Table E-19
Difference in Commercial Timber Growth Rates With and Without The CAAA

Region	Difference in 2000		Difference in 2010	
	Softwoods	Hardwoods	Softwoods	Hardwoods
PN W-E	1.68%	1.58%	2.11%	1.25%
PN W-W	1.17%	0.42%	-0.56%	1.13%
S. West	0.84%	1.77%	-0.14%	1.59%
N.Rocky	2.67%	0.40%	4.46%	2.05%
S. Rocky	4.77%	2.25%	4.14%	3.88%
S. Central	4.54%	4.80%	7.93%	8.41%
S. East	5.40%	5.65%	10.38%	10.91%
N. Central	1.80%	5.74%	4.36%	9.22%
N. East	4.27%	6.68%	9.58%	11.49%

It is important to note that the difference in growth rates gradually grows from zero percent in 1990 to the values presented for 2000, and then 2010. In other words, the difference in growth rate estimated for 2010 is not experienced over the entire 1990-2010 modeling period.

Economic Impacts

TAMM estimates that there is a measurable difference in timber harvests attributable to ozone exposure under our two scenarios. At the outset of our modeling period, early 1990s, virtually no change is measured in forest harvest volumes. This is an expected result because increases in growth rates should not substantively affect timber volume over so short a period of time. By the end of our modeling period, late 2000s, increased growth rates over the previous decade(s) begin to affect overall forest yields in the form of harvestable timber. This is observed in Figure E-8 as an increasing annual benefit estimate over the modeling period.

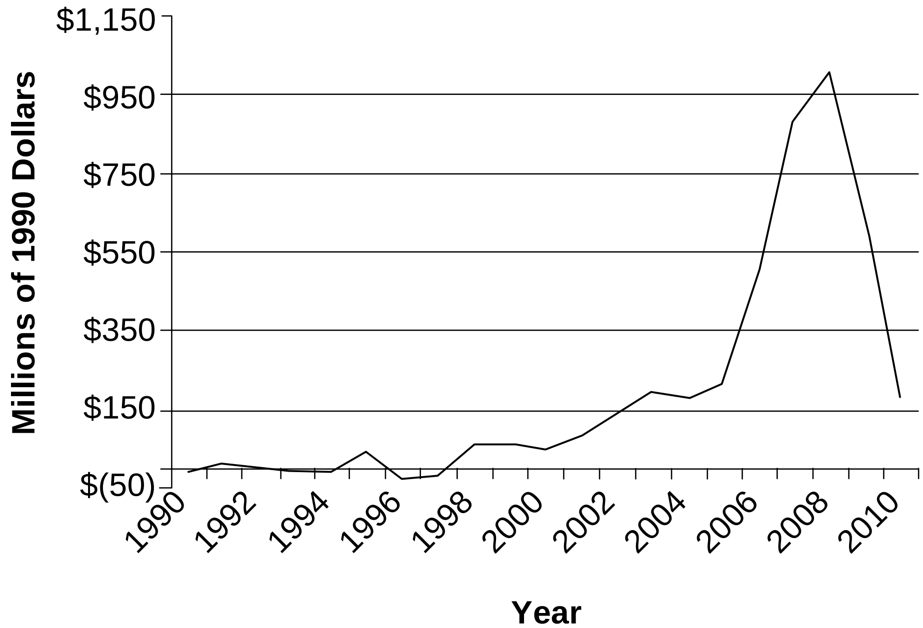
The shape of the benefits time-series reveals a production shift in one region of the United States as a result of increased timber availability. This shift produces a spike in economic surplus for a period of three years. Although this change is small in percentage terms relative to total economic surplus generated by the timber sector it contributes to a large portion of the benefits estimate over the 1990-2010 period.

The cumulative value of annual benefits is calculated as the sum of the annual differences in consumer and producer surplus from commercial timber harvests under our CAAA and no CAAA ozone exposure scenarios from 1990 to 2010. We discount annual benefits to 1990 dollars using a five percent discount rate. The total cumulative benefits estimate is $1.87 billion.

Caveats and Uncertainties

In interpreting results from this analysis, several points should be considered. First, large-scale analyses of complex ecosystem processes are typically conducted with simulation models because it is impossible to conduct large-scale manipulation experiments that would provide similar predictive capabilities. This brings with it inherent uncertainties in that there may be little or no data with which to validate model predictions. In the case of ozone effects on forest production, the absence of controlled, whole-forest fumigation studies across the range of climatic, vegetation and pollution conditions experienced across the U.S. makes it presently impossible to validate all model predictions. In this

Figure E-8
Annual Economic Welfare Benefit of Mitigating Ozone Impacts on Commercial Timber: Difference Between the Pre-CAAA and Post-CAAA Scenarios



analysis, we have combined established empirical relationships between ozone exposure and plant physiological function in a peer-reviewed model that is based on sound forest growth processes. As such, the resulting model predictions should be viewed as a set of refined hypotheses, but nevertheless, hypotheses that have not been thoroughly tested.

Second, while ozone has repeatedly been identified as an important environmental stress agent affecting forest vegetation, it is not the only such factor to which forests are currently exposed at regional to global scales. Human activities have profoundly affected global cycles of carbon, nitrogen and a number of other elements in ways that may be at least as important as ozone. Because a number of changes (e.g. elevated CO_2 and increased atmospheric nitrogen deposition) have significant potential to cause large-scale fertilization effects, growth predictions that include ozone effects alone should be viewed as incomplete.

Ozone Modeling

- Because it is not possible to model ozone levels throughout the country during the months of October through April during future years, it is necessary to employ another method to obtain estimates for ozone levels during these months. We assume that ozone levels during these months for 2000 and 2010 will be identical to the levels during the same months of 1990. Thus, any differences in timber production under the two scenarios of CAAA promulgation and no CAAA promulgation will be driven solely by ozone differences during the warmer part of the year that comprises the majority of the growing season.

- It is important to note that ozone monitoring is not complete, with coverage especially low in forested regions of the United States.

Only two percent of ozone monitors are in forested areas (U.S.EPA 1996). We work with the best possible estimates of tropospheric ozone concentrations but identify this as a significant area of uncertainty in this analysis.

Ecological Modeling

- Preliminary model results revealed an interesting and unexpected interaction between ozone, drought stress and carbon allocation. On moist, productive sites, ozone resulted primarily in decreased wood growth because the simulated trees can afford to lose wood without reducing more important tissues which are given higher allocation priority in the model (leaf and root). On progressively colder or drier sites, ozone exposure causes reductions in all plant tissues because plants are already stressed enough that additional reductions in carbon gain must come from all plant pools. Complex interactions among ozone, drought and this carbon allocation dynamic produced unexpectedly variable results, which, in some cases caused an increase in growth in response to ozone. Although these are interesting and biologically feasible interactions, in the absence of any real data in this area, it is impossible to determine the extent to which they actually occur.

Economic Modeling

- There are two important caveats to the economic modeling. First, we generalize changes in growth rates for entire forest types across potentially heterogeneous regions. TAMM is capable of modeling timber growth and harvest with greater precision, breaking down forests into many species and age-classes and by county. We do not anticipate that increasing the precision of growth rate data on a national scale would substantially alter our results.
- The second caveat is economic benefits may be underestimated by using so short a modeling period. It is evident from the data we present that improved growth takes years to affect actual harvests. Therefore, the complete benefits of improved growth during 1990 to 2010 will not be accrued until after 2010. By not including these years in our analysis we can not fully account for the commercial timber benefits of ozone mitigation over the period of our analysis.

Carbon Sequestration Effects

It is possible to extend the analysis of timber growth rates to account for the differences in temporary and long-term carbon sequestration under each of our ozone scenarios. This is accomplished by linking two USDA Forest Service Models to TAMM/ATLAS to generate estimates of carbon sequestered in standing forest, and carbon sequestered in commercial forest products. We briefly summarize those steps here.

TAMM/ATLAS provides an estimate of the standing timber stock and the commercial timber harvests that will occur under each of our ozone exposure scenarios. Using this information we estimate the respective volumes of carbon sequestered in each scenario using the forest carbon model (FORCARB) and harvested carbon model (HARVCARB).

FORCARB contains a set of stand level carbon budgets that relate the timber growth and yield output from ATLAS to trends in total ecosystem carbon over the course of stand development. These include carbon sequestered in trees, woody debris, understory vegetation, and the forest floor. Using these data, FORCARB estimates the total carbon sequestered in commercial forests at any point in time. This information provides a useful baseline for the rate of forest carbon sequestration that can be expected under different ozone exposure scenarios. For a complete description of FORCARB and its application see Turner et al. (1993) and Turner et al. (1995).

The age of natural forests and the management regime of commercial forests largely determine the fate of forest carbon. In natural forests, carbon sequestration is temporary, with sequestered carbon eventually returning to the nutrient cycle. Alternatively, harvested timber is transformed into commercial products that alter the life cycle of sequestered carbon. Using the HARVCARB model, we use harvest information from TAMM to track the lifecycle of timber. The ultimate fate of this sequestered carbon depends on the efficiency of timber conversion (i.e. how much timber becomes a product), and the durability of that product. HARVCARB estimates the long-term carbon sequestration resulting from timber harvests under each of our scenarios. A full description of HARVCARB is found in Row and Phelps (1990).

Forest ecosystems help mitigate increasing anthropogenic carbon dioxide emissions by sequestering carbon from the atmosphere, converting atmospheric carbon into biological structures or substances needed in physiological processes. Some air pollutants, however, may adversely affect the potential of forests to sequester carbon by slowing down the rate of biomass accumulation of sensitive forest tree species. This may affect the global carbon cycle and may contribute to anthropogenically induced changes in the earth's climatic conditions.

Using output from TAMM/ATLAS, timber inventories can be converted into estimates of carbon sequestered in commercial forests by a forest carbon model (FORCARB). FORCARB estimates the carbon storage in each of four ecosystem components: trees; forest understory, forest floor, and soil. The model uses forest carbon storage and flux estimates based on ecological analyses of each of the forest ecosystem components. The details of these studies and their synthesis into the FORCARB model can be found in Birdsey (1992a, 1992b) and Heath and Birdsey (1993). Heath and Birdsey (1995) provide a technical description of integrated simulations using TAMM/ATLAS and FORCARB. Of the carbon sequestered in forests, some portion is subsequently harvested as timber and processed into wood products, paper, and biomass fuel. We use a harvest carbon model (HARVCARB) to estimate the life-cycle of harvested forest timber and thereby adjust the forest carbon sequestration estimates of FORCARB. HARVCARB relies on a range of assumptions approximately 50 percent of harvested wood ultimately becomes a wood or paper product, the remainder becomes waste from the production process. Of the final wood and paper products, a small percentage become durable products or are landfilled and decompose at a rate of less than one percent a year (Row and Phelps, 1990). Wood that is either manufactured into a durable product (e.g. permanent building construction material, furniture) or materials that are landfilled (e.g. paper) contribute to long-term carbon sequestration. The remainder of the harvested wood mass (e.g. biomass fuel, non-durables that are not landfilled) is re-released to the environment and therefore is not included in the volume of carbon estimated to be sequestered in forests.

We find that forest carbon sequestration increases with improved air quality under the CAAA. This result corresponds with the intuition that forests tend to grow faster when tropospheric ozone exposure is reduced. Carbon flux, or annual forest carbon sequestration minus forest harvest losses (excluding long-term carbon sequestration in forest products) is also greater under the CAAA than under our No-CAAA air quality scenario. We summarize our results in Table E-20.

Table E-20
Differences in Carbon Flux (millions of metric tons/year)

	1990-1999	2000-2010
Forest Flux	8	28
Land Use Change	> -1	> -1
Cumulative Fate of Removals	> 1	> 1
TOTAL FLUX	**8**	**29**

Forest carbon flux attributable to the CAAA represents approximately four to sixteen percent of anticipated total carbon flux in U.S. forests between 1990-2010.

In the event of a binding international carbon mitigation agreement, the implication of this result is that substantial costs of carbon mitigation may be avoided by improved forest growth attributable to the CAAA. Though it is not possible to evaluate the monetary value of the avoided cost at this time due to uncertainty regarding the actual cost of carbon mitigation, it will be possible to estimate the value using the data in this analysis once reliable carbon mitigation costs become available.

Caveats and Uncertainties

Additional caveats and uncertainties associated with the estimation of carbon sequestration in U.S. commercial forests include the following:

- FORCARB estimates are based on a synthesis of a variety of empirical studies of the four ecosystem components (soil, forest floor, understory, and trees). The total error of the composite of these studies is not treated explicitly as a modeling output.

- FORCARB also estimates the carbon storage and flux for a variety of forest types based on a synthesis of empirical studies. The error associated with extrapolating these data across a variety of forest ecosystem types is not explicitly treated.

- HARVCARB utilizes data on the life span of durable wood products that is over 50 years old, originally compiled by the Internal Revenue Service for purposes of calculating depreciation of these products. Though the authors of HARVCARB state that this data continues to be reliable, changes in construction, product and their uses most likely biases these data. No estimate is made of the magnitude or direction of this bias.

Aesthetic Degradation of Forests

The purpose of this section is to evaluate the prospective benefits of forest aesthetic improvements associated with improved air quality attributable to the CAAA. In order to assess these benefits, we first evaluate the known changes in visible injuries over time. Available scientific methods and data on the visual appearance of forest stands and their impact on perceived forest aesthetics, however, make it difficult to precisely describe changes in forest aesthetics. Nevertheless, it is possible to describe a range of visual impacts that may be caused by air pollutants and their potential effect on forest aesthetics. Second, we assess the economic value associated with such aesthetic changes. The focus of much of this work tends to be site-specific, describes the aesthetic impacts of a number of causal factors, and utilizes a variety of experimental methods making it difficult to generalize results. We conclude that air quality improvements attributable to the CAAA should result in improved forest health, possibly providing aesthetic value to society in the range of billions of dollars. A more detailed description of this analysis is found in *Characterizing the Forest Aesthetics Benefits Attributable to the 1990 Clean Air Act Amendments, 1990-2010* (IEC, 1999c).

Forest Aesthetic Effects from Air Pollutants

Air pollution can cause a wide variety of visual injuries to forest stands, ranging in severity from subtle injuries (e.g., minor leaf discoloration) to severe forest decline (e.g., extensive defoliation and death of trees). The severity of symptoms depends on many factors including the atmospheric concentration of air pollutants, the sensitivity of tree species to air pollution and the presence of other environmental stress factors (Fox and Mickler, 1995; Eagar and Adams, 1992; Olson et al., 1992; Smith, 1990).

Many CAAA-regulated air pollutants are associated with visual symptoms, including, but not limited to, tropospheric ozone, sulfur dioxide and hydrogen fluoride, the three major pollutants known to have caused significant visual injuries to forest trees in the past (NAPAP, 1987). Other air pollutants known to potentially cause visual injuries to plants are strong mineral acids, precursors of which are also regulated by the CAAA (NAPAP, 1987). In addition, there are a variety of other air pollutants potentially affecting the visual appearance of plants, including heavy metals such as lead and mercury (EPA, 1997d; Gawel et al., 1996; Smith, 1990; NAPAP, 1987); nitrogen oxides; ammonia; peroxyacetyl nitrate; chlorides; and ethylene (Smith, 1990; NAPAP, 1987; Jacobson and Hill, 1970). However, very limited information is presently available on visual damages caused by these pollutants. Tables E-21 and E-22 summarize the known visual impacts of air pollutants on forests and their geographic extent.

As a consequence of complex natural forest dynamics, lack of extensive long-term monitoring networks, and difficulties in establishing cause and effect relationships, it is not possible to quantify the extent of visual forest injuries caused by air pollutants or changes that may have occurred since the implementation of the CAAA. In addition, mechanisms that induce threats to forests may operate on such a long-term scale that benefits in the visual appearance of forests may not be exhibited during the period of our analysis.

Table E-21
Typical Impacts of Specific Pollutants on the Visual Quality of Forests

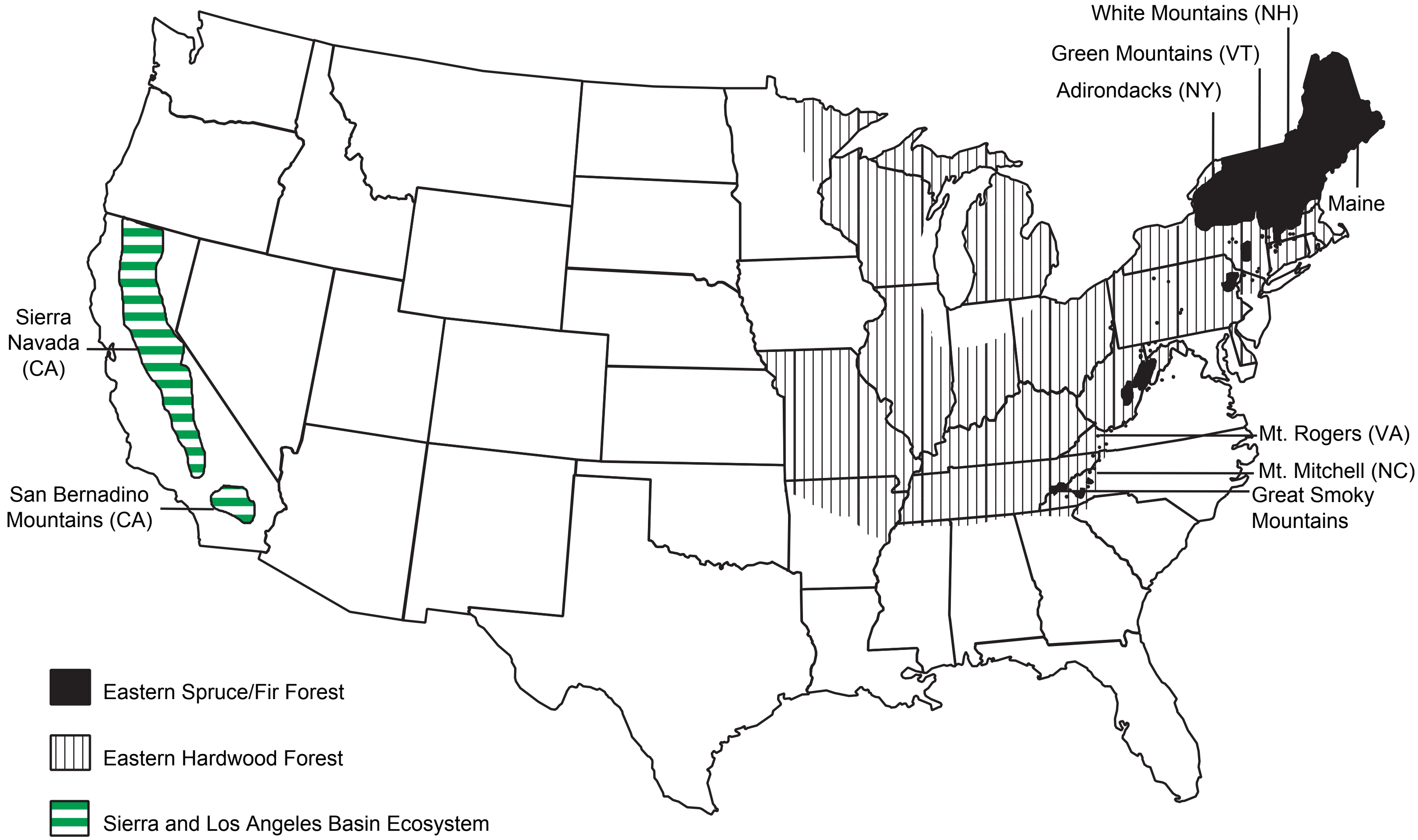
	Geographic Extent	Direct/Indirect Injuries	Major Types of Visual Injuries
Ozone	Area or regional effects	Direct injuries	Foliar injuries (e.g., pigmented stipple), increased needle/leaf abscission, premature senescence of leaves. Pattern, size, location, and shape of foliar injuries to indicator species can be specific for ozone.
		Indirect Injuries	Increased susceptibility to visual injuries that may result from other adverse environmental factors, such as insect attacks. For example, increased needle/leaf abscission, elevated mortality rates, and/or changes in species composition.
Acidic Deposition	Area or regional effects	Indirect Injuries	Increased susceptibility to visual injuries that may result from other adverse environmental factors, such as climatic factors. For example, increased needle/leaf abscission, elevated mortality rates, and/or changes in species composition. Acidic deposition can also cause direct foliar injuries. Acids are, however, more likely to indirectly affect the visual appearance of forest trees, unless exposure levels are very high.
Sulfur Dioxide	Point source pollution	Direct Injuries	Foliar injuries including leaf/needle discoloration and necrosis. Pattern, size, location, and shape of foliar injuries to indicator species can be specific for sulfur dioxide. At high concentrations, elevated mortality rates of sensitive species and changes in species composition may occur. Sulfur dioxide may also cause indirect injuries. Indirect injuries, however, are not well documented.
Hydrogen Fluoride	Point source pollution	Direct Injuries	Foliar injuries including leaf/needle discoloration and necrosis. Pattern, size, location, and shape of foliar injuries to indicator species can be specific for sulfur dioxide. At high concentrations, elevated mortality rates of sensitive species and changes in species composition may occur. Hydrogen fluoride may also cause indirect injuries. Indirect injuries, however, are not well documented.

Table E-22
Forests Affected by Regional Pollution

Affected Forest Type / Species	Region	Major Air Pollutants	Documented Visual Injuries	Suspected Mechanisms of Injury	Sources
Mixed Conifer Forest / Ponderosa and Jeffrey Pines	San Bernardino Mountains, California	Ozone and nitrogen containing substances	Foliar injuries include chlorotic mottle, tip necrosis, premature senescence of needles, and increased needle abscission. Elevated mortality rates and changes in species composition have occurred.	Direct ozone-induced foliar injuries. Heavy bark beetle attacks facilitated by drought, ozone, and nitrogen containing air pollutants. Ponderosa and Jeffrey pine have shown air pollution-related symptoms of decline probably since the mid 1950s.	E PA 1996a; Miller, 1992; Stolte et al., 1992; NAPAP, 1991; Miller and McBride, 1998
	Sierra Nevada, California	Ozone	Foliar injuries include chlorotic mottle, tip necrosis, premature senescence of needles, and increased needle abscission.	Direct ozone-induced foliar injuries. The Sierra Nevada contains the largest forest area in the world with documented damage from a non-point source pollutant but ozone exposure and injuries are not as severe as in the San Bernardino Mountains. Visible ozone-induced foliar injuries were first documented in the early 1970s.	EPA, 1996a; Peterson and Arbaugh, 1992; NAPAP, 1991; Miller and Millecan, 1971

Affected Forest Type / Species	Region	Major Air Pollutants	Documented Visual Injuries	Suspected Mechanisms of Injury	Sources
Spruce-Fir Forest / Red Spruce	High elevation areas in the northern Appalachians.	Acidic deposition (esp. acidic cloud water), and ozone	Foliar dieback, bud injury, foliar loss, Elevated mortality rates.	Acidic deposition increases the susceptibility of red spruce to winter injury (freezing). A dramatic increase in the frequency of winter injury in red spruce stands occurred in the late 1950s and 1960s, coincident with a significant increase in the emissions of precursors of acidic deposition.	EPA, 1995a; Johnson et al., 1992; DeHayes, 1992; NAPAP, 1991
	High elevation areas in the southern Appalachians.	Acidic deposition (esp. acidic cloud water) and ozone	Crown thinning and pockets of high red spruce mortality have been detected on a few mountain sites. Ozone-induced foliar injury.	Acidic deposition leads to nutrient imbalances through accelerated foliar leaching and soil acidification. Soil acidification is characterized by a loss of soil nutrient cations and occurrence of toxic aluminum levels. Also: direct foliar injuries caused by ozone.	EPA, 1995a; Johnson et al., 1992; Johnson and Fernandez, 1992; Cook and Zedaker, 1992; NAPAP, 1991
Eastern Hardwood Forest / Sugar Maple	Northeastern US and Canada	Acidic deposition and ozone	Crown thinning, branch dieback, elevated mortality rates	Acidic deposition leads to nutrient imbalances through accelerated foliar leaching and soil acidification. Soil acidification is characterized by a loss of soil nutrient cations and occurrence of toxic aluminum levels. During 1980s sugar maple declined in many stands in the northeastern US and Canada. Involvement of acidic deposition in sugar maple decline has not been demonstrated but cannot be ruled out.	USFS, 1995b; EPA, 1995a; NAPAP, 1991

Figure E-9
U.S. Major Forest Types Affected by Air Pollution-Induced Visual Injuries



Note: Only areas affected by non-point pollution are shown. Scientific certainty varies with location. Direct ozone-induced injuries also occur in several other locations not indicated (e.g., Southern Forests, Berraug et al, 1995).
Sources: NAPAP, 1991 and White and Cogbill, 1992.

Despite limitations in detecting trends in forest health and associated causal agents, it is possible to identify areas in the US that contain forests known or suspected to experience visual injuries. Forests affected by high concentrations of air pollutants in the vicinity of point sources may provide useful case studies because cause and effect relationships may be easier to establish and visual injuries can be severe enough to cause significant aesthetic impacts. In particular, point sources can lead to well-defined concentration gradients in the prevailing downwind direction causing corresponding gradients of visual injuries (Smith, 1990; NAPAP, 1987).

In contrast, concentrations of regionally distributed air pollutants (e. g., ozone and acidic deposition), can be fairly uniform over large geographic areas. Visual symptoms can be more intense in the vicinity of urban areas or industrial sites but may not be limited to these regions (NAPAP, 1987) making it more difficult to establish cause-and effect relationships. Despite difficulties in establishing cause-and-effect relationships, all identified forest ecosystems likely to have experienced air pollution-induced visual injuries in recent history are affected by regionally distributed air pollutants.

Economic Value of Changes in Forest Aesthetics

Though studies that attempt to estimate the value of changing aesthetics are limited in number and scope, they do suggest that people value forest aesthetics and change outdoor recreational behavior according to the quality of forest health in recreational areas. The shear volume of forest-based recreation in the United States suggests that improvements in forest aesthetics could result in substantial benefits. For example, the United States Forest Service reports that recreation visitor days to national forests have increased over the last ten years from 250 million to over 350 million. With the potential magnitude of aggregated individual preferences in mind, we review several studies that relate individual preference for forests with respect to overall appearance and attempt to extend these analyses to those regions where forests are most affected by air pollution.

Peterson *et al.* (1987) used the contingent valuation (CV) method and a hedonic property valuation model to estimate willingness to pay to avoid ozone-induced forest damage in the Los Angeles area. This contingent valuation survey involved two samples: one made up of recreationalists in the greater Los Angeles area, and the second made up of individuals who owned property within the boundaries of the San Bernardino and Angeles National Forests. Each group was shown a set of photographs depicting varying degrees of vegetative damage. Mean WTP by recreationalists and residents were found to be approximately $43 and $137 per household per year, respectively. The hedonic analysis revealed a significant and positive WTP to avoid homes located in forested areas exhibiting ozone damage. Using these two methods, total damages resulting from the current levels of ozone induced forest injury were estimated to be between $31 and $161 million per year. The study authors rejected a significant percentage of responses as "protest" or "inconsistent" bids (40 percent), which would indicate that many respondents may not have understood or accepted the scenario and the commodity being valued. Apart from this, the study also does not address a series of concerns related to the application of CV to assess nonuse values. First, the survey instrument did not include reminders of budget constraints or substitute goods and services. Second, the survey did not clearly define the commodity. The WTP scenario did not clearly indicate how forest damages were to be mitigated.

Walsh *et al.* (1990) interviewed 200 individuals representing the general population of Colorado and were shown three color photographs representing three levels of forest quality. The mid-level quality was said to represent the present state of the forest (100 to 125 live trees measuring more than six inches in diameter at breast height (dbh) per acre). Respondents were asked their WTP to prevent the lowest state (zero to 50 live trees measuring more than six inches dbh per acre) and attain the highest state (125 to 175 trees per acre in this size class). All respondents were informed beforehand that the damage being valued was due to pine beetle and spruce budworm infestations. Mean WTP per respondent was estimated to be $47. An evaluation of the Walsh et al (1990) study reveals several notable strengths. The survey included reminders of budget constraints, and the authors ensured that respondents were familiar with the commodity being valued and were accustomed to paying for access to recreation sites with good forest quality. Only five percent of the responses were rejected as "protest" or "large" bids. Weaknesses of the study include a small sample size (198), inconsistency between results solicited using different question formats (iterative bidding vs. direct question), and potential biases attributable to framing the question as one of the most important issues affecting Colorado residents and the possibility of a "warm glow" affect concerning payment for a social cause.

Holmes et al (1992) used a CV survey to determine WTP to protect threatened spruce-fir forests in Southern Appalachia from insect and air pollution damage. In this study, residents within 500 miles of Asheville, NC were surveyed about their willingness to pay to eliminate damages to regional spruce-fir forests. The authors used two survey formats, discrete choice and payment cards. The mean willingness to pay for protecting the spruce-fir forests was $20.86 using the payment card method, and $99.57 using the discrete choice method. The study ensured that the sample had adequate knowledge of the commodity being valued, and the overall sample size was large. Unfortunately, several weaknesses arise from the fact that the sample was divided into two groups in order to test different survey formats. The study used a small sample size for each of the tested methods (232 and 236, respectively). The number of protest bids was small (7 to 10 percent), indicating that the respondents understood the function of the survey, but the final results generated by the two different methods were substantially different. This study was later revised in Holmes and Kramer (1996), where the results were published as mean willingness to pay of $36.22 for forest users, and $10.37 for nonusers.

Extending Economic Estimates to a Broader Area

These studies provide an incomplete picture of the total benefits that could be obtained by eliminating visual damages to forests associated with air pollution in the country. As an illustrative calculation, we extend the range of valuation estimates provided in Peterson (1987); Walsh et al. (1990); and Holmes and Kramer (1996) to the major regions of affected landscape in the United States. We do not estimate aesthetic value as a function of forest damage from varying levels of air pollution, but rather provide an estimate of the values placed on avoiding damages characteristically experienced during the 1980s in the United States.

In Table E-23 we present the results from the three studies. We base our calculations of benefits on the value per household of avoiding forest damages multiplied by the number of households in the study region.

In Table E-24 we present the results of an illustrative calculation that extends the "market" for this commodity to a broader group of households. The annual value of avoiding the forest damages is the product of the range of household values in Table E-23 and the total number of households in the states most affected by air pollution.

Table E-23
Summary of Monetized Estimates of the Annual Value of Forest Quality Changes

Study	Aesthetic Change Valued	Value of Change per Household (Current Dollars)	Value of Change per Household (1990 Dollars)[i]	Total Annual Value of Change for Region (Current Dollars)	Total Annual Value of Change for Region (1990 Dollars)[i]
Peterson et al. (1987)	Ozone damage to San Bernardino and Angeles National Forests	$6.31-$32.70[ii]	$7.26-$37.62	$27-$140 million	$31-$161million
Walsh et al. (1990)	Visual damage to Colorado's Front Range	$47	$61.68	$55.7 million	$73.09 million
Holmes and Kramer (1996)	Visual damage to spruce-fir forests in southern Appalachia	$10.81 nonusers $36.22 users	$10.37 nonusers $34.76 users	NA	NA

Note: i.) Values adjusted using all item Consumer Price Index, Economic Report of the President, 1998. Years for current dollar estimates: Peterson et al, 1987; Walsh et al, 1983; Holmes et al, 1991.
ii) Based on 4.3 million households in Los Angeles, Orange, and San Bernardino counties.
iii) Assumes 2.5 million households in North Carolina and 1.8 million in Tennessee.

Table E-24
Illustrative Value of Avoiding Forest Damage in the United States
(1990 Dollars)

Affected System	States Included	Value per Household	Households[i]	Estimated Total Annual Value[ii]	Cumulative Value (1990-2010)[iii]
Sierra Nevada and Los Angeles Basin	CA	$7.26-$37.62	10.4 million	$75.5 million -$391.2 million	$1.02 billion - $5.27 billion
Eastern Spruce Fir and Selected Eastern Hardwood	ME, VT, NH, MA, NY, PA, WV, TN, KY, NC, VA	$7.26-$37.62	23.2 million	$168 million - $872.8 million	$2.27 billion - $11.75 billion

Notes: i.) Household data from 1990 Census; ii) Total Value = Households x Value per Household; iii)Assumes a 5 percent real discount rate.

The results of existing work in this area suggest that improvements in air pollution controls result in positive changes in the aesthetic quality of forest stands. Pollutant control provisions of the 1970 CAA and the 1977 CAAA, for example, may have resulted in a significant decrease or elimination of forests visually affected in the vicinity of emission sources. Further reductions in air pollution emissions mandated by the 1990 CAAA should result in additional improvements in forest health and associated economic benefits derived from improved forest aesthetics.

Our illustrative calculation of the regional effects of improving the aesthetic quality of forest stands (Table E-24) likely overstates the extent of market for this commodity. Estimates presented in Table E-23, however, based on a more conservative application of the extent of market for this commodity, provide a better basis to estimating the order of magnitude of this category of effects of air pollution on ecosystem health. Considering only the Peterson et al. and Walsh et al. studies, conducted in two areas that have been shown in previous assessments to be affected by accumulated air pollution damages, estimates of the total annual value of improvements in the aesthetic quality of forests are in the $100 million to $250 million range.

Caveats and Uncertainties

To quantitatively assess the effects of air pollution emission reductions on forest aesthetic benefits, considerable amounts of high-quality data are required. These data include extensive long-term monitoring networks producing consistent and comparable information over time frames as long as several decades. In addition, injuries captured by monitoring networks have to be linked to the causal agent(s), a task that is currently associated with high factors of uncertainty. Only rarely, if ever, is air pollution the only factor negatively affecting forest health. Typically, a variety of adverse environmental factors act synergistically to induce injuries, considerably limiting our ability to detect air pollution as one of the factors causing injury and to quantitatively assess the amount of injuries attributable to air pollutants.

There are caveats to the use of benefits transfer in this context. The application of this method is intended to provide an order of magnitude estimate of the benefits associated with avoided aesthetic damages to forests in the United States. More sophisticated estimation methods will be required if a truly accurate estimate of value, especially the marginal value of incremental changes, is to be derived. Following is a summary of the caveats to using this approach.

- The impacts that we value are not equivalent to those avoided through the implementation of the CAAA, they are historical effects. A comprehensive assessment of forest aesthetics-related benefits associated with improvements in air quality is limited by significant factors of uncertainty occurring in both the natural science component of the assessment and the economic analysis. Factors of uncertainty in natural sciences include difficulties detecting trends in forest health in general, attributing changes in forest health to specific factors such as air pollution, and establishing valid dose-response relationships of forest exposure to air pollutants and resulting visual injuries.

- The types of aesthetic deterioration in the original studies are not necessarily the same as those experienced in other regions. The nature of forest aesthetic deterioration will vary (e.g. the yellowing of conifer needles vs. gypsy moth defoliation of hardwoods) as will the intensity.

- We do not fully assess the range of potential substitutes for the aesthetic health of regional forests to each household. Having ready substitutes could lower the value a specific household might place on aesthetic quality of regional forests.

- The distinction between marginal values for forest health and average value is not made. As marginal values for changes in forest health diverge from the assumed average value in this analysis, the estimates develop bias.

- We assume that differences in average regional income do not affect estimates.

Toxification of Freshwater Fisheries

The purpose of this section is to assess, from 1990 through 2010, the ecological benefits likely to accrue as a consequence of reductions in the emissions of hazardous air pollutants (HAPs), as mandated by the CAAA. Title III of the CAAA lists 189 chemicals considered to be HAPs. Ideally, a comprehensive economic analysis of the ecological benefits of CAAA-mandated reductions in HAP emissions would include analyses for all service flows potentially affected by the emissions of HAPs. However, a broad quantitative analysis of all these benefits is not yet scientifically possible. What is possible is a qualitative analysis of the likely benefits of reduced HAP emissions for recreational fishing. A more detailed description of this analysis is found in *Economic Benefits of Decreased Air Toxics Deposition Attributable to the 1990 Clean Air Act Amendments*, 1990-2010 (IEc 1998d).

Impacts of Toxic Air Emissions

Five HAPs, mercury, PCBs, chlordane, dioxins, and DDT were responsible for nearly 95 percent of the fishing advisories extant in 1995 (EPA 1996b). The use of three of these compounds (PCBs, chlordane, and DDT) was effectively illegal in the United States prior to 1990 (EPA 1992a), and there are currently no plans for additional CAAA regulations of these compounds (Federal Register Unified Agenda 1998). The remaining two HAPs, mercury and dioxins, are therefore the focus of this analysis.

Because the ecosystem responses to toxic contamination are poorly understood, and observable service flow impacts are difficult to model, we use fishing advisories as a measure of the extent of toxic contamination. In addition, we can characterize the economic impact of HAPs emissions based on altered fishing behavior caused by toxic contamination of freshwater fisheries. It is important to note that fishing advisories alone do not provide a comprehensive view of impacts of toxic contamination on ecosystems, and more expansive measures should be examined in future research.

Fishing advisories are issued by state and tribal agencies when the levels of toxins in the tissue of fish exceed limits established by both state and federal authorities. Fishing advisories generally take one of four forms:

- Advisory for any consumption by the general population;
- Advisory for pregnant women, nursing mothers, and children;
- Advisory for limitation on consumption based on size of fish and frequency of consumption; and
- Advisory for limitation on consumption for specific sub-populations.

According to the U.S. Fish and Wildlife Service (1998), the total number of advisories in the U.S. in 1997 was 2,299, increasing five percent from 1996. The number of water bodies under advisory represents 16.5 percent of the nation's total lake acres and 8.2 percent of total river miles. In addition, 100 percent of the Great Lakes waters and their connecting waters and a large portion of the nation's coastal waters are also under advisory. The total number of advisories in the U.S. has steadily increased for mercury and dioxin.

Mercury is responsible for approximately 75 percent of all fish consumption advisories in effect in 1995 (EPA 1996b). Mercury from point sources, as opposed to mercury deposited from the atmosphere, may be responsible for many of these advisories. The lakes and streams with advisories are concentrated in the northern portions of Minnesota and Wisconsin, as well as in Florida, Missouri, Indiana, Ohio, North Carolina and New England (EPA 1997a, 1997d). Judging by fish consumption advisories, fish mercury levels do not appear to be a widespread problem in the remainder of the United States, and EPA (1997d) found that the typical consumer eating purchased fish is not at risk of methylmercury poisoning. Approximately three percent of fish consumption advisories in effect in 1995 were due to the presence of dioxins (EPA 1996b), and in 1996, 18 states had one or more water bodies under advisement because of dioxin levels in fish (EPA 1997a). Dioxins from point sources may be responsible for many of these advisories.

Several limitations to the fish advisory data exist. First, many lakes, rivers and streams have not been analyzed for toxicity, and it is possible that advisories eventually will be issued for these water bodies. Table E-25 summarizes the sampling intensity for toxicity through 1997. Second, current levels of toxics in watersheds may result in future toxification of healthy water bodies, even in the absence of additional future HAP deposition. Therefore, the current set of fish advisories underestimates the magnitude of toxification from air deposition to date. Third, the protocol for fishing advisory issuance may vary from

Table E-25
Summary of National Data on Toxicity Sampling for Fishing Advisories

Water Body	Percentage of Water Bodies Assessed for Contaminants	Percentage of Assessed Water Bodies Under Advisory
Lakes (acres)	11.36	78.61
Rivers and Streams (miles)	2.41	29.58

Source: EPA 1997a

state to state, removing any consistent basis on which to judge the levels and causes of fisheries' toxicity for each state.

Illustration of Economic Cost to Anglers

The economic welfare implication of water quality changes to recreational fishing are well studied. Most literature in this field focuses on the impacts of deteriorating water quality in a specific fishery. More recently, economic models are appearing that address the social welfare cost of water quality deterioration in multiple fisheries within a region. Such an approach accounts for choices made by fishermen concerning travel to, and the attributes of (e.g., fish advisories), multiple fisheries. Random utility models (RUM) provide the computational method for these regional analyses.

Montgomery and Needelman (1997) were the first to use direct water quality measures in conjunction with a RUM approach to analyze the economic impacts of toxification on regional anglers. Using data from the New York Department of Environmental Conservation (NYDEC), Montgomery and Needelman identify 23 water bodies with toxicity advisories among 2,561 lakes and ponds in the state. Using water quality data and geographic location of both water bodies and anglers, the authors estimate the economic cost of the toxification within the state. The results are presented in Table E-26.

Table E-26
Estimates of the Welfare Cost of Toxification in New York State (1990 Dollars)

Level of Toxicity	Compensating Variation per Trip	Compensating Variation per Capita per Day	Compensating Variation per Capita per Season
Toxic Contamination	$1.23	$0.37	$51.51
Site Closed Due to Toxic Contamination	$1.69	$0.50	$70.92

Source: Montgomery and Needelman 1997

The results from Montgomery and Needelman indicate that the economic welfare implication of existing toxic contamination is substantial for New York State, as described below:

> $0.37/person/day x 17,990,000 people x 140 fishing days/season = $931,882,000/season.

In perpetuity,[22] the value of eliminating toxicity in New York State, using a five percent discount rate, is calculated to be $18,637,640,000.

Clearly, the results using these assumptions are very large. Applications of this model for purposes of estimating the effects of air toxics deposition on recreational fishing requires further investigation of the assumptions in this model.

Jakus et al. (1997) conducted a similar RUM analysis of toxification of reservoirs in Tennessee. Data from the Tennessee Valley Authority showed fishing advisories for two of 14 reservoirs in central Tennessee, and six of 14 reservoirs in the eastern portion of the state. Again, using water quality data and the geographic locations of both water bodies and anglers, Jakus et al. (1997) estimated the economic impact of the fish consumption advisories. Anglers living in central Tennessee suffered a $17.92 per trip per season loss from the advisories, and anglers in eastern Tennessee suffered a $38.27 loss (1990 dollars). Therefore, considering an angler population of 146,450 individuals, the impact of this level of toxification into perpetuity, using a five percent discount rate, is approximately $65.96 million.

These results indicate that fish advisories impose substantial economic cost on anglers in the United States. Measuring the marginal changes in toxification that would occur in the absence of the CAAA is not possible, but it is plausible to state that continued HAP emissions impose a cost on society if they result in the issuance of additional fish advisories. Any efforts to minimize these emissions, including the CAAA, may generate corresponding benefits.

If air deposition of toxics results in statewide fishing advisories (e.g., Connecticut, Washington D.C., Illinois, Maine, Massachusetts, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Vermont), substitution away from recreational fishing for other activities may begin to occur. No models are available to estimate the economic impact of a large-scale substitution away from recreational fishing. The RUM approach does not adequately capture the magnitude of ubiquitous toxification because the models measure only the choice to participate in the activity and not the welfare implications of participation in alternative activities, nor do they account for the industries that provide supplies and services to anglers in the region. However, the economic cost of statewide advisories could be substantial.

Although Montgomery and Needelman (1997) and Jakus et al. (1997) examined only two areas of the country - New York State and part of Tennessee - their work demonstrates that HAP emissions have a measurable economic cost when the consequence of these emissions is the issuance of fish advisories for recreational fisheries. While it is not possible to measure the differences in HAP deposition and the marginal ecological impacts that will result from the CAAA, it is clear that continued emissions of HAPs will result in further toxification of aquatic resources, and reductions in HAP emissions may provide economic benefits.

The toxification of freshwater ecosystems in the United States by mercury and dioxins is a problem, and emissions of mercury and dioxins to the atmosphere contribute significantly to the problem. Quantifying the magnitude of ecosystem effects of air toxics deposition is not yet possible, but it is clear that the deposition of air toxics to some ecosystems, such as freshwater recreational fisheries, can result in measurable economic costs.

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[22] A perpetuity is a stream of benefits, accrued over an infinite time horizon. A simplified formula for calculating a perpetuity of equal benefits accrued annually, in which the first payment is received at the end of year one, the second payment is received at the end of year two, etc., is: (Nominal Value of Benefit) / (Discount Rate)

Caveats and Uncertainties

Because of limitations in the currently available data and models, a comprehensive quantitative analysis of the ecological benefits of reduced mercury and dioxin emissions for recreational fishing is not possible. However, such an analysis may be possible in the foreseeable future.

- The potential for mercury and dioxins to persist for long periods of time in the environment is a confounding factor in this analysis. Because these pollutants can persist in aquatic ecosystems for decades, even though the CAAA may reduce their emissions, it is possible that the status of toxified ecosystems may not be significantly affected during the time frame of the analysis (i.e., through 2010).

- In addition, the persistent nature of toxification presents challenges with respect to how benefits are discounted over time. In those cases where recovery from toxification will take a number of years, the benefits accrued by society will be diminished in terms of their present value. In other words, if all air emissions ceased, many fish consumption advisories would remain in place until the fisheries recovered. If this recovery period were to extend for several decades, the present value of economic benefits from the eventual retraction of advisories could be reduced dramatically. In a cost-benefit decision analysis, these benefits might not justify the costs of HAP regulations. In this case, an inter-generational benefits assessment, where discounting is not applied, would be required.

- The global nature of mercury pollution is another confounding factor Because a significant portion of mercury deposited within the U.S. comes from the global pool, a decrease in U.S. emissions may be offset by increases in emissions in other countries. If this should occur, it might be difficult to detect or predict actual changes in the toxicity of U.S. aquatic ecosystems, despite reductions in U.S. emissions.

- To quantitatively assess the effects of mercury and dioxin emission reductions on recreational fishing, more and better data and models are required. The most pressing research needs in this area are a model that can predict the national fate and transport of dioxin, and models that can, on a national scale, convert mercury and dioxin deposition quantities to amounts of the contaminants in fish. Data to verify these models is also highly desirable.

- Even if it were currently possible to perform the analysis discussed here, it would likely capture only a fraction of all the benefits attributable to CAAA-mandated HAP emissions reductions. The analysis focused entirely on two HAPs and on one endpoint. Neither the potential benefits of reductions in the emissions of other HAPs nor other endpoints were considered.

Conclusions and Implications

Our analysis has identified four major categories of air pollutants that affect ecological structure and function: sulfur compounds, nitrogen compounds, tropospheric ozone, and hazardous air pollutants. Each of these pollutants is scientifically documented as a cause of ecosystem degradation due to acute and chronic exposure. Sulfur and nitrogen compounds contribute to episodic and chronic acidification of aquatic and terrestrial ecosystems, while the chronic deposition of nitrogen compounds alone may cause harmful eutrophication to terrestrial and aquatic ecosystems. Tropospheric ozone disrupts the normal functioning of plants, leading to acute, visible damages to terrestrial ecosystems, and chronic exposure at levels that do not produce acute damages may result in reduced growth rates and eventually alter ecosystem nutrient cycling. Finally, hazardous air pollutants deposited across the landscape are accumulating in aquatic organisms and subsequently entering both aquatic and terrestrial foodchains. Though the ecological impacts are not fully understood, the long-term effects of introducing hazardous air pollutants to ecosystems may be slow to manifest and irreversible in nature.

Ecological effects can occur at different levels of biological organization. Most effects that are currently quantifiable are understood at the individual or population level, perhaps because of the feasiblity of conducting controlled experiments at this level. For example, research on the effects of ozone on timber began with experimental research on the response of seedlings and leaves of mature trees to elevated levels of ozone. Only recently have modeling efforts begun to consider interactions of factors at the community level, taking into account the dynamics of competitive relationships among tree and plant species. Experimental research continues to progress toward a better understanding of the full range of ecological impacts including effects at the ecosystem level. Continued consideration of these higher-order effects of pollutants on ecological systems is necessary for a more complete understanding of the benefits of pollution control.

Because the chronic ecological effects of air pollutants may be poorly understood, difficult to observe, or difficult to discern from other influences on dynamic ecosystems, our analysis focuses on acute or readily observable impacts. Disruptions that may seem inconsequential in the short-term, however, can have hidden, long-term effects through a series of interrelationships that can be difficult or impossible to observe, quantify, and model. This factor suggests that many of our qualitative and quantitative results may underestimate the overall, long-term effects of pollutants on ecological systems and resources.

Summary of Quantitative Results

Although the effects of air pollutants on ecological systems are likely to be widespread, many effects may be poorly understood and lack quantitative effects characterization methods and supporting data. In addition, many of our quantitative results reflect an incomplete geographic scope of analysis; for example, we generated monetized acidification results only for the Adirondacks region of New York State. As a result, quantitative results we generate for the purposes of estimating the benefits of the CAAA reflect only a small portion of the overall impacts of air pollution on ecological systems. Our quantitative overview of effects nevertheless suggests that the overall impacts of air pollution are far greater than those quantified.

Table E-27
Summary of Monetized Ecological Benefits (millions 1990$)

Description of Effect	Air Pollutant	Geographic Scale of Economic Estimate	Range of Annual Impact Estimates in 2010	Primary Central Estimate for 2010	Primary Central Cumulative Impact Estimate 1990-2010	Key Limitations
Freshwater acidification	Sulfur and nitrogen oxides	Regional (Adirondacks)	\$12 to \$88	\$50	\$260	- Captures only recreational fishing impact - Incomplete geographic coverage leads to underestimate of benefits
Reduced tree growth - Lost commercial timber	Ozone	National	\$190 to \$1000	\$600	\$1,900	- Uncertainties in stand-level response to ozone exposure - Uncertainty in future timber markets
TOTAL MONETIZED ECONOMIC BENEFIT			\$200 to \$1,100	\$650	\$2,200	- Partial estimate that omits major unquantifiable benefits categories; see text

Note: Estimates reflect only those benefits categories for which quantitative economic analysis was supported. A comprehensive total economic benefit estimate would likely greatly exceed the estimates in the table. Range of estimates for timber assessment is based on variation in annual point estimates for 2005 through 2010.

Despite these limitations, it is important to recognize the magnitude of the monetized ecological benefits that we could estimate and reflect those results in the overall estimates of benefits generated in the larger analysis. Table E-27 provides a tabular summary of the results documented earlier in this appendix. It is not possible to indicate the degree to which ecological benefits are underestimated, but considering the magnitude of benefits estimated for the select endpoints considered in our analysis, it is reasonable to conclude that a comprehensive benefits assessment would yield substantially greater total benefits estimates.

Recommendations for Future Research

Previous sections of this appendix have discussed several areas for future research related to the individual research and analytic efforts conducted. From a broader perspective, there are three key research needs to improve benefits assessments of this type:

- Exemplary assessments that incorporate a greater emphasis on ecosystem structure and function rather than specific service flows;
- Assessments with broader geographic coverage of impacts categories assessed in this report; and
- More sophisticated treatment of uncertainty and complexity, including careful consideration of the irreversibility of ecosystem impacts.

Assessing Changes in Ecosystem Structure and Funtion

A major limitation of our quantitative analysis is that by focusing on individual acute and chronic impacts it is possible to lose sight of ecosystem-level changes to structure and function. These ecosystem-level changes could eventually lead to large-scale impacts far greater in degree and geographic extent. Determining the appropriate ecological level of analysis is crucial to properly account for ecological benefits that may accrue from environmental regulations. While quantifying the decrease in impacts on species attributable to air pollutant control is analytically tractable, the impact of pollutant reductions on ecosystem structure and function may be a more appropriate measure that can be further explored in future analyses.

Changes in ecosystem structure and function may not be obvious to the lay person, and the ultimate effects of such changes in ecosystems are sometimes unpredictable in scale and nature. Ecosystems affected by humankind may respond in a discontinuous manner around critical thresholds that are boundaries between locally stable equilibria. Complexity in ecosystems prevents analysts from using linear methods to "add up" the discrete ecological effects of pollution. Understanding the complex cause and effect relationships between pollution and deterioration of ecosystem structure and function is fundamental to making adequate policy decisions that will protect ecological resources. The isolation of service flows may often imply an oversimplified cause and effect relationship between pollution and the provision of the service flow, when more often the service flow is affected by complex non-linear relationships that govern ecosystem structure and function. The result is that ecosystem impacts may not be adequately assessed by analyses that focus on specific service flows.

One potentially fruitful approach to assessing impacts on the ecosystem scale would be to more adequately model a wide range of ecosystem functions that do not necessarily contribute to human welfare. Assessments at the watershed scale might provide an appropriate level of detail to more adequately characterize some of these intermediate service flows. This type of research effort would require close cooperation between air pollution specialists, ecologists, and economists to be most useful within the context of benefit-cost analyses such as this one.

Broader Geographic Scale

Several of the ecological analyses conducted to support the first prospective section 812 report are limited by their partial geographic coverage. For example, while nitrogen deposition is an important contributor to eutrophication in a wide range of Eastern and Gulf Coast estuaries, resource, time, and data availability constraints, as well as limitations in our ability to reasonably apply an avoided cost approach, prevented EPA from conducting a national economic assessment for this category of impacts. In this and many other effects categories, extension of the methods applied here to new geographic areas could greatly enhance the comprehensiveness of the physical effects and economic impact estimates.

Alternative Treatment of Uncertainty

At present a variety of economic schools of thought are converging on quantitative analysis of environmental impacts that integrate uncertainty, irreversibility and ecological complexity. Efforts within the field of "ecological economics" to develop structured appraisals of uncertainty associated with environmental management and procedural rationale for decision making have yielded a variety of theoretical proposals. Drepper and Mansson (1993) argue that most aspects of uncertainty are compressed into the discount rate for policy analysis, resulting in the inappropriate use of a constant positive discount rate for environmental existence values. These existence values, they argue, may be more appropriately assigned negative discount rates. Faucheux and Munda (1997) advance a similar criticism of the unified discount rate and posit that a differentiated discount rate be applied to multiple aspects of a policy decision according to the implied uncertainty of each aspect. This quantitative approach evolves into a multi-criteria decision framework that departs from conventional cost-benefit analysis. Alternatively, Hinterberger and Wegner (1997) abandon quantitative analysis as a futile exercise due to ecosystem complexity in favor of simply applying the precautionary principal of reducing any and all environmental impacts that have uncertain outcomes.

In the resource economics literature, discussion of alternatives to cost-benefit analysis when the magnitude of benefits or costs are uncertain have focused on the concept of quasi-option value (see Freeman 1993 for a summary). The term was coined by Arrow and Fisher (1974) to describe the potential welfare gain of altering the timing of development/preservation decisions under uncertainty and when at least one of the choices involves an inrreversible commitment of resources (either spent or preserved). While much of the quasi-option value literature suggests that adopting this type of framework would lead to greater environmental protection, Freeman (1993) argues that it is also possible that the information gained by some incremental development of ecological resources might be the only way to reduce uncertainty and gain information about the magnitude of the trade-offs involved in preventing ecological exposures. It is nonetheless important to recognize that option and quasi-option value should not be considered as additional components of willingness-to-pay, but rather a value of altering decision making practices (e.g., the value of moving from a benefit-cost framework based on expected value to a framework that better considers the value of information gained over time and the irreversibility of certain effects).

The main implication of this body of work is that cost-benefit analysis may well underestimate the value of both the costs and benefits of uncertain, irreversible environmental outcomes from public policy. From the cost perspective, regulating a pollutant that may have no environmental consequence may cause economic losses that reduce unknown investment and growth opportunities in the future. From the benefits perspective, the value of preserving ecosystem integrity may include the mitigation of irreversible damage to a variety of service flows previously not associated with simplified dose-response relationships between pollution and ecosystems. Applications of these principles in economic assessments, including more rigorous assessments of option and quasi-option value, probabilistic analysis of multiple scenarios, and value of information approaches have the potential to greatly increase the utility of uncertain ecological assessment results for the purposes of making environmental policies.

References

Aber, J.D., Nadelhoffer, K.J., Steudler, P., and Melillo, J.M., 1989. Nitrogen Saturation in Northern Forest Ecosystems. *BioScience*, 39(6): 378-386.

Arrow, K.J. 1968. Optimal capital policy and irreversible investment. (In ed. J.N. Wolfe) *Value, Capital and Growth*" Aldine: Chicago.

Arrow, K.J. and A.C. Fisher. 1974. Environmental preservation, uncertainty, and irreversibility. *Quarterly Journal of Economics* 88: 312-319.

Asman, W.A.H., and S.E. Larsen. 1996. Atmospheric Processes, (Ch. 2) *Eutrophication in Coastal Marine Ecosystems Coastal and Estuarine Studies*, 52: 21-50. American Geophysical Union.

Ayers, H., Hager, J., and Little, C.E., 1997. *An Appalachian Tragedy. Air Pollution and Tree Death in the Eastern Forests of North America.* (Eds. Ayers, H., Hager, J., and Little, C.E.) Sierra Club Books:, San Francisco.

Baden, S.P., L.O. Loo, L. Pihl, and R. Rosenberg. 1990. Effects of eutrophication on benthic communities including fish: Swedish West Coast. *Ambio* 19(3): 113-123.

Baggetta, A.M. 1998. List of Dioxin-Producing Industry Sectors Gets Tentative OK From Peer Review Panel. *Environmental Reporter* 29(7):377-378. June 12.Bartell, S.M., R.H. Gardner, and R.V. O'Neill. 1992. *Ecological Risk Estimation.* Lewis Publishers: Chelsea, MI.

Bell, J.D., and D.A. Pollard. 1989. Ecology of fish assemblages and fisheries associated with seagrasses. *Aquatic Plant Studies* Vol. 2: 565-609. (Eds. A.W.D. Larkum, A.J. McComb, and S.A. Shepherd) Elsevier: Amsterdam.

Birdsey, R.A., 1992a. *Carbon storage and accumulation in United States forest ecosystems.* Gen. Tech. Report WO-59. Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Birdsey, R.A., 1992b. *Changes in forest carbon storage from increasing forest area and timber growth.* In: Forest and Global Change. Volume One: Opportunities for Increasing Forest Cover. (R.N. Sampson and D. Hair, eds.) Washington, DC 1992. p.23-39.

Birdsey, R.A., and L.S. Heath, 1995. *Carbon changes in U.S. forests.* In: Productivity of America's Forests and Climate Change (Joyce, L.A., ed.), U.S. Department of Agriculture, Forest Service, General Technical Report RM-271.

Binkley, D., T.D. Droessler, and J. Miller, 1992. Pollution impacts at the stand and ecosystem level. (In eds. R.K.Olson, D. Binkley, and M. Boehm) *The Response of Western Forests to Air Pollution*,. Ecological Studies 97. Springer-Verlag: New York, p. 235-258.

Black, F, and M. Scholes. 1973. The Pricing of Options and Corporate Liabilities. *Journal of Political Economy*, 81: 637-659.

Boesch, D.F. 1997. "The Cambridge Consensus" Forum on Land-Based Pollution and Toxic Dinoflagellates in Chesapeake Bay. W.H. Bell and D.A. Nemazie, Rapporteurs.

Boesch, D.F., D.M. Anderson, R.A. Horner, S.E. Shumway, P.A. Tester, and T.E. Whitledge. 1997. "Harmful algal blooms in coastal waters: Options for prevention, control and mitigation" An assessment conducted for the National Fish and Wildlife Foundation and The National Oceanic and Atmospheric Administration Coastal Ocean Program.

Bonsdorff, E., E.M. Blomquist, J. Mattila, and A. Norkko. 1997. Coastal eutrophication: Causes, consequences, and perspectives in the archipelago areas of the northern Baltic Sea. *Estuarine Coastal & Shelf Science* 44(Suppl A): 63-72.

Boring, L.R., W.T. Swank, J.B. Waide, and G.S. Henderson. 1988. Sources, fates, and impacts of nitrogen inputs to terrestrial ecosystems: review and synthesis. *Biogeochemistry* 6: 119-125.

Boynton, W.R., J.H. Garber, R. Summers, and W.M. Kemp. 1995. Inputs, transformations, transport of nitrogen and phosphorus in Chesapeake Bay and selected tributaries. *Estuaries* 18: 285-314.

Brown, T.C., 1987. Production and cost of scenic beauty: Examples for a ponderosa pine forest. *Forest Science* 33(2): 394-410.

Brown, T.C.and T.C. Daniel, 1984. Modeling Forest scenic beauty: Concepts and applications to ponderosa pine. USDA Forest Service Research Paper RM-256. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Bruck, R.I., Robarge, W.P., and McDaniel, A., 1989. Forest decline in the boreal montane ecosystems of the southern Appalachian Mountains. *Water, Air, and Soil Pollution*. 48: 161-180.

Buhyoff, G.J. and J.D. Wellman, 1980. The specification of a non-linear psychophysical function for visual landscape dimensions. *J. Leisure Res* 12(3): 257-272.

Buhyoff, G.J., J.D. Wellman, and T.C. Daniel, 1982. Predicting scenic quality for mountain pine beetle and western spruce budworm damaged forests. *Forest Science* 28(4): 827-838.

Buhyoff, G.J., R.B. Hull IV, J.N. Lien, and H.K. Cordell, 1986. Prediction of scenic quality for southern pine stands. *Forest Science* 32(3): 769-778.

Buyoff, G. J., and W. A. Leuschner. 1978. Estimating psychological disutility from damaged forest stands. *Forest Science*, 28(3).

Buhyoff, G.J., W.A. Leuschner, and J.D. Wellman, 1979. Aesthetic impacts of southern pine beetle damage. *Journal of Environmental Management* 8:261-267.

Buhyoff, G. J., and J. D. Wellman, 1980. The specification of a non-linear psychological function for visual landscape dimensions. *Journal of Leisure Research*, 12(3).

Burkholder, J.M., H.B. Glasgow Jr., C.W. Hobbs. 1995. Fish kills linked to a toxic ambush-predator dinoflagellate: distribution and environmental conditions. *Marine Ecology Progress Series* 124: 43-61.

Burkholder, J.M., K.M. Mason, H.B. Glasgow, Jr. 1992. Water-column nitrate enrichment promotes decline of eelgrass *Zostera marina*: evidence from seasonal mesocosm experiments. *Marine Ecology Progress Series* 81: 163-178.

Burkholder, J.M., G.B. Glasgow, and J.E. Cooke. 1994. Comparative effects of water column nitrate enrichment on eelgrass *Zostera marina*, shoalgrass *Halodule wrightii,* and widgeongrass *Ruppia maritima. Marine Ecology Progress Series* 105:121-138.

Bytnerowicz, A., and N.E. Grulke. 1992 . Physiological effects of air pollutants on western trees. (In eds. R.K.Olson, D. Binkley, and M. Boehm) *The Response of Western Forests to Air pollution*. Ecological Studies 97. Springer-Verlag: New York, p.183-234.

Camacho, Rodolfo, *Chesapeake Bay Program Nutrient Reduction Strategy Reevaluation, Financial Cost Effectiveness of Point and Nonpoint Source Nutrient Reduction Technologies in the Chesapeake Basin*, December 1992.

Canela, M.C. and W.F. Jardim. 1997. The Fate of Hg^0 in Natural Waters. *J. Braz. Chem. Soc.* 8(4): 421-426.

Carroll, G. 1998. Are our coastal waters turning deadly. *National Wildlife* April/May.42-46.

Chesapeake Bay Program, *1997 Nutrient Reduction Reevaluation Summary Report*, obtained online at www.chesapeakebay.net/bayprogram/pubs/97rpt.

Chichilnisky, G and G. Heal. 1998. Economic Returns form the Biosphere. *Nature* 392: 629-30.

Church, M.R., K.W. Thornton, P.W. Shaffer, D.L. Stevens, B.P. Rochelle, G.R. Holdren, M.G. Johnson, J.J. Lee, R.S. Turner, D.L. Cassell, D.A. Lammers, W.G. Campbell, C.I. Liff, C.C Brandt, L.H. Liegel, G.D. Bishop, D.C. Mortenson, S.M. Pierson, and D.D. Schmoyer. 1989. *Direct/Delayed Response Project: Future Effects of Long-term Sulfur Deposition on Surface Water Chemistry in the Northeast and Southern Blue Ridge Province.* EPA/600/3-89/026a-d, U.S. Environmental Protection Agency, Washington, DC.

Church, M.R., P.W. Shaffer, K.W. Thornton, D.L. Cassell, C.I. Liff, M.G. Johnson, D.A. Lammers, J.J. Lee, G.R. Holdren, J.S. Kern, L.H. Liegel, S.M. Pierson, D.L. Stevens, B.P. Rochelle, and R.S. Turner. 1992. *Direct/Delayed Response Project: Future Effects of Long-term Sulfur Deposition on Stream Chemistry in the Mid-Appalachian Region of the Eastern United States.* EPA/600/R-92/186, U.S. Environmental Protection Agency, Washington, DC.

Coastlines. 1994. Seagrasses as a primary indicator of water quality, obtained online, http://www.epa.gov/docs/OWOW/estuaries/coastlines/fall94/seagrasses.html(June 1998).

Coggins, J.S. and C.A. Ramezani. 1998. An Arbitrage-Free Approach to Quasi-Option Value. *Journal of Environmental Economics and Management* 35: 103-125.

Connecticut Department of Environmental Protection. 1998. *Nitrogen Removal Program: Long Island Sound.*

Connelly, N.A., B.A. Knuth and T.L. Brown. 1996. Sportfish Consumption Patterns of Lake Ontario Anglers and the Relationship to Health Advisories. *North American Journal of Fisheries Management* 16: 90-101.

Cook, E.R., and Zedaker, S.M., 1992. The dendroecology of Red Spruce decline. (In eds. C. Eagar, and M.B. Adams) *Ecology and Decline of Red Spruce in the Eastern United States*, Ecological Study 96. Springer-Verlag: New York, p.192-234.

Correll, D.L., and D. Ford. 1982. Comparison of precipitation and land runoff as sources of estuarine nitrogen. *Estuarine Coastal and Shelf Science* 15: 45-56.

Cosby, B.J., G. Hornberger, J. Galloway. 1985a. Time scales of catchment acidification: a quantitative model for estimating freshwater acidification. *Environmental Science and Technology* 19 (1144-1149).

Cosby, B.J., G.M. Hornberger, J.N. Galloway, and R.F. Wright. 1985b. Modeling the effects of acid deposition: Assessment of a lumped parameter model of soil water and streamwater chemisty. *Water Resources Research* 21: 51-63.

Costa, J.E., B.L. Howes, A.E. Giblin, and I. Valiela. 1992. Monitoring nitrogen and indicators of nitrogen loading to support management action in Buzzards Bay. p. 499-431; (In eds. DH McKenzie, DE Hyatt, and VJ McDonald) *Ecological Indicators*. Elsevier Applied Science:: New York.

Costanza, R., L. Wainger, C. Folke, K. Maler. 1993. Modeling Complex Ecological Economic Systems. *BioScience* 43: 545-555.

Crocker, T. D., 1985. On the value of the condition of a forest stock. *Land Economics*, 61(3).

Daily, G. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.

Daily, G., P. Matson and P. Vitousek. 1997. Ecosystem services supplied by soil. (In ed. G. Daily) *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press: Washington, DC.

Dame, R.F. 1993. *Bivalve filter feeders in estuarine and coastal ecosystem processes, Vol. G33*. Springer Verlag: Berlin.

Dame, R.F., J.D. Spurrier, and T.G. Wolaver. 1989. Carbon, nitrogen, and phosphorous processing by an intertidal oyster reef. *Marine Ecology Progress Series* 54:249-256.

Dame, R.F. R.G. Zingmark, and E. Haskin. 1984. Oyster reefs as processors of estuarine materials. *Journal of Experimental Marine Biology and Ecology* 83: 239-247.

Dame, R.F., R.G. Zingmark, L.H. Stevenson and D. Nelson. 1980. Filter feeder coupling between the estuarine water column and benthic subsystems (In ed. V.C. Kennedy) *Estuarine Perspectives*. Academic Press: New York, pp. 521-526.

Day, J.W., A.S. Hall, W.M. Kemp, and A. Yanez-Arancibia. 1989. *Estuarine Ecology*. Wiley-Interscience: New York.

DeHayes, D.H., 1992. Winter injury and development of cold tolerance of Red Spruce. (In eds. C. Eagar and M.B. Adams) *Ecology and Decline of Red Spruce in the Eastern United States*, Ecological Studies 96. Springer Verlag: New York, p. 295-337.

Delaware Bays NEP. 1996 Personal communication with National Oceanic and Atmospheric Association. As cited in Valigura et al.

De Steiguer, J., J. Pye, C. Love. 1990. Air Pollution Damage to U.S. Forests. *Journal of Forestry*, Aug 90, p. 17-22, 1990.

Desvousges, W.H., V. Kerry Smith, and A. Fisher. 1987. Option Price Estimates for Water Quality Improvements: A Contingent Valuation Study for the Monongahela River. *Journal of Environmental Economics and Management* 14: 248-267.

Diana, S.C., C. A. Bisogni, K. L. Gall. 1993. Understanding Anglers Practices Related to Health Advisories for Sport-Caught Fish. *Journal of Nutrition Education* 25(6): 320-328.

Dixit, A.K and R.S. Pindyck. 1994. *Investment Under Uncertainty*. Princeton University Press: Princeton, NJ.

Doering, P.H. 1989. On the contribution of the benthos to pelagic production. *Journal of Marine Research* 47: 371-383.

Drepper, F.R. and B.A. Mansson. 1993. Intertemporal valuation in an unpredictable environment. *Ecological Economics* 7: 43-67.

Duarte, C.M. 1995. Submerged aquatic vegetation in relation to different nutrient regimes. *Ophelia* 41:87-112.

Eagar, C., and M.B. Adams, 1992. *Ecology and Decline of Red Spruce in the Eastern United States.* Ecological Studies 96. Springer Verlag: New York, 1992.

Elks, R.D., Director of Water Resources, Greenville Utilities Commission, Greenville, NC.

Englin, J.E., T.A. Cameron, R.E. Mendelsohn, G.A. Parsons and S.A. Shankle. 1991. *Valuation of Damages to Recreational Trout Fishing in the Upper Northeast Due to Acidic Deposition*, Prepared for the National Acidic Precipitation Assessment Program, Washington, D.C. by Pacific Northwest Laboratory. PNL-7683.

Engstrom, D.R. and E.B. Swain. 1997. Recent Declines in Atmospheric Mercury Deposition in the Upper Midwest. *Environ. Sci. Technol.* 31:960-967.

Faucheux, S., G. Froger, G. Munda. 1997. "Toward an integration of uncertainty, irreversibility, and complexity in environmental decision making." In eds. J. van den Bergh, J. van der Straaten, *Economy and Ecosystems in Change*, Cheltenham, UK: Edward Elgar.

Federal Register. 1998. Unified Agenda. 63(80), Book 3. April 27.

FDA (U.S. Food and Drug Administration). 1994. Action Levels for Poisonous or Deleterious Substance in Human Food and Animal Feed. Industry Activities Staff Booklet. Obtained online, http://vm.cfsan.fda.gov/~lrd/fdaact.html July 30, 1998.

Fisher, D., J. Ceraso, T. Mathew, and M. Oppenheimer. 1988. *Polluted Coastal Waters: The Role of Acid Rain.* Environmental Defense Fund: New York.

Fisher, D.J., and M. Oppenheimer. 1991. Atmospheric Nitrogen Deposition and the Chesapeake Bay Estuary. *Ambio* 20(3-4):102-108.

Fitzgerald, W.F. 1995. Is Mercury Increasing in the Atmosphere? The Need for an Atmospheric Mercury Network (AMNET). *Water, Air, and Soil Pollution* 80:245-254.

Flowers, P.J., H.J. Vaux, P.D. Gardner, and T. J. Mills, 1985. *Changes in recreation values after fire in the northern rocky mountains*. Research Note PSW-373, USDA.

Frankel, O., A Brown, and J. Burdon. 1995. *The Conservation of Plant Biodiversity*. Cambridge University Press: Cambridge.

Freeman, M., 1997. On Valuing the Services and Functions of Ecosystems. (In eds. Simpson, R.D. and N.L. Christensen, Jr.) *Ecosystem Function & Human Activities*. Chapman & Hall: New York.

Freeman, M., 1993. *The Measurement of Environmental and Resources Values: Theory and Methods* Resources for the Future: Washington, DC.

Fogel, M.L., and H.W. Paerl. 1994. Isotopic tracers of nitrogen from atmospheric deposition to coastal waters. *Chemical Geology* 107:233-236.

Folke, C., C. Holling, and C. Perrings. 1994. *Biological Diversity, Ecosystems and Human Welfare.* Beijer Institute, Stockholm.

Fox, S., and R.A. Mickler, 1995. Impact of Air Pollutants on Southern Pine Forests *Ecological Studies* 118. Springer Verlag: New York.

Gawel, J.E., B.A. Ahner, A.J. Friedland & F.M.M. Morel., 1996. Role for heavy metals in forest decline indicated by phytochelatin measurements. *Nature* 381, p. 64-65.

Gray, J.S. 1992. Eutrophication in the sea. (In eds. G. Colombo, I. Ferrari, VU Ceccherelli, and R Rossi) *Eutrophication and Population Dynamics*. Olsen and Olsen, Fredensburg, Denmark, pp. 3-15.

Greening, H., Science Director. 1998. Tampa Bay National Estuary Program, personal communication.

Hammitt, W. E. et al., 1994. Identifying and predicting visual preferences of southern appalachian forest recreation vistas. *Landscape and Urban Planning*, 29 (2): 171-183.

Hanifen, J.G., W.S. Perret, R.P. Allemand, and T.L. Romaire. 1998. "Louisiana's fishery-independent data: potential impacts of hypoxia" On-line Hypoxia Conference Proceedings. Http://pelican.gmpo.gov/gulfweb/hypoxia/.hypoxia.html (June 1998).

Hansson S., and L.G. Rudstam. 1990. Eutrophication and Baltic fish communities. *Ambio* 19(3): 123-125.

Heath, L.S., and R.A. Birdsey, 1993. *Carbon trends of productive temperate forests of the conterminous United States. Water, Air, and Soil Pollution.* In Press.

Heimlich, R. Forthcoming. Wetlands and Agriculture: Private Interests and Public Benefits. Office of Policy, Economics and Statistics Administration, U.S. Department of Commerce.

Henry, C. 1974. Investment decisions under uncertainty: The irreversibility "effect". *American Economic Review* 64: 1006-1012.

Heywood, V., Baste, and KA Gardner. 1995. Introduction, pp.1-19. *Global Biodiversity Assessment* UNEP, Cambridge University Press: Cambridge.

Hinga, K.R., A.A. Keller, and C.A. Oviatt. 1991. Atmospheric deposition and nitrogen inputs to coastal waters. *Ambio* 20(6): 256-260.

Hinga, K.R., H. Jeon, and N.F. Lewis. 1995. Marine Eutrophication Review NOAA Coastal Ocean Program Decision Analysis Series No. 4. NOAA Coastal Ocean Office, Silver Spring, MD. Parts 1 & 2.

Hinterberger, F., G. Wegner. 1997. Limited knowledge and the precautionary principle: On the feasibility of environmental economics. (In eds. J. van den Bergh, J. van der Straaten) *Economy and Ecosystems in Change*, Cheltenham, UK: Edward Elgar.

Hollenhorst, S. J., S. M. Brock, W. A. Freimund, and M. J. Twery, 1993. Predicting the effects of gypsy moth on near-view aesthetic preferences and recreation appeal. *Forest Science*, 39(1): 28-40.

Holmes, T., R. Kramer, M. Haefele. 1992. Economic Valuation of Spruce-Fir Decline in the Southern Appalachian Mounains: A Comparison of Value Elicitation Methods. Presented at the *Forestry and the Environment: Economic Perspectives* Conference, March 9-11, 1992 in Jasper, Alberta, Canada.

Howard, R.K., G.J. Edgar, and P.A. Hutchings. 1989. Faunal assemblages of seagrass beds. (In eds. A.W.D. Larkum, A.J. McComb, and S.A. Shepherd) *Biology of Seagrasses*. Aquatic Plant Studies Vol. 2.. Elsevier, Amsterdam, pp. 536-564.

Howarth, R.W. 1988. Nutrient limitation of net primary production in marine ecosystems. *Annual Reviews in Ecology* 19: 89-110.

Howell, P., and D. Simpson. 1994. Abundance of marine resources in relation to dissolved oxygen in Long Island Sound. *Estuaries* 17(2): 394-402.

Hudson, R.J.M., S.A. Gherini, W.F. Fitzgerald, and D.B. Porcella. 1995. Anthropogenic Influences on the Global Mercury Cycle: A Model-Based Analysis. *Water, Air, and Soil Pollution* 80:265-272.

Hull, J. 1997. *Options, Futures, and other Derivative Securities*. Third Ed., Prentice Hall, Englewood Cliffs, NJ.

HydroQual. 1996. "Water Quality Modeling Analysis of Hypoxia in Long Island Sound Using LIS 3.0" Job Number NENGOO35. HydroQual Inc. Mahwah, NJ.

Industrial Economics (IEc). 1998a. *Overview of Ecological Impacts of Air Pollutants Regulated by the 1990 Clean Air Act Amendments*. Prepared by Industrial Economics, Inc. for B. Heninger, EPA Office of Policy.

Industrial Economics (IEc). 1998b. *Methods for Selecting Monetizable Benefits Derived from Ecological Resources as a Result of Air Quality Improvements Attributable to the 1990 Clean Air Act Amendments, 1990-2010*. Prepared by Industrial Economics, Inc. for B. Heninger, EPA Office of Policy.

Industrial Economics (IEc). 1998d. *Economic Benefits of Decreased Air Toxics Deposition Attributable to the 1990 Clean Air Act Amendments, 1990-2010.*

Industrial Economics (IEc). 1999a. *Benefits Assessment of Decreased Nitrogen Deposition to Estuaries in the United States Attributable to the 1990 Clean Air Act Amendments, 1990-2010*. Prepared by Industrial Economics, Inc. for B. Heninger, EPA Office of Policy.

Industrial Economics (IEc). 1999b. *Economic Benefits Assessment of Decreased Acidification of Fresh Water Lakes and Streams in the United States Attributable to the 1990 Clean Air Act Amendments, 1990-2010*. Prepared by Industrial Economics, Inc. for B. Heninger, EPA Office of Policy.

Industrial Economics (IEc). 1999c. *Characterizing the Forest Aesthetics Benefits Attributable to the 1990 Clean Air Act Amendments, 1990-2010*. Prepared by Industrial Economics, Inc. for B. Heninger, EPA Office of Policy.

Industrial Economics (IEc), 1999d. *Prospective Carbon Sequestration Benefits of the 1990 Clean Air Act Amendments (CAAA), 1990-2010*. Prepared by Industrial Economics Inc. for B. Heninger, EPA Office of Policy.

Industrial Economics(IEc), 1999e. *Characterizing the Commercial Timber Benefits from Tropospheric Ozone Reduction Attributable to the 1990 Clean Air Act Amendments, 1990-2010*. Prepared by Industrial Economics Inc. for B. Heninger, EPA Office of Policy.

IRIS. 1997. Integrated Risk Information System. U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/iris/ July 30, 1998.Jacobs, R.P.W.M., D. Hartog, B.F. Braster, and F.C. Carriere. 1981. Grazing of the seagrass *Zostera noltii* by birds at Terschelling (Dutch Wadden Sea). *Aquatic Botany*10: 241-259.

Jacobson, L.L. and A.C. Hill, 1970. *Recognition of air pollution injury to vegetation: A pictorial atlas*. Air Pollution Control Association: Pittsburgh.

Jakus, P.M., M. Downing, M. Bevelhimer, J.M. Fly. 1997. Do Sportfish Advisories Affect Reservoir Angler's Site Choice? *Agricultural and Resource Economics Review* 26(2).

Jaworski N.A., R.W. Howarth, and L.J. Hetling. 1997. Atmospheric deposition of nitrogen oxides onto the landscape contributes to coastal eutrophication in the northeast United States. *Environmental Science and Technology* 31: 1995-2004.

Jenkins, A., P.G. Whitehead, B.J. Cosby and H.J.B. Birks. 1990. Modeling long-term acidification: a comparison with diatom reconstructions and the implications of reversibility. *Phil. Trans. R. Soc. London B* 327 (433-440).

Johansson, J.O.R. 1997. Seagrass in Tampa Bay: Historic Trends and future expectations. (In ed. S.F. Treat) *Tampa Bay Area Scientific Information Symposium (Tampa B-A-S-I-S) 3: Applying Our Knowledge*, Tampa Bay Regional Planning Council.

Johansson, J.O.R. and R.R. Lewis III. 1992. Recent improvements in Hillsboro Bay, a highly impacted subdivision of Tampa Bay, Florida, USA. *Science of the Total Environment* Supplement 1992. Elsevier Science BV, Amsterdam.

Johnson, A.H., S.B. McLaughlin, M.B. Adams, E.R. Cook, D.H. DeHayes, C. Eagar, I.J., Fernandez, D.W. Johnson, R.J. Kohut, V.A. Mohnen, N.S. Nicholas, D.R. Peart, G.A. Schier, and P.S. White. 1992. Synthesis and conclusions from epidemiological and mechanistic studies of Red Spruce decline. (In eds. C. Eagar and M.B. Adams) *Ecology and Decline of Red Spruce in the Eastern United States*. Ecological Studies 96. Springer Verlag New York, p. 385-411.

Johnson, D.W., and G.E Taylor, Jr., 1989. Role of air pollution in forest decline in eastern North America.. *Water, Air, and Soil Pollution.* 48: 21-43.

Johnson, D.W. and Fernandez, I.J., 1992. Soil mediated effects of atmospheric deposition on eastern U.S. spruce-fir forests. (In eds. C. Eagar and M.B. Adams) *Ecology and Decline of Red Spruce in the Eastern United States,* Ecological Studies 96. Springer Verlag: New York, p. 235-270.

Johnson, J.D., A.H. Chappelka,F.P. Hain, and A.S. Heagle, 1995. Interactive effects of air pollutants with abiotic and biotic factors on southern pine forests. (In eds. S. Fox, and R.A. Mickler) *Impact of Air Pollutants on Southern Pine Forests*, Ecological Studies 118. Springer Verlag: New York, p. 281-314.

Johnson, J.E., W. D. Heckathorn, Jr., and A.L. Thompson. 1996. Dispersal and Persistence of 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD) in a Contaminated Aquatic Ecosystem, Bayou Meto, Arkansas. *Trans. Amer. Fisheries Soc.* 125:450-457.

Jordan, T.E., D.L. Correll, J. Miklas, and D.E. Weller. 1991. Nutrients and chlorophyll at the interface of a watershed and an estuary. *Limnology and Oceanography* 36(2): 251-267.

Karr, J.R. and D.R. Dudley. 1981. Ecological perspective on water quality goals. *Environmental Management* 5: 55-68.

Kauffman, J. 1980. Effect of a Mercury-Induced Consumption Ban on Angling Pressure. *Fisheries* 5(1): 10-12.

Kemp, WM, R.R. Twilley, W.R. Boynton, and J.C. Means. 1983. The decline of submersed vascular plants in upper Chesapeake Bay: Summary of results concerning possible causes. *Marine Technology Society Journal* 17:78-89.

Kerr, S.R. and R.A. Ryder. 1992. Effects of cultural eutrophication on coastal marine fisheries: a comparative approach. *Science of the Total Environment Suppl.* 599-614.

Kittel, T.G.F., N.A. Rosenbloom, T.H. Painter, D.S. Schimel, H.H. Fisher, A. Grimsdell, VEMAP Participants, C. Daly, and E.R. Hunt, Jr. 1996. The VEMAP Phase I Database: An Integrated Input Dataset for Ecosystem and Vegetation Modeling for the Conterminous United States. CDROM and World Wide Web (URL=http://www.cgd.ucar.edu/vemap/).

Leuscher, W.A. and R. L. Young., 1978. Estimating the southern pine beetle's impact on reservoir campsites. *Forest Science*, 24(4).

Levin, L. 1997. Risk Approaches for Water-Borne Exposure to Atmospherically Deposited Trace Substances. *The Environmental Professional* 19:43-47.

Levin, S.A., M.A. Harwell, J.R. Kelly, and K.D. Kimball. 1989. *Ecotoxicology: Problems and Approaches,* Springer Verlag, N.Y.

Leffler, M. 1997. Harmful algal blooms on the move. *Maryland Marine Notes* 15(4).

Linker, L. 1997. Using RADM and water quality models of Chesapeake Bay. *Atmospheric Deposition of Pollutants to the Great Waters,* SETAC Publication.

Limburg, R.H., S.A. Levin, and C.C. Harwell. 1989. Ecology and environmental impact assessment: lessons learned from the Hudson River (USA) and other estuarine experiences. *Journal of Environmental Management* 22: 255-280.

Long Island Sound Study Program. 1994. The Comprehensive Conservation and Management Plan, The Long Island Sound Study.

Long Island Sound Study. 1993. Hypoxia and Nutrient Enrichment – Assessment of Conditions and Management Recommendations.

Lucotte, M., A. Mucci, C. Hillaire-Marcel, P. Pichet, and A. Grondin. 1995. Anthropogenic Mercury Enrichment in Remote Lakes of Northern Quebec (Canada). *Water, Air and Soil Pollution* 80:467-476.

Mason, R.P., W.F. Fitzgerald, and F.M.M. Morel. 1994. The Biogeochemical Cycling of Elemental Mercury: Anthropogenic Influences. *Geochim. et Cosmochim. Acta* 58(15): 3191-3198.

MacDonald, H.F. and K.J. Boyle. 1997. Effect of Statewide Sport Fish Consumption Advisory on Open-Water Fishing in Maine. *North American Journal of Fisheries Management* 17: 687-695.

Massachusetts Bays National Estuaries Program. 1996. Comprehensive Conservation and Management Plan, and Program Fact Sheet No. 6.

McBride, J.R., P.R. Miller, and R.D. Laven. 1985. Effects of Oxidant Air Pollutants on Forest Succession in the Mixed Conifer Forest Type of Southern California. In: *Air Pollutants Effects On Forest Ecosystems*, Symposium Proceedings, St. P., p. 157-167.

McMahon, G., M.D. Woodside. 1996. Nutrient mass balance for the Albemarle-Pamlico drainage basin, North Carolina and Virginia, 1990. *Journal of the American Water Resources Association* 33(3): 573-590.

McLaughlin, S.B., Andersen, C.P., Hanson, P.J., Tjoelker, M.G., and Roy, W.K. 1991. Increased dark respiration and calcium deficiency of red spruce in relation to acid deposition at high elevation southern Appalachian mountain sites. *Can. J. for Res.* 21: 1234-1244.

Michaels, A.F., D. Olson, J.L. Sarmiento, J.W. Ammerman, K. Fanning, R. Jahnke, A.H. Knap, F. Lipschultz, and J.M. Prospero. 1996. *Biogeochemistry* 35(1): 181-226.

Miller, P.R., 1973. Oxidant-induced community change in a mixed conifer forest. *Advances in Chemistry Series* 122: 101-117.

Miller, P.R., 1983. *Ozone effects in the San Bernardino National Forest.* In: Proceedings: Air pollution and the Productivity of the Forest. Izaak Walton League and Penn State University, pp 161-197.

Miller, P.R., 1992. Mixed Conifer Forests of the San Bernardino Mountains. (In eds.R.K.Olson, D. Binkley, and M. Boehm) *The Response of Western Forests to Air Pollution* Ecological Studies 97. Springer-Verlag: New York, p. 461-500.

Miller, E.K., and A.J. Friedland. 1994. Lead Migration in Forest Soils: Response to Changing Atmospheric Inputs. *Environmental Science & Technology* 28(4):662-669.

Miller, P.R., and J.R. McBride, 1975. Effects of air pollutants on forests. (In eds. J.B. Mudd, and T.T. Kozlowski) *Responses of Plants to Air Pollution*. Academic Press: New York, p.196-235.

Miller, P.R., and J.R. McBride, 1998. *Air pollution impacts in the montane forests of southern California: The San Bernardino case* study. (DRAFT). Publication expected in: Ecological Study Series 134. (P.R. Miller, and J.R. McBride, eds.) Springer Verlag: New York.

Miller, P.R., O.C. Taylor, R.G. Wilhour, 1982. *Oxidant Air Pollution Effects on a Western Coniferous Forest Ecosystem*. Corvallis, OR: U.S. Environmental Protection Agency, Environmental Research Laboratory; EPA-600/D-82-276.

Montgomery, M. and M. Needelman. 1997. The Welfare Effects of Toxic Contamination in Freshwater Fish. *Land Economics* 73(2): 211-23.

Morey, E.R. and W.D. Shaw. 1990. An Economic Model to Assess the Impact of Acid Rain: A Characteristics Approach to Estimating the Demand for and Benefits from Recreational Fishing. *Advances in Micro-Economics* 5: 195-216.

Mullen, J.K., and F.C. Menz. 1985. The Effects of Acidification Damages on the Economic Value of the Adirondack Fishery to New York Anglers. *American Agricultural Economics Association*, Feb: 112-119.

Musser, W. N., R. Ziemer, and F. C. White, 1982. *Trade-offs between nonmarket and market land use: Crop production, forestry and outdoor recreation*. Research Bulletin 270, The University of Georgia College of Agricultural Experiment Stations.

Nabhan, G., S. Buchmann. 1997. "Services Provided by Pollinators." In ed. G. Daily. *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.

NAPAP, 1987. *Diagnosing Injuries to Eastern Forest Trees*. National Acid Precipitation Assessment Program. Forest Response Program. National Vegetation Survey.

NAPAP, 1991. *National Acid Precipitation Assessment Program. 1990 Integrated Assessment Report*. National Acid Precipitation Program. Office of the Director, Washington DC.

National Research Council. 1993. *Managing Wastewater in coastal Urban Areas: Committee on Wastewater Management for Coastal Urban Areas*, National Academy Press: Washington, DC.

Naylor, R., P. Ehrlich. 1997. Natural Pest Control Services and Agriculture. (In ed. G. Daily) *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.

NCLAN. 1988. Assessment of Crop Loss from Air Pollutants. (Eds. Walter W. Heck, O. Clifton Taylor and David T. Tingey) Elsevier Science Publishing Co.: New York,. Pp. 1-5. (ERL,GB 639).

NOAA, U.S. Department of Commerce. 1993. Natural Resource Damage Assessments Under the Oil Pollution Control Act of 1990, 57 FR 23067, June 1, 1992.

NOAA. 1998. Reporting on the State of Our Coasts. http://www.enn.com/enn-news archive/1998/02/021398/coastrpt.asp (Feb, 1998).

NESCAUM (Northeast States and Eastern Canadian Provinces). 1998. *Mercury Study: A Framework for Action.*

New York Statewide Angler Survey 1996. *Report 2: Angler Preferences, Satisfaction, and Opinion on Management Issues*. New York State, Department of Environmental Conservation. Division of Fish, Wildlife and Marine Resources. Albany, New York. April, 1998.

Newell, R.I.E. 1988. Ecological changes in Chesapeake Bay: Are they a result of over-harvesting the American Oyster, *Crassostrea virginica*? In *Understanding the Estuary: Advances in Chesapeake Bay Research* Conference Proceedings, Chesapeake Bay Consortium, Baltimore, MD.

Nixon, S.W. 1990. Marine eutrophication: a growing international problem. *Ambio* 19(3): 101.

Nixon, S.W. 1995. Eutrophication: a definition, social causes, and future concerns. *Ophelia* 41: 199-220.

Nixon, S.W., L.S. Granger, D.I. Taylor, P.W. Johnson, and B.A. Buckley. 1994. Subtidal volume fluxes, nutrient inputs and the brown tide – an alternate hypothesis. *Estuarine, Coastal and Shelf Science* 39: 303-312.

Nixon, S.W., C.A. Oviatt, J. Frithsen, and B. Sullivan. 1986. Nutrients and the productivity of estuarine and coastal marine ecosystems. *Journal of the Limnological Society of South Africa* 12(1/2): 43-71.

Norton, S.B., D.J. Rodier, J.H. Gentille, W.H. van der Schalie, W.P. Wood, and M.W. Slimack. 1992. A framework for ecological risk assessment at the EPA. *Environmental Toxicology and Chemistry* 11: 1663-1672.

Norwood, R. and P. Stacey. 1998. Connecticut Department of Environmental Protection, Personal Communication.

Nriagu, J.O. and J.M. Pacyna. 1988. Quantitative Assessment of Worldwide Contamination of Air, Water, and Soils by Trace Metals. *Nature* 333:134-139.

Ollinger, S.B., Aber. J.D., and Reich, P.B. 1997. Simulating ozone effects on forest productivity: interactions among leaf-, canopy-, and stand-level processes. *Ecological Applications* 7(4): 1237-1251.

Olson, R.K., D. Binkley, and M.Boehm, 1992. *The Response of Western Forests to Air Pollution* (R.K. Olson, D. Bonkley, and M. B öhm, eds.). Ecological Studies 97. Springer Verlag: New York.

Orth, R.J. and K.A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. *Science* 22:51-53.

Orth, R.J., M. Luckenback, and K.A. Moore. 1994. Seed dispersal in a marine macrophyte: implications for colonization and restoration. *Ecology* 75(7): 1927-1939.

Orth, R.J., R.A. Batiuk, and J.F. Nowack. 1994. *Trends in the distribution, abundance, and habitat quality of submerged aquatic vegetation in Chesapeake Bay and its tidal tributaries: 1971-1991.* USEPA for Chesapeake Bay Program. Annapolis, Maryland. EPA 903-R-95-009.

Oviatt, C.A., P.H. Doering, B.L. Nowicki, and A. Zoppini. 1993. Net system production in coastal waters as a function of eutrophication, seasonality, and benthic macrofaunal abundance. *Estuaries* 16(2): 247-254.

Oviatt, C.A., A.A. Keller, P.A. Sampou, and L.L. Beatty. 1986. Patterns of productivity during eutrophication: a eutrophication experiment. *Marine Ecology Progress Series* 28: 69-80.

Patwardhan, A.S. and A.S. Donigian, Jr. 1997. *Assessment of nitrogen loads to aquatic systems*. EPA Project Summary USEPA. EPA/600/SR-95/173.

Paerl, H.A. 1993. Emerging role of atmospheric nitrogen deposition in coastal eutrophication: biogeochemical and trophic perspectives. *Canadian Journal of Fisheries and Aquatic Science* 50: 2254-2269.

Paerl, H.A. and J.L. Pinkney. 1997. Hypoxia, anoxia, and fish kills in relation to nutrient loading in the Neuse River Estuary: Why was 1995 a 'bad' year? Unpublished.

Paerl, H.W. 1997. Coastal eutrophication and harmful algal blooms: importance of atmospheric deposition and groundwater as 'new' nitrogen and other nutrient sources. *Limnology and Oceanography* 42(5, part 2): 1154-1165.

Paerl, H.W., C. Aguilar, and M.L. Fogel. 1997. Atmospheric nitrogen deposition in estuarine and coastal waters: biogeochemical and water quality impacts. Chapter 22 (Id ed. J.E. Baker) *Atmospheric Deposition of Contaminants to the Great Lakes and Coastal Waters*, SETAC 15th Annual Meeting Proceedings 30 Oct.-3 Nov. 1994. SETAC Press, Pensacola, FLA.

Paerl, H.W. and M.L. Fogel. 1994. Isotopic characterization of atmospheric nitrogen inputs as sources of enhanced primary production in coastal Atlantic Ocean waters. *Marine Biology* 119: 635-645.

Paerl, H.W., J. Rudek, and M.A. Malin. 1990. Simulation of *phytoplankton* production in coastal waters by natural rainfall inputs: nutritional and trophic implications. *Marine Biology* 107: 247-254.

Pearl, H.W. 1988. Nuisance *phytoplankton* blooms in coastal, estuarine, and inland waters. *Limnology and Oceanography* 33(4, part 2): 823-847.

Paquet, J., and L. Belanger, 1997. Public acceptability thresholds of clearcutting to maintain visual quality of boreal balsam fir landscapes. *Forest Science*, 43(1): 46-55.

Peart, D.R., N.S. Nicholas, S.M. Zedaker, M.M. Miller-Weeks, and T.G. Siccama, 1992. Condition and recent trends in high-elevation Red Spruce populations. (In eds. C. Eagar, and M.B. Adams) *Ecology and Decline of Red Spruce in the Eastern United States* Ecological Study 96.p.125-191.

Peine, J.D., J.C. Randolph, and J.J. Presswood, Jr. 1995. Evaluating the Effectiveness of Air Quality Management within the Class I Area of Great Smokey Mountains National Park, *Environmental Management* 19(4): 515-526.

Pelley, J. 1998. What is causing toxic algal blooms? *Environmental Science and Technology* 26A-30-A.

Peterson D.L., and M.J. Arbaugh, 1992. Coniferous forests of the Colorado front Range. Part B: Ponderosa Pine second-growth stands. (In eds. R.K.Olson, D. Binkley, and M. Boehm) *The Response of Western Forests to Air pollution* Ecological Studies 97. Springer-Verlag: New York, p. 433-460.

Peterson, D. G., et al., 1987. *Improving Accuracy and Reducing Cost of Environmental Benefit Assessments*. Draft report to the U.S. Environmental Protection Agency, by Energy and Resource Consultants, Boulder, CO.

Petersen, G., J. Munthe, and R. Bloxam. 1995. Numerical Modeling of Regional Transport, Chemical Transformations and Deposition Fluxes of Airborne Mercury Species. (In eds. Baeyerns, W., R. Ebinghaus, O. Vasilev). *Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances*. NATO Advanced Science Institute (ASI) Series, sub-series 2. Environment, Vol. 21. Kluwer Academic Publishers: Dordrect, The Netherlands. p. 191-217.

Pimentel, D., C. Wilson, C. McCullum, R. Huang, P. Dwen, J. Flack, Q. Tran, T. Saltman, and B. Cliff. Economic and Environmental Benefits of Biodiversity. *BioScience* 47 (11): 747-57.

Porcella, D.B., J.W. Huckabee, and B. Wheatley, eds. 1995. Mercury as a Global Pollutant: Proceedings of the Third International Conference held in Whistler, British Columbia, July 10-14, 1994. Reprinted from *Water, Air, and Soil Pollution* 80(1-4). Kluwer Academic Publishers: Dordrecht, The Netherlands.

Postel, S. and S. Carpenter. 1997. Freshwater Ecosystem Services. (In ed. G. Daily) *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.

Price, KS, D.A. Flemer, J.L. Taft, G.B. Mackiernan, W. Nehlsen, R.B. Biggs, N.H. Burger, D.A. Blaylock. 1985. Nutrient enrichment of Chesapeake Bay and its impact on the habitat of striped bass: A speculative hypothesis. *Transactions of the American Fisheries Society* 114 (1): 97-106.

Prospero, J.M., and D.L. Savoie. 1989. Effects of continental sources on nitrate concentrations over the Pacific Ocean. *Nature* 339: 687-689.

Pye, J.M., Impact of ozone on the growth and yield of trees: A review. *Journal of Environmental Quality* 17:347-360, 1988.

Rahel, F.J., and Magnuson, J.J., 1983. Low pH and the Absence of Fish Species in Naturally acidic Wisconsin lakes: Inference for Cultural Acidification. *Can. J. Fish. Aquat. Sci.* 40: 3-9.

Randall, A., 1984. Benefit estimation for scenic and visibility services. (In eds.G.L. Peterson and A. Randall) *Valuation of Wildland Resource Benefits*. Westview Press: Boulder, CO.

Regier, H.A., P. Tuunainen, Z. Russek, and L.E. Persson. 1988. Rehabilitative redevelopment of the fish and fisheries of the Baltic Sea and the Great Lakes. *Ambio* 17: 121-130.

Rendell, A.R., C.J. Ottley, T.D. Jickells, and R.M. Harrison. 1993. The atmospheric input of nitrogen species to the North Sea. *Tellus* 45B: 53-63.

Research Triangle Institute (RTI). 1996. *Risk Assessment Support to the Development of Technical Standards for Emissions from Combustion Units Burning Hazardous Wastes: Background Information Document.* Prepared for Industrial Economics, Inc. EPA Contract # 68-W3-0028.

Ribe, R.G., 1990. A general model for understanding the perception of scenic beauty in northern hardwood forests. *Landscape Journal*, 9(2): 86-101.

Richardson, K, 1996. Conclusion, Research, and Eutrophication Control. (In eds. BB Jorgensen and K Richardson) *Eutrophication in Coastal Marine Ecosystems Coastal and Estuarine Studies* Vol. IV, American Geophysical Union, pp. 243-269.

Richardson, K. and B.B. Jorgensen. 1996. "Eutrophication: definition, history and effects (In eds. BB Jorgensen and K Richardson) *Eutrophication in Coastal Marine Ecosystems Coastal and Estuarine Studies* Vol. IV, American Geophysical Union, pp 1-20.

Ridker, R.G. and J.A. Henning, 1967. Determinants of residential property values with special reference to air pollution. *Review of Economics and Statistics*, 49: 246-257.

Rosseland, B.O. and Staurnes, M., 1994. Physiological Mechanisms for Toxic Effects and Resistance to Acidic Water: An Ecophysiological Approach. (In eds. Steinberg and R.F. Wright) *Acidification of Freshwater Ecosystems: Implications for the Future.* Chapter 16. C.E.W. John Wiley & Sons Ltd., 1994.

Rosenberg, R. 1985. Eutrophication - future marine coastal nuisance? *Maine Pollution Bulletin* 16:227-231.

Row, C. and R.B. Phelps. 1990. Tracing the Flow of Carbon through U.S. Forest Product Sector. Prepared for the 19th World Congress, International Union of Forestry, Research Organizations, Montreal, Canada, August 11, 1990.

Rowe, R., C. Lang, L. Chestnut, D. Latimer, D. Rae, S. Bernow, D. White. 1995. *The New York Electricity Externality Study, Vol. 1: Introduction and Methods.* Prepared by Hagler Bailly Consulting, Inc. for the Empire State Electric Energy Research Corporation (ESEERCO), Proj. No. EP91-50.

Rowe, C. and R.B. Phelps, 1990. *Tracing the Flow of Carbon through U.S. Forest Product Sector.* Presented at the 19th World Congress, International Union of Forestry Research Organizations, Montreal, Canada.

Ruddell, E. J., and J. H. Gramann, 1989. The psychological utility of visual penetration in near-view forest scenic-beauty models. *Environment and Behavior*, 21(4):393-412.

Rudis, V.A., J.H. Gramann, E.J. Rudell, and J.M. Westphal, 1988. Forest inventory and management-based visual preferences models of southern pine stands. *Forest Science* 34(4): 846-863.

Ryther, J.H., and W.M. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. *Science* 171: 1008-1112.

Sarasota Bay National Estuarine Program notes cite Camp, Dresser, and McKee, Inc. (1992). Point-/non-point-source pollution-loading assessment. Phase 1. Final Report to Sarasota Bay National Estuary Program.

Schier, G.A., and K.F. Jensen, 1992. Atmospheric deposition effects on foliar injury and foliar leaching in Red Spruce. (In eds. C. Eagar and M.B. Adams) *Ecology and Decline of Red Spruce in the Eastern United States* Ecological Studies 96. Springer Verlag: New York, p. 271-294.

Schroeder, H.W. and T.C. Daniel, 1981. Progress in predicting the perceived scenic beauty of forest landscapes. *Forest Science* 27(1): 71-80.

Short, F.T., G.E. Jones, and D.M. Burdick. 1991. Seagrass decline: problems and solutions. (In ed. HS Bolton) *Coastal Wetlands Proceedings of Coastal Zone '91 Conference*. American Society of Civil Engineers, New York, p. 439-453.

Short, F.T., D.M. Burdick, and J.A. Kaldy III, 1995. Mesocosm experiments quantify the effects of eutrophication on eelgrass, *Zostera marina*. *Limnology and Oceanography* 40(4):740-749.

Short, F.T. and D.M. Burdick. 1996. Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. *Estuaries* 19:730-739.

Shuyler, L. 1995. Cost Analysis for Nonpoint Source Control Strategies in the Chesapeake Basin. Unpublished.

Sigal, L.L. and G.W. Suter, 1987. Evaluation of Methods for Determining Adverse Impacts of Air Pollution on Terrestrial Ecosystems. *Environmental Management* 11: 675-694.

Smayda, T.J. 1990. Novel and nuisance *phytoplankton* blooms in the sea: evidence for a global epidemic (In eds. E. Graneli) *Toxic Marine Phytoplankton* Elsevier Science Publishers: Amsterdam, Netherlands, p. 29-40.

Smith, W.H., 1990. *Air Pollution and Forests: Interaction Between Air Contaminants and Forest Ecosystems*. 2nd edition, Springer Verlag: New York.

Smith, V.K. 1987. Uncertainty, Benefit-Cost Analysis, and the Treatment of OptionValue. *Journal of Environmental Economics and Management* 14: 283-292.

SOS/T 9, 1990. *Current Status of Surface Water Acid-Base Chemistry*. Baker, L.A., Kaufmann, P.R., Ross-Todd, B.M., and Beauchamp, J.J. National Acid Precipitation Assessment Program. State of Science and Technology Report 9.

SOS/T 10, 1990. *Watershed and Lake Processes Affecting Chronic Surface Water Acid-Base Chemistry*. Turner, R.S., Cook, R.B., Miegrot, H.V., Johnson, D.W., Elwood, J.W., Bricker, O.W., Lindberg, S.E., Hornberger, G.M. National Acid Precipitation Assessment Program. State of Science and Technology Report 10.

SOS/T 12, 1990. *Episodic Acidification of Surface Waters Due to Acidic Deposition*. Wigington, P.J., Davies, T.D., Tranter, M., and Eshleman, K.N. National Acid Precipitation Assessment Program. State-of-Science/Technology Report 12.

SOS/T 13, 1990. *Biological Effects of Changes in Surface Water Acid-Base Chemistry*. Baker, J.P., Bernard, D.P., Christensen, S.W., Sale, M.J., Freda, J., Heltcher, K., Marmorek, D., Rowe, L., Scanlon, P., Suter, G., Warren-Hicks, W., and Welbourne, P. National Acid Precipitation Assessment Program. State of Science and Technology Report 13.

SOS/T 16, 1990. *State of Science/Technology Report 16*. In: Summaries of National Acid Precipitation Assessment Program State-of-Science/Technology Report 16.

SOS/T 18, 1990. *Response of Vegetation to Atmospheric Deposition and Air Pollution.* Shriner, D.S., W.W. Heck, S.B. McLaughlin, D.W. Johnson, J.D. Joslin, and C.E. Peterson. National Acid Precipitation Assessment Program. State-of-Science/Technology Report 18.

SOS/T 27, 1990. *Methods for valuing acidic deposition and air pollution effects.* National Acid Precipitation Assessment Program. State-of-Science / Technology Report 27, Part B.

Sorensen, J.A., G.E. Glass, K.W. Schmidt, J.K. Huber, and G.R. Rapp, Jr. 1990. Airborne Mercury Deposition and Watershed Characteristics in Relation to Mercury Concentrations in Water, Sediments, Plankton, and Fish of Eighty Northern Minnesota Lakes. *Environ. Sci. Technol.* 24(11):1716-1731.

Soule, M. 1991. Conservation: tactics for a constant crisis. *Science* 253, pp.744-749.

Stacey, Paul E., *Report on Nitrogen Loads to Long Island Sound, Connecticut Department of Environmental Protection*, Draft, April 1998.

Stoddard, J.L., 1994. Long-Term Changes in Watershed Retention of Nitrogen. (In ed. Lawrence A. Baker) *Environmental Chemistry of Lakes and Reservoirs*, American Chemical Society, Washington, DC, pp. 223-284.

Stein, E.D., Y. Cohen, and A.M. Winer. 1996. Environmental Distribution and Transformation of Mercury Compounds. *Critical Reviews in Environmental Science and Technology* 26(1):1-43.

Stolte, K.W., D.M. Duriscoe, E.R. Cook, and S.P. Cline. Methods of assessing responses of trees, stands and ecosystems to air pollution. (In eds. R.K.Olson, D. Binkley, and M. Boehm) *The Response of Western Forests to Air Pollution.* Ecological Studies 97. Springer-Verlag: New York, p.259-332.

Suchanek, T.H., P.J. Richerson, L.J. Holts, B.A. Lamphere, C.E. Woodmansee, D.G. Slotton, E.J. Harner, and L.A. Woodward. 1995. Impacts of Mercury on Benthic Invertebrate Populations and Communities within the Aquatic Ecosystem of Clear Lake, California. *Water, Air and Soil Pollution 80:951-960.*

Swain, E.B., D.R. Engstrom, M.E. Brigman, T.A. Henning, and P.L. Brezonik. 1992. Increasing Rates of Atmospheric Mercury Deposition in Midcontinental North America. *Science* 257:784-787.

Systems Applications International, Inc. 1999. *Air Quality Modeling to Support the Section 812 Prospective Analysis*, Prepared for EPA.

Tampa Bay Nitrogen Management Consortium. 1990. *Tampa Bay Nitrogen Management Consortium* 1995-1999 Action Plan.

Tampa Bay National Estuary Program. 1994. Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida," Technical Publication #04-94. Prepared by P.E. Hans Zarbock, A. Janicki, D. Wade, D. Heimbuch, and H. Wilson. Coastal Environmental, Inc. St. Petersburg, Florida, May, 1994.

Tampa Bay National Estuary Program. 1995. Submerged aquatic vegetation distribution in tributaries of Tampa Bay," Technical Publication #08-94 Prepared by King Engineering Associates, Inc. 5010 W. Kennedy Blvd

Tampa Bay National Estuary Program. 1996. *Charting the Course: The Comprehensive Conservation and Management Plan for Tampa Bay*.

Tampa Bay Estuary Program. 1998. Tampa Bay Nitrogen Management Consortium 1995-1999 Action Plan, 1998.Tar-Pamlico NSW Implementation Strategy, as revised Feb. 13, 1992.

Tar-Pamlico Association and Hydroqual. 1995. Application of a Coupled Hydrodynamic/Water Column/Sediment Model for the Tar-Pamlico River, North Carolina.

Taylor, G.E. Jr., D.W. Johnson, and C.P. Andersen, 1994. Air pollution and forest ecosystems: A regional to global perspective. *Ecological Applications*, 4(4): 662-689.

Tedesco, M. 1998. Long Island Sound Study Program, Stamford, CT, Personal Communication.

Tingey, D.T., and G.E. Taylor. 1982. Variation in plant response to ozone: a conceptual model of physiological events (In eds.Unsworth, M.H., Omrod, D.P.) *Effects of Gaseous Air Pollution in Agriculture and Horticulture*. Butterworth Scientific: London, UK, pp. 113-138.

Tomasko, D.A., D.M. Alderson, P. Clark, J. Culter, L.K. Dixon, R. Edwards, E. Estevez, M.G. Heyl, S. Lowrey, Y.P. Sheng, and J. Stevely. 1992. Technical synthesis of Sarasota Bay, p. 14.1-14.16 (In eds. P. Roat, C. Ciccolella, H. Smithy, and D. Tomasko), Sarasota Bay: Framework for Action. Sarasota Bay National Estuary Program.

Tomasko, D.A., C.J. Dawes, and M.O. Hall. 1996. The effects of anthropogenic nutrient enrichment on the turtle grass (*Thalassia testudinum*) in Sarasota Bay, Florida. *Estuaries* 19(2B): 448-456.

Turner, D.P., J.J. Lee, G.J. Koerper, and J.R. Barker. 1993. *The Forest Sector Carbon Budget of the United States: Carbon Pools and Flux Under Alternative Policy Options.* EPA/600/3-93/093, EPA Environmental Research Laboratory, Corvallis, OR.

Turner, D.P., G.J. Koerper, M. Harmon, J. Lee. 1995. Carbon Sequestration by Forests in the United States. Current Status and Projections to the Year 2040. *Tellus* 47(B): 232-239.

Turner, K., C. Perrings, C. Folke. 1997. Ecological Economics: Paradigm or Perspective. (In eds. J. van den Bergh, J. van der Straaten) *Economy and Ecosystems in Change*, Edward Elgar: Cheltenham, UK.

Twilley R.R. , W.M. Kemp, K.W. Staver, J.C. Stevenson, and W.R. Boynton. 1985. Nutrient enrichment of estuarine submersed vascular plant communities 1. Algal growth and effects on production of plants and associated communities. *Marine Ecology Progress Series* 23:179-191.

Tyler, M. 1988. *Contributions of Atmospheric Nitrate Deposition to Nitrate Loading in the Chesapeake Bay,* Report No. RP-1052, Versar, Inc.

United States Environmental Protection Agency. 1984. *Ambient Water Quality Criteria for 2,3,7,8-Tetrachlorodizenzo-p-dioxin*. EPA 440/5-84-007.

United States Environmental Protection Agency. 1990. *Air Pollution Emission Standards and Guidelines for Municipal Waste Combustors: Revision and Update of Economic Impact Analysis and Regulatory Impact Analysis*. EPA-450/3-91-003.

United States Environmental Protection Agency. 1992a. National Study of Chemical Residues in Fish. Vol.s I and II. EPA 823-R-92-008a, EPA 823-R-92-008b.

United States Environmental Protection Agency. 1992b. *Report on the Ecological Risk Assessment Guidelines Strategic Planning Workshop*. Risk Assessment Forum Washington, D.C., EPA/630/R-92/002.

United States Environmental Protection Agency. 1993. *Interim Report on Data and Methods for Assessment of 2,3,7,8-Tetrachlorodibenzo-p-dioxin to Aquatic Life and Associated Wildlife*. EPA-600/R-055.

United States Environmental Protection Agency. 1994a. *Workshop on the Use of Available Data and Methods for Assessing the Ecological Risks of 2,3,7.8-Tetrachlorodibenzo-p-dioxin to Aquatic Life and Associated Wildlife*. EPA-630-R-94-002.

United States Environmental Protection Agency. 1994b. *Medical Waste Incinerators - Background Information for Proposed Standards and Guidelines: Analysis of Economic Impacts for Existing Sources*. EPA-453/R-94-048a.

United States Environmental Protection Agency. 1995a. *Acid Deposition Standard Feasibility Study Report to Congress*. EPA/430-R-95-001a.

United States Environmental Protection Agency. 1995b. *National Primary Drinking Water Regulations: Contaminant Specific Fact Sheets*. EPA 811-F-95-003-T.

United States Environmental Protection Agency. 1996a. *Air Quality Criteria for Ozone and Related Photochemical Oxidants, National Center for Environmental Assessment*. Office of Research and Development. U.S. Environmental Protection Agency, NC. Vol. II, 1996.

United States Environmental Protection Agency. 1996b. Update: National Listing of Fish and Wildlife Consumption Advisories. Fact Sheet EPA 823-F-96-006. June.

United States Environmental Protection Agency. 1997a. Listing of Fish and Wildlife Advisories - 1997. Version 3.0 EPA 823-C-98-001.Obtained online, http://www.epa.gov/OST/fishadvice/ July 30, 1998.

United States Environmental Protection Agency. 1997b. *Issue fact sheet on nutrients* Report of Annual Meeting of National Estuary Program Directors, March 1997. National Estuary Program, Washington, D.C.

United States Environmental Protection Agency. 1997c. *Deposition of Air Pollutants to the Great Waters Second Report to Congress*. Washington, D.C.

United States Environmental Protection Agency EPA, 1997d. *Mercury Study Report to Congress.* Office of Air Quality Planning and Standards and Office of Research and Development, EPA -452/R-97-003.

United States Environmental Protection Agency. 1997e. *Benefits of reducing deposition of atmospheric nitrogen in estuarine and coastal waters.*

United States Environmental Protection Agency. 1997f. *Long Island Sound Study Proposal for Phase III Actions for Hypoxia Management.* EPA 840/R/97/001.

United States Environmental Protection Agency. 1998e. *The Inventory of Sources of Dioxin in the United States.* External Review Draft. EPA/600/P-98/002a.

United States Environmental Protection Agency. 1998f., *The Costs of Water Pollution Control in the Chesapeake Bay Drainage Basin*, Office of Water, September 30, 1998.

U.S. Fish and Wildlife Service. 1998. Database of Fishing Advisories.

United States Forest Service. 1992. *Forest Health Monitoring. Summary Report. New England/Mid-Atlantic 1991.* United States Department of Agriculture Forest Service. NE\NA-INF-115-92.

United States Forest Service. 1993a. *Forest Health Monitoring. Summary Report. New England/Mid-Atlantic 1992.* United States Department of Agriculture Forest Service. NE\NA-INF-115-R93.

United States Forest Service. 1993b. *Forest Health Monitoring. Northeastern Area Forest Health Report*

United States Department of Agriculture Forest Service. NA-TP-03-93.

United States Forest Service. 1995a. *Forest Health Monitoring. Forest Health Assessment for the Northeastern Area 1993.* United States Department of Agriculture Forest Service Northeastern Area and Northeastern Forest Research Station. NA-TP-01-95.

United States Forest Service. 1995b. *Forest Health Monitoring. Forest Health Highlights. Northeastern States*

United States Department of Agriculture Forest Service.

United States Forest Service. 1996. *Forest Health Monitoring. 1996 Summary Report. Northern Forest Health Monitoring. New England/Mid-Atlantic/Lake States* (DRAFT). United States Department of Agriculture Forest Service. NE\NA-INF-115-R96.

United States Forest Service. 1997a. *Forest Health Monitoring. Summary Report. Northern Forest Health Monitoring. New England, Mid-Atlantic/Lake States 1995.* United States Department of Agriculture Forest Service. NE/NA-INF-115R-97.

United States Forest Service. 1997b. *Forest Health Monitoring. Forest Health Highlights for New York and New England States. Northeastern States.* United States Department of Agriculture Forest Service.

United States Forest Service. 1998. *Forest Health Monitoring. Field Methods Guide (National 1998).*

United States Forest Service. National Forest Health Monitoring Program. Research Triangle Park, NC.

United States Forest Service. 1998. http://www.fs.fed.us/news/roads/19980121_qa.html.

Unsworth, R. E., et al., 1992. *Approaches to Environmental Benefits Assessment to Support the Clean Air Act Section 812 Analysis*. IEc report to the EPA Office of Policy Analysis and Review.

Valiela, I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and C.H. Sham. 1997. Nitrogen loading from coastal watersheds to receiving estuaries: new method and its application. *Ecological Applications* 7(2): 358-380.

Valiela, I., J. Costa, K. Forman, J.M. Teal, B.L. Howes, and D. Aubrey. 1990. Transport of groundwater-borne nutrients from watersheds and their effects on coastal waters. *Biogeochemistry* 10:177-97.

Valigura, R.A., W.T. Luke, R.S. Artz, and B.B. Hicks. 1996. Atmospheric nutrient input to coastal areas: Reducing the uncertainties. NOAA Coastal Ocean Program Decision Analysis Series No. 9.

Van Sickle, J. and M.R. Church. 1995. *Nitrogen Bounding Study: Methods for Estimating the Relative Effects of Sulfur and Nitrogen Deposition on Surface Water Chemistry.* U.S. Environmental Protection Agency.

Vaux, H.J., P.D. Gardner, and T.J. Mills, 1984. *Methods for assessing the impact of fire on forest recreation*. General Technical Report PSW-79, USDA, Berkeley, CA.

Velicer, C.M. and B.A. Knuth. 1994. Communicating Contaminant Risks from Sport-Caught Fish: The Importance of Target Audience Assessment. *Risk Analysis* 14(5): 833-841.

Vermaat et al. 1998. The capacity of seagrasses to survive increased turbidity and siltation: the significance of growth form and light use. *Ambio* 26(8): 499-504.

Vitusek P.M., and R.W. Howarth, 1991. Nitrogen Limitation on Land and in The Sea: How Can It Occur? *Biogeochemistry* 13: 87-115.

Vollenweider, R.A., R. Marchetti, and R. Viviani, 1990. *Marine Coastal Eutrophication: The Response of Marine Transitional Systems to Human Impact: Problems and Perspectives for Restoration.* Elsevier: New York.

Walsh R. G., R. D. Bjonback, R. S. Aiken, and Donald H. Rosenthal, 1990. Estimating the public benefits of protecting forest quality. *Journal of Forest Management*, 30: 175-189.

Walsh, R. G., F. A. Ward, and J. P. Olienyk, 1989. Recreational demand for trees in national forests. *Journal of Environmental Management*, 28: 255-268.

Watras, C.J., K.A. Morrison, and R.C. Back. 1996. Mass Balance Studies of Mercury and Methyl Mercury in Small Temperate/Boreal Lakes of the Northern Hemisphere. (In eds. Baeyerns, W., R. Ebinghaus, O. Vasilev) *Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances*. NATO Advanced Science Institute (ASI) Series, sub-series 2. Environment, Vol. 21. Kluwer Academic Publishers: Dordrect, The Netherlands. p.329-358.

White, D.H., and J.T. Seginak. 1994. Dioxins and Furans Linked to Reproductive Impairment in Wood Ducks. *J. Wildl. Manage.* 58(1):100-106.

White, P.S., and C.V. Cogbill, 1992. Spruce-fir forests of eastern North America. (In eds. C. Eagar and M.B. Adams) *Ecology and Decline of Red Spruce in the Eastern United States* Ecological Studies 96. Springer Verlag: New York, p. 3-39.

Williams, S.L., and M.H. Ruckleshaus. 1993. Effects of nitrogen availability and herbivory on eelgrass (*Zostera marina*) and epiphytes. *Ecology* 74:904-918.

Winner, W.E., 1994. Mechanistic Analysis of Plant Responses to Air Pollution. *Ecological Applications* 4(4): 651-661.

Winner, W.E., and C.J. Atkinson. 1986. Absorption of air pollution by plants, and consequences for growth. *Trends in Ecology and Evolution* 1:15-18.

World Health Organization (WHO). 1989. Environmental Health Criteria 88: Polychlorinated Dibenzo-*para*-dioxins and Dibenzofurans. International Programme on Chemical Safety. Geneva.

World Health Organization (WHO). 1990. Environmental Health Criteria 101: Methylmercury. International Programme on Chemical Safety. Geneva.

World Health Organization (WHO). 1998. WHO Experts Re-evaluate Health Risks from Dioxins. Press Release WHO/45. June 3.

Wright, R.F., B.J. Cosby, R.C. Ferrier, A. Jenkins, A.J. Bulger, R. Harriman. 1994. Changes in acidification of lochs in Galloway, southwestern Scotland, 1979-1988: The MAGIC model used to evaluate the role of afforestation, calculate critical loads, and predict fish status. *Journal of Hydrology* 161 (257-285).

Zacaroli, A. 1998. Utilities Told to Monitor Mercury Levels in Coal Under EPA Requirement. *Environmental Reporter* 28(48):2629-2630. April 10.

Zarbock, P.A., A. Janicki, D. Wade, D. Higmuch, and H. Wilson. 1994. Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida. Prepared by Coastal Environmental Inc., for the Tampa Bay Estuary Program.

Zimmerman, R., J. Nance, and J. Williams. 1998. On-line Hypoxia Conference Proceedings http://pelican.gmpo.gov/ gulfweb/hypoxia/hypoxia.html (June, 1998).

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