the prey population of policy interest supports.

The question now becomes one of how to aggregate the indirect values for consumed prey into a willingness-to-pay estimate for an entire population, or for individual examples of a population given uncertainty about their fate. To be more specific, we have shown how to derive indirect value for those individuals of a particular prey species consumed by the known value predator species. From the perspective of the policy-maker it may be uncertain which of several possible predators are supported by particular members of the prey species being affected by the policy under consideration. We therefore adopt a weighted average approach to aggregating indirect values into a single indirect willingness-to-pay estimate for policy purposes. For example, if prey X that feeds three predators, then we would use the proportion of total number of X consumed by each predator to construct a weighted average indirect value as shown in Table 1 below.

Table 1
Example of calculating a predation-weighted indirect value

Predator	Indirect value of prey X to predator	Number of X consumed/ year	Proportion of indirect use of prey X	Weighted indirect value
1	\$200	25	0.25	\$50
2	\$50	50	0.5	\$25
3	\$75	25	0.25	\$18.75
			Predation-weighted-average indirect value	\$93.75

For this simplified case, the indirect willingness-to-pay estimate for X would be \$93.75. It is important to note that not all individual members of any prey population of policy interest will be consumed by a predator (some may die from other human action and some from natural causes). Because of this, the predation-weighted-average approach that we propose likely somewhat overestimates the indirect value of a particular prey. Offsetting this concern are two factors. First, because policy decisions will have long-term effects on the prey populations, it is likely that, over the life of the policy, the change in prey numbers caused by the policy will directly affect predator populations and thus our indirect values are a valid way to quantify these effects. Second, if the reader will recall Eq. (3), the indirect value that we derive in this paper is only a part of overall willingness-to-pay for a species. Thus, while the weighted-predation-average approach to indirect value may overestimate the indirect component of value, this component is still almost certain to be only a lower bound for total willingness-to-pay. We also recognize the derived values will only be as accurate as the underlying willingness-to-pay estimates and biological data are. However, we believe that providing policy makers with even rough estimates of relative values of these prey species is better than not estimating any value because policy-makers would otherwise use an implicit value of zero in their decision making.

4. Empirical example

In this section, we provide an empirical example of our technique for deriving indirect values using an example predator–golden eagles in the Snake River Basin of Idaho–and its supporting prey populations.

This example describes the process that an analyst interested in valuation of various eagle prey in this area might undertake in evaluating a policy that would not directly affect the golden eagle populations, but rather the habitat of their prey species.

We examine the biology and ecology literature to provide the reader an example of where one might find the information necessary to estimate Eqs. (4) and (7) and how to conduct the calculation. We then perform the calculation process and provide partial indirect values for each of the relevant prey species. These values, in conjunction with other indirect values from other known-value predator populations can provide a partial estimate of societal willingness-to-pay for each of the prey species examined here.

From the available ecology literature (Collopy, 1983), we identify the five major prey items for the Snake River golden eagle population. Collopy reports five eagle diet estimates from several different years. Combining this information with an estimate of an eagle's annual caloric needs found in Stalmaster and Gessaman (1984) allows us to mathematically derive long-term average energy relationships necessary to specify the function given in Eq. (5). The prey species that have indirect value to the eagles and their long-term average per-item energy contributions are reported in Table 2, the relevant energy production function is the specified as Eq. (8).

$$\text{Eagle energy} = 132.85{*}x_{\text{jackrabbit}} + 66.82{*}x_{\text{cottontails}} + 203.26{*}x_{\text{marmot}} + 90.06{*}x_{\text{pheasant}} + 48.07{*}x_{\text{small birds}}. \quad (8)$$

In the manner described in the discussion of Eqs. (5)–(7) above, with the specific empirical values in Eq. (9), we can derive a set of equalities between the ratios of net energy contribution and the ratios of indirect values. The equalities relevant to the eagle prey system are specified in Eq. (9) below.

$$\begin{aligned}
132.85/66.82 &= I_{\text{jackrabbit}}/I_{\text{cottontails}}\\
66.82/203.26 &= I_{\text{cottontails}}/I_{\text{marmot}}\\
203.26/90.06 &= I_{\text{marmot}}/I_{\text{pheasant}}\\
90.06/28.07 &= I_{\text{pheasant}}/I_{\text{small birds}}. \quad (9)
\end{aligned}$$

We now draw upon a willingness to pay estimate for an eagle population and annual eagle prey consumption estimates for the five prey populations relevant to our example. These pieces of information allow us to define the indirect value budget function shown above as Eq. (7).

An average willingness-to-pay per household was computed using the Loomis and White (1996) meta-model; this was done in the interest of keeping this example as simple as possible, it may be preferable in a policy setting to use a range of WTP inputs to derive a range of indirect value estimates. Our use of Loomis and White is an implicit benefit transfer approach to defining a willingness-to-pay for golden eagles in Idaho because the literature does not contain a site-specific estimate. This will, of course, introduce some additional empirical error into this example. However, we expect that many cases where our technique may be utilized will require a similar approach and that the estimate derived will be superior to the implicit zero estimate otherwise adopted. All estimates were converted to 2003 dollars. We take a conservative approach and multiply the individual household willingness-to-pay estimate only by the number of households in the state of Idaho (Idaho Department of Commerce, 2003). Data on annual per-eagle prey consumption comes from the five estimates presented in Collopy (1983) and an eagle population estimate of an average of 12 eagles present per year in the study site comes from Kochert and Steenhof (2002). The budget equation specification relevant to our example is provided in Eq. (10). This specification is for a population scale with a population WTP value and estimates of the mean annual consumption of each prey species by the eagle population.

$$\$8.06\text{ million} = 9240I_{\text{jackrabbit}} + 4032I_{\text{cottontails}} + 392I_{\text{marmot}} + 1624I_{\text{pheasant}} + 6440I_{\text{small birds}} \quad (10)$$

Table 2
Net energy contributions of golden eagle prey items

Prey item (common name)	Net energy contribution (kcal)
Lepus calfornicus (jackrabbits)	132.85
Sylvagus species (cottontails)	66.82
Marmota flaviventris (yellow-bellied marmots)	203.26
Phasianus colchicus (ring-necked pheasant)	90.96
Various small birds	48.07

Table 3
Derived indirect values for an individual of each species

Species (common name)	Indirect value (WTP in \$2003/year)
Lepus calfornicus (jackrabbits)	\$562
Sylvagus species (cottontails)	\$283
Marmota flaviventris (yellow-bellied marmots)	\$861
Phasianus colchicus (ring-necked pheasant)	\$381
Various small birds	\$118

With the equalities in Eq. (9) and the budget in Eq. (10), we solve the system of equations to derive indirect values for each member of the relevant prey species as a way to define partial willingness-to-pay for those species. The results are shown in Table 3.

Thus, if the willingness-to-pay for the population of eagles in the Idaho Snake River region is \$8.06 million, then an indirect value of each jackrabbit consumed by the eagle population is approximately \$560 and each marmot approximately \$860.

A policy-maker interested in evaluating indirect value for the jackrabbit populations would use the \$562 value and also the indirect value for jackrabbits derived from all of the other known predators that jackrabbit populations support (in this example, perhaps mountain lions and coyotes) to determine an indirect value for a representative jackrabbit. In order to do so, one would repeat the process used in this example, and described in Eqs. (4)–(8) of our theoretical approach. Once these predator-specific values are estimated, they should be aggregated using the predation-weighted-average approach described in the discussion preceding and in Table 1. This value could, by repeated implementation of our method, be assigned all the way down the ecosystem and even to the jackrabbit's terrestrial habitat.

5. Discussion and conclusion

The method that we develop in this paper should allow analysts in need of willingness-to-pay estimates for species that have not year been examined through the conventional contingent valuation method and for which complete ecosystem response models are unavailable to leverage the concept of indirect value to derive partial willingness-to-pay estimates. Thus, we have constructed a useful benefit transfer estimator for willingness-to-pay in these cases. This method allows analysts who are constrained in terms of time or other resources to use existing valuation estimates and existing biology and ecology literature to derive partial values for species of policy interest. Our method also allows the valuation of lesser known species in terms of their contribution to better known species and may allow a more complete willingness-to-pay estimate in some cases where a CVM estimate is available but likely only captures (some or all of) the direct value of the species of policy interest. In other words, where a CVM estimate does not capture the indirect value, it may be appropriate to add the estimated indirect value to the stated willingness-to-pay for the prey species. Of course, if the available CVM estimate did capture the indirect value this would lead to double counting so an analyst using our method in this way must carefully assess what the CVM estimate does and does not capture.

In our empirical example we show how this process might be carried through for a particular predator–prey relationship. In the area used in our empirical example, it is likely that the prey species valued support a number of predator species—several of which may have known values. We also describe how an analyst would repeat the procedure for other predators who use the prey species of interest and how the analyst would use our predation-weighted-average approach to aggregate the various predator-dependent indirect values into a value to be used for a representative individual of the species of policy interest in a policy analysis.

This method can be extended (by calculating full indirect, predation-weighted, values for one or more prey) to begin to answer a variety of interesting policy questions. For example, our method would shed insights regarding the tradeoffs involved in harvesting wildlife that support predators that are endangered or have recreational use value. Our method would also have applications in discussing the tradeoffs in commercial harvest of wildlife that support other commercially harvested or potentially commercially harvested wildlife. Finally, it would be interesting to test the convergent validity of our method compared to the direct CVM elicitation of indirect support values or of complete WTP that includes such indirect values. This may help us to understand the relative accuracy of our quasi-benefit transfer approach compared to a more expensive and time consuming original study.

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