Valuing the impacts of climate change on terrestrial ecosystem services

Alan Krupnick and David McLaughlin

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Climate change is already having impacts on terrestrial ecosystem services, according to the IPCC, the Millennium Ecosystem Assessment and many other scientific reports, and such impacts are only expected to broaden and worsen as greenhouse gas emissions (GHGs) continue at their historic levels. To set appropriate policies for reducing GHG emissions, economists recommend the use of cost-benefit analysis to help decide on the appropriate stringency of policies, such as the size of a cap in a cap and trade system, the size of a carbon tax, or the stringency of a carbon fuels standard. To perform such analyses, the predominant approach has been to use integrated assessment models (IAMs), such as DICE. However, these models lack geographic specificity, must make hugely simplifying assumptions to capture the myriad effects caused by climate change and the welfare losses associated with them and not all components are based on public preferences. As such, there is a need for more targeted valuation studies to serve as further evidence about the willingness to pay (WTP) to reduce climate change.

The purpose of this brief paper is to sample and classify the literature valuing terrestrial ecosystem services and make some judgments about its usefulness to benefits analysis associated with climate change mitigation. As the valuation literature relevant to all types of terrestrial ecosystem services is enormous, this review is limited to studies valuing ecosystems, primarily nonuse values, which are likely to provide the largest aggregate values of any service one would label as based on terrestrial ecosystems (defined as land, river, and lake-based systems, excluding coastal and saltwater systems). With the emphasis on nonuse values, this paper focuses on stated preference studies, but also gives some attention to use values, and so includes revealed preference studies, such as those on recreation.

Classification of Ecological Endpoints Associated with Climate Change

Prior to the entrance of climate change into the valuation literature, this literature was mainly focused on ecological endpoints related to acid rain, ozone, land use change from urbanization, dam creation/removal, etc. This literature has relevance to climate change valuation, to be sure; yet it is inadequate for several reasons. First, there are novel types of ecosystem effects associated with climate change, such as shifts in the range of a species or subtle perturbations in ecosystem function related to incremental seasonal changes, such as from early alpine snowmelt. Second, climate change may effect geographical locations that have not been previously studied for valuation purposes. Third, climate change may produce larger scale effects (e.g., mass extinctions rather than one at a time). Fourth, the geographic scale of effects related to climate change, even if these effects are familiar, may be much larger, and the time phasing of these effects may take longer to begin and longer to reach a new equilibrium.

Fortunately, there are a variety of studies (e.g., IPCC report) that classify the full range of ecosystem damages associated with climate change. Unfortunately, these classifications involve much double-counting and contain endpoints that the public would be unable to value (Boyd and Krupnick, 2009) because they are inherently complex, require advanced scientific knowledge or are too far from their experience. It is beyond the scope of this paper to develop a complete classification system that includes only "valuation-relevant" endpoints and eliminates double counting, meaning that inputs to the processes affecting valuation-relevant endpoints, as well as the processes themselves, will not both be counted. Take for example an input and process such as submerged aquatic vegetation (SAV) (an input) and its provision of shelter to fish eggs and hatchlings (a process). Changes to the SAV affect its ability to provide shelter, which will ultimately affect the fish populations, the endpoint in this example. In the paper, we argue that people most easily and reliably value, and understand such endpoints and counting only them avoids double-counting.

For this literature review of valuation studies, we nevertheless needed some classification framework of relevant endpoints drawn from the scientific literature on climate change. These endpoints are not meant to be comprehensive. They appear along the top row of table 1, covering, first, recreation-related endpoints, such as fish populations, snow cover in ski areas, tourism, etc. Another category is related to "standard" nonuse values associated with species, which could include plant, bird, mammal and various aquatic species and cover changes in the population size, whether they are endangered or facing extinction and, looking across many species living interrelated in an ecosystem, measures of biodiversity. The term "standard" is used to indicate that endpoints under these subcategories are quite familiar to economists engaged in their valuation. The next set of categories is related to combinations of endpoints.

Three subcategories are highlighted that appear to be related to climate change, and other drivers of disturbance (e.g., land use or management changes). These include the changes in endpoints associated with wildfires and other events related to climate change, as well as aggregations of endpoints associated with climate change, such as large changes in biodiversity or mass extinctions. The last subcategory, "complete," is included to capture combinations of endpoints that include all the major categories of endpoint changes identified in the scientific literature (such as IPCC reports). The last category are endpoints that are unique to climate change (or at least long lasting changes in weather patterns), such as changes in the range of a species or ecosystem and perhaps some of the more subtle changes in an ecosystem associated with early snowmelt (e.g., changes in migratory patterns).[1] How one classifies endpoints of the same type that are affected over larger time periods or geographical area is arbitrary (are they “unique” or are they “standard”?). Not noted above, but essential to be mindful of, is the large degree of uncertainty associated with the magnitude and timing of climatic effects relative to the more modest uncertainty associated with, say, effects related to acid rain or ozone.

	Use Values	“Standard” Non-use values			Combinations			Unique endpoints	
	Recreation	Species			Disturbances	Multiple commodities	Complete	Events	
Study Design	e.g. Fishing, skiing, hunting, beach	Population change	Endangered or facing extinction	Decreased biodiversity	e.g. Wildfire, habitat loss, etc.	e.g., Biodiversity and habitat loss	All/Most relevant commodities	Range or ecosystem shift	Early snow melt impacts
1.) Top-down SP studies							X		
2.) Studies valuing ecosystem commodities from climate change	X	X	X	X	X	X		X	
3.) Studies transferring values to a climate change context	X	X	X	X		X		X	X
4.) Studies valuing relevant endpoints in a non-climate change context	X	X	X	X	X	X	X		

Table 1. Terrestrial Ecosystem Studies by study design and commodity: Classification of Reviewed Literature

Classification of the Valuation Literature

Table 1 contains a classification framework for the valuation literature that is somewhat unorthodox, in that it does not distinguish these studies by whether they are stated or revealed preference or meta-analysis, etc. The classification in the first column of table 1 relates to the credibility of cost-benefit analyses that would use this literature, beyond that of the methodology itself.

[1] Note that there are positive effects of climate change predicted for terrestrial ecosystems, such as faster tree growth (at least for a time). For simplicity, we ignore these in the discussion.

The top category covers studies that are designed to elicit WTP to avoid most, if not all, ecosystem-related changes expected from climate mitigation policy. The breadth of this "commodity" is so wide that only stated preference approaches can be used. The second category is studies valuing ecosystem endpoints in a climate change context. These are studies that were designed with the idea of valuing the types of ecosystem changes thought to be associated with climate change. Nevertheless, even if designed this way, they may not actually mention climate change. They are applicable to specific locations and types of terrestrial ecosystems, (e.g., the Murray River ecosystem or Colorado forests). The third category covers studies that have applied findings from studies valuing changes in terrestrial ecosystem services in a non-climate change context to estimated climate change impacts in a benefit transfer exercise. Before writing this paper, we were unaware whether many such studies existed and were surprised to learn that they do.

The final category (at the bottom of the first column) refers to studies valuing relevant endpoints in a non-climate change context. In this category is basically the entire ecosystem valuation literature that is motivated by non-climate change problems (e.g., acid rain). This literature provides values for a large number of the types of effects associated with climate change, e.g., species extinction, but might lack the scale or magnitude of effects associated with policies to mitigate climate change.

Turning to the interior of table 1, an "X" means that studies of one of the four types apply to the ecosystem endpoints indicated in the columns. By definition, the top category has an X only under "Complete" (even though their descriptions may be far from complete). And by definition, there are blank cells for the bottom row under the Complete and Unique columns.

The literature search that supports these X's was conducted using standard Google and Google Scholar searches, augmented by reference lists found in studies, as well as the Environmental Resource Valuation initiative (EVRI) database. We make no claim that this search was comprehensive. But, we feel we have a reasonable handle on the literature.

The surprise in the table is that there are X's in so many cells. Missing is benefit transfer studies for disturbances, but this may be occurring because of the limitations of our literature review.

Results from examining this literature

The following tentative findings emerge.

Timing. Because of the long lead times associated with the onset of some types of climate changes (or at least their most severe manifestations) and their potentially long duration, how preferences are related to this type of timing is important. While there are few studies upon which to make firm conclusions, in these it appears that the timing of the benefits of climate change mitigation doesn't seems to matter. That is, the longer term and the very distant future appear to be treated equally with respect to willingness to pay, implying very low or zero discount rates (Layton and Brown, 1999; Fleischer et al., 2006). These findings are consistent with the general tenor of the literature on temporal preferences. However, in our recent experience with focus groups comparing WTP for commodities offered in the near term (10 years) versus those offered further into the future (50 years), the latter timing creates scenario credibility problems. Respondents tend to believe that ecological improvements are less likely to occur the further into the future such changes are offered (Boyd and Krupnick, 2009). In a field study, statistically distinguishing such behavior from normal discounting would be very challenging. Some studies simply punt on the issue of communicating long-term changes and bring such changes into the near-future, or within the lifetime of the respondent, thereby overestimating WTP, assuming any positive discounting.

Scope sensitivity. With the profession moving more and more to choice experiment formats, scope sensitivity is now generally limited to showing that there is a positive and statistically significant coefficient on an attribute (i.e., that people are willing to pay statistically more for larger reductions in the same commodity). Such tests are run with panel data, where each respondent answers multiple choice questions, each with different levels of at least one attribute, including an associated cost.[2] This approach is less restrictive than the split sample set-up recommended by the NOAA Panel for contingent valuation studies.

Nevertheless, with this set-up, the studies reviewed here indicate that scope sensitivity is generally demonstrated, and further that there is decreasing marginal willingness to pay for increased number of species protected or for other metrics of increasing ecosystem services.

Uncertainty. Science has limited ability to predict both the future status quo effects from climate change and the ecosystem improvements arising off this baseline following a given GHG reduction. Thus, characterizing this scientific uncertainty in stated preference studies is important. Very few of the studies we reviewed explicitly vary the certainty with which mitigating actions will improve ecosystem qualities or quantities. Indeed, most appear to treat ecosystem improvements as if they would occur with certainty. In our focus group experience, admitting to uncertainty in ecosystem improvements from an intervention scenario results in respondents' questioning the science or the survey creator's understanding of the science, which itself results in lower or zero bids from some people. Statistically separating this type of "protest" bid from the normal behavior of being willing to pay less for a commodity that has a non-zero probability of being realized (relative to the same commodity offered with certainty) is another major challenge.

A Tempting Option. The studies classified as "top-down" (see row one of table 1) are a very tempting alternative to the messy and almost impossible business of doing very detailed valuation studies in many habitats and using benefit transfer to fill in the rest. The existing literature in this category covers studies that ask for WTP for reducing greenhouse gas emissions

[2] Occasionally, studies bundle several terrestrial ecosystem services to account for tradeoffs between valuing different ecosystem services. (Riera et al., 2007)

and avoiding the consequences of climate change. Some studies ask for the WTP to offset air travel (Brouwer et al., 2008), or for taking mitigation actions (Akter and Bennet, 2008), or to reduce dependence on foreign oil and carbon emissions (Li et al., 2009), to implement the Kyoto Protocol (Berrens et al., 2004), or more explicitly (Berk and Fovell (1999)) to prevent significant climate changes. Cameron (2005) used a convenience sample of college students and found that respondents who are more certain about a given increase in average temperatures have higher WTP to prevent such an increase. In line with these results, Viscusi and Zeckhauser (2005) and Akter and Bennett (2008) also found that people who find global warming to be more likely also have higher WTP. Hence, as might be expected, one important explanatory factor for how much individuals are willing to pay for mitigating climate change is if they believe in climate change.

Details on a Broad Climate Mitigation Valuation Study (Carlsson et al, 2010)

In a survey performed by Carlsson et al. (2010), respondents were told that the magnitude of future temperature increases will depend on the amount of future global CO_2 emissions; specifically, if CO_2 emissions are reduced from current emission levels by 30%, 60%, and 85% respectively, then the temperature increase will be limited to 4°F, 3°F, or 2°F. If the world instead does not reduce emissions but continues with “business as usual” (BAU), the temperature is expected to increase by more than 4°F in 2050. The survey explained, based on information from the IPCC, that this would most likely correspond to large changes in the global ecosystem and most countries would be negatively affected. An information screen (figure 1) summarized these effect of temperature increases on harvests, increased flooding and storms, and ecosystem effects by the year 2050.

Global emissions reduction	**85% reduction**	**60% reduction**	**30% reduction**
Temperature increase	2°F increase	3°F increase	4°F increase
Harvest	Harvests in countries near the equator decrease by 4-6%. Harvests in countries in the northern hemisphere increase by 1–3%.	Harvests in countries near the equator decrease by 10–12%. Harvests in countries in the northern hemisphere are unaffected.	Harvests in countries near the equator decrease by 14–16%. Harvests in the northern hemisphere decrease by 0–2%.
Increased flooding and storms	Small tropical islands and lowland countries (for example, Bangladesh) experience increased flooding and storms.	Additional low-lying areas in the Americas, Asia, and Africa experience increased flooding and storms.	Populous cities face increased flood risks from rivers and ocean storms. Existence of small island countries is threatened.
Threatened ecosystems	Sensitive ecosystems, such as coral reefs and the Arctic, are threatened.	Most coral reefs die. Additional sensitive ecosystems and species around the world are threatened.	Sensitive and less-sensitive ecosystems and species around the world are threatened.

Figure 1. Global Emissions Reduction, Temperature Increase and Its Effects as Presented to Survey Respondents in Carlsson et al. (2010)

This survey screen is a good example of responses to the above key issues (and others). Overall, the "commodities" being valued encompass both ecosystem effects as well as harvests and storms/flooding, with some specific species – coral reefs – and specific locations called out. These choices are in line with the IPCC's "most likely" predictions. Timing of the effects of global warming is set at 2050, a simplification and forward telescoping of the path of effects we might see. Uncertainty is handled obliquely by providing ranges of likely effects (e.g., 1-3 percent reduction in harvests) in the table, and using words like "most likely" in the text. However, in the information screen above (which also doubles -- with slight modifications – as the choice experiment screen) declarative phrases are used, e.g., "most coral reefs die", as opposed to using qualifiers on the verb, such as "may die." These choices were guided by focus group feedback. Probably the most subtle approach to uncertainty is with description (or lack of description) of the future baseline, of which is said only that temperature change of greater than 4 degrees F "…would most likely correspond to large changes in the global ecosystem and most countries would be negatively affected" (Carlsson et al., 2010). This decision to so vaguely define the baseline also was made in response to focus group feedback and the difficulty of concisely describing widespread and possibly dramatic effects. Finally, the survey passed scope sensitivity, although as designed the test was of internal (rather than external) scope sensitivity.

In any event, the survey yielded many interesting results. Carlsson et al. (2010) found that a large majority of the respondents in *all three* countries believe the mean global temperature has increased over the last 100 years and that humans are responsible for the increase. Americans, however, believe less in both aspects compared to Chinese and Swedes. A larger share of Americans appears to be pessimistic; they believe that we cannot do anything to stop climate change. Carlsson et al. (2010) also found that Sweden has the highest WTP for reduction of CO2 and China has the lowest. In going from a 30% reduction in GHGs to 60%, for instance, the Swedes were willing to pay $20 per household month, while the U.S. sample was willing to pay $10 and the Chinese $4. Interestingly, when the WTP is measured as the share of household income, the willingness to pay is about the same for American and Chinese sample, but much higher for the Swedes.

The findings from Carlsson et al. (2010) show that the U.S. population contains a far larger percentage of climate skeptics (24 percent by one metric) than in Sweden or even China (both around 5-6 percent). With such a large fraction of the population thinking this way, survey researchers must be concerned that WTP for ecosystem improvements themselves, irrespective of the cause, not be biased downwards simply because respondents discount the link between climate change and the ecosystem changes being offered or biased upwards through double-counting due to the respondent's inclusion of joint benefits (e.g., human health) in their WTP.

This situation is not unlike that faced by researchers seeking values for reducing mortality risks from air pollution. Best practice is to avoid conveying the cause of reducing such risks (e.g., reducing particulate emissions) because such reductions carry with them cognitive linkages to other types of improvements (say in morbidity or visibility or materials damages), which tend to inflate WTP, or feelings leading to scenario rejection or downward bias. The most common of these feelings in our focus group work has been that respondents should not be responsible or pay for reductions in air pollution because it is "industry's fault." Both of these problems – linkage bias and scenario rejection – are likely to be present to an even greater extent in climate change valuation studies relative to valuation studies for conventional air pollutants.

This situation could lead to more efforts, such as that from MacDonald et al. (2010) on the Murray River region in Australia, where climate change is not even mentioned as a causal driver of change, and mitigation of GHGs is not mentioned as a motivator for ecosystem improvements. It remains to be determined whether plausible alternative stories can be constructed for delivering such widespread and large improvements in ecosystems as are thought to be realizable from large GHG reductions. If they can't, perhaps the best approach would be to include questions to determine whether or to what degree a respondent is a climate skeptic and to adjust for this statistically or through their exclusion. To do so, however, risks overvaluing the improvements, as legitimate zeros or low values may be excluded.

Conclusion

Is this literature ready for prime time, i.e., to be used to help develop and justify a social cost of carbon? A top level response is that, with the pervasiveness of the effects of global warming on all types of natural and human systems, and given the interconnectedness of those systems, it seems too reductionist to focus on valuation of changes to specific resources or systems, in this case terrestrial ecosystems. That is, the value of slowing climate change needs to be estimated from a holistic perspective. To do so, the only possible way to go is with the top-down studies like those defined in the first row of table 1, recognizing that these studies can never provide the detail and the preciseness of commodity definition that is desirable in, say, natural resource damage assessments. However we must ask ourselves as a society if we are willing to trade off precision for comprehensiveness/breadth.

What is the alternative? In our view, the vast literature simply valuing ecosystem services is not largely motivated or directly applicable to climate change. And use of these studies in benefits transfers therefore involves huge assumptions (e.g., about how much two extinctions are worth avoiding relative to one) and, even then, there will be gaps in geographic coverage. On a more hopeful note, there are an increasing number of ecosystem valuation studies motivated by climate change that have the right scale and type of commodities being valued (see table 1, row 2). Yet, such studies are invariably place-based and draw relatively tight, rather than porous boundaries between the ecosystem of interest and its linkages to other systems. Thus, one will not be able to easily aggregate such studies, properly account for overlaps and gaps and eventually come out with a cost of carbon. However, examining such studies one at a time and drawing insights out of them may both inform the design of information treatments for the studies, like those found in the first row of our classification, and lead to a more qualitative/judgmental basis for settling on a cost of carbon number.

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