challenge, especially for ex ante economic valuation with revealed-preference methods—that is, when one wants to estimate the value of an ecological service that takes into account any potential threshold effects. Since such severe and abrupt changes have not been experienced, peoples' choices in response to them have not been observed. This means that stated-preference methods are the only tool for measuring such values, but there are two complications that warrant discussion.

The first is that there is likely to be considerable uncertainty surrounding both the magnitude and the timing of any threshold effect associated with ecosystem disturbance. Thus, the ecological information may not be available to accurately develop a scenario to describe the ecosystem change in a stated-preference survey. In such a case, a stated-preference survey might be designed to value a variety of plausible ecosystem changes so that it is possible to describe the sensitivity of value estimates to likely outcomes.

The second complication may be that survey respondents will simply reject the valuation scenario as implausible or unbelievable. A large-scale oil spill is one example when survey respondents may reject the valuation scenario out of hand and state that the responsible company should pay for damages, not the general public. Carson et al. (1992) avoided this problem by asking survey respondents to value a public program to prevent an oil spill of the magnitude of the *Exxon Valdez*. Thus, substantial creativity and design effort may be required to develop plausible stated-preference valuation scenarios for large-scale disturbances to aquatic ecosystems that have threshold effects.

Threshold effects can also occur in peoples' preferences. Over some range of change in ecosystem services, marginal values may be quite small, but change dramatically when a drastic change occurs (e.g., listing of an aquatic species as endangered). This suggests that threshold changes in aquatic ecosystem may stimulate threshold changes in preferences. This issue further complicates the valuation of threshold changes because stated-preference valuation methods must be designed to convey the threshold change and motivate people to think how their values would change with the different set of relative prices that would be present after the ecosystem threshold change occurs.

Limitations of Ex Ante and Ex Post Valuation

The limitations of ex ante valuation using stated-preference methods and real choices are not limited to large-scale, threshold effects. There are many common instances in which people may not have experienced an ecological improvement or degradation and revealed-preference valuation methods are not applicable. Although stated-preference methods are applicable to such changes, it may be difficult for individuals to value trade-offs implied by changes they have not personally experienced. Thus, while stated-preferences are very helpful for ex ante valuation, they are not a complete or infallible solution. There will be circumstances in which nonmarket valuation methods cannot develop accurate value estimates in an ex ante setting.

In the ex post situation, the change has been observed but does not always translate to the revealed choices. For example, the market price of fish may reflect a change in the underlying ecological service, such as the loss of coastal nursery grounds, and thus, there appears to be no value assigned to this ecosystem service. Again, stated-preference methods are the alternative, but they may not be applicable in all situations.

Partial versus General Equilibrium Approaches

Most valuation methods and valuation studies represent a partial equilibrium approach to a particular policy question. However, as is clear from Chapter 3, the ecological functioning and dynamics that result in most aquatic ecosystem services suggest that to more fully capture the affects of ecosystem changes on the provision of these services, a more general equilibrium approach may be required. A series of independent value estimates for different ecosystem services, when added together, could substantially understate or overstate the full value of changes in all services. The key issue is whether there is substitute or complementary relationships between the services (Hoehn and Loomis, 1993).

As discussed above, there have been a number of recent attempts to use such an approach, or integrated economic-ecological modeling, to value various services of aquatic ecosystems. In essence, these approaches represent the extension of the production function approach to a full ecosystem level.

Scope

Insensitivity to scope is a major issue in contingent valuation studies of nonuse values of ecosystem services. This issue was raised by the National Oceanic and Atmospheric Administration Panel on Contingent Valuation (1993), which stated that this problem demonstrates "inconsistency with rational choice." Insensitivity to scope is exhibited by value estimates' being insensitive to the magnitude of the ecosystems change being valued. For example, if values estimated for restoring 100 and 1,000 acres of wetlands were statistically identical, this would indicate lack of sensitivity to scope. The inconsistency with rational choice arises because it is expected that people would pay more for the larger restoration project, all other factors being equal. The basis for the NOAA panel's concern was a study by Boyle et al. (1994) who found that estimates of nonuse values were not sensitive to whether 2,000, 20,000, or 200,000 bird deaths were prevented in waste oil holding ponds. While this study was criticized in a variety of public fora, Ahearn et al. (2004) reported a similar result in another study of grassland bird numbers. Notably, this latter study generally followed the NOAA panel's (1993) guidelines for the design of a credible contingent valuation study of nonuse values.

Insensitivity to scope is a major issue for valuing aquatic ecosystems services because stated-preference methods, which include contingent valuation, are likely to be important in estimating many component values in a TEV framework. There are many instances in which there is no visible behavior that supports the use of revealed-preference methods, although two important caveats should be considered.

First, the NOAA panel focused on the use of contingent valuation to estimate nonuse values. There will be many cases in which stated-preference methods are needed to estimate use values for aquatic ecosystem services. Sensitivity to scope has been demonstrated clearly in the estimation of use values in the literature, and some of these studies are applications to aquatic ecosystems (e.g., Boyle et al., 1993). In fact, Carson (1997) provides a list of contingent valuation studies that have demonstrated scope effects when use values are involved, and the vast majority of these studies have implications for valuing aquatic ecosystem services. Moreover, Carson et al. (1996) show that contingent valuation estimates are comparable to similar revealed-preference estimates—thereby, demonstrating the convergent validity of the stated-preference and revealed-preference estimates. Thus, the literature supports the use of contingent valuation for estimating use values for aquatic ecosystem services.

The second caveat applies to the use of contingent valuation to estimate nonuse values. Although the NOAA panel stated that contingent valuation can provide useful information on nonuse values, the ability of contingent valuation methods to demonstrate scope effects has not been demonstrated clearly in the literature. This a major concern for valuing aquatic ecosystems because nonuse values would be expected to be an important and large component of any total economic value assessment. In this regard, attribute-based, conjoint analysis provides a promising option. This approach presents the description of the aquatic ecosystem to be valued in component services and clearly informs survey respondents that there are different levels of these services. Respondents are then asked to select alternatives that differ in terms of the component services. This relative context has been shown to demonstrate scope effects (Boyle et al., 2001). The key difference is that contingent valuation has used a between-subjects design where independent samples are asked to value each of the different levels of the ecosystem. Conjoint analysis uses a within-subjects design where each respondent sees multiple levels of the ecosystem. Although a between-subjects design is appealing from an experimental design perspective, this is not the way real-world decisions are made. People make revealed choices where they observe ecosystem goods and services with different levels of attributes, and whereas conjoint analysis mimics this choice framework, contingent valuation does not. A question then arises as to what standard should contingent valuation be held. A between-subjects design to test for scope holds contingent valuation to a higher standard than market decisions are based upon (Randall and Hoehn, 1996), whereas the within-subject design of conjoint analysis mimics the relative choices that occur in markets. These results imply that conjoint analysis may be the better method to employ in estimating nonuse values for aquatic ecosystems services.

SUMMARY: CONCLUSIONS AND RECOMMENDATIONS

This chapter demonstrated that there is a variety of nonmarket valuation approaches that can be applied to valuing aquatic and related terrestrial ecosystem services.

For revealed-preference methods, the types of applications are limited to a set number of specific aquatic ecosystem services. However, both the range and the number of services that can potentially be valued are increasing with the development of new methods, such as dynamic production function approaches, general equilibrium modeling of integrated ecological-economic systems, conjoint analysis, and combined revealed- and stated-preference approaches.

Stated-preference methods can be applied more widely, and certain values can be estimated only through the application of such techniques. On the other hand, the credibility of estimated values for ecosystem services derived from stated-preference methods has often been criticized in the literature. For example, contingent valuation methods have come under such scrutiny that it led to the NOAA panel guidelines of "good practice" for these methods.

Benefit transfers and replacement cost/cost of treatment methods are increasingly being used in environmental valuation, although their application to aquatic ecosystem services is still limited. Economists generally consider benefit transfers to be a "second-best" valuation method and have devised guidelines governing their use. In contrast, replacement cost and cost of treatment methods should be used with great caution if at all. Although economists have attempted to design strict guidelines for using replacement cost as a last resort "proxy" valuation estimation for an ecological service, in practice estimates employing the replacement cost or cost of treatment approach rarely conform to the conditions outlined by such guidelines.

Although the focus of this chapter has been on presenting the array of valuation methods and approaches currently available for estimating monetary values of aquatic and related terrestrial ecosystem services, it is important to remember that the purpose of such valuation is to aid decision-making and the effective management of these ecosystems. Building on this critical point, at least three basic questions arise for any method that is chosen to value aquatic ecosystem services:

1. Are the services that have been valued those that are the most important for supporting environmental decision-making and policy analyses involving benefit-cost analysis, regulatory impact analysis, legal judgments, and so on?
2. Can the services of the aquatic ecosystem that are valued be linked in some substantial way to changes in the functioning of the system?
3. Are there important services provided by aquatic ecosystems that have not yet been valued so that they are not being given full consideration in policy decisions that affect the quantity and quality of these systems?

In many ways, the answers to these questions are the most important criteria for judging the overall validity of the valuation method chosen.

It is clear that economists and ecologists should work together to develop valid estimates of the values of various aquatic ecosystem services that are useful to inform policy decision-making. The committee's assessment of the literature is that this has not been done adequately in the past and most valuation studies appear to have been designed and implemented without any such collaboration. Chapter 5 helps to begin to build this bridge.

The range of ecosystem services that have been valued to date are very limited, and effective treatment of aquatic ecosystem services in benefit-cost analyses requires that more services be subject to valuation. Chapter 3 begins to develop this broad perspective of aquatic ecosystem services.

Nonuse values require special consideration; these may be the largest component of total economic value for aquatic ecosystem services. Unfortunately, nonuse values can be estimated only with stated-preference methods, and this is the application in which these methods have been soundly criticized. This is a clear mandate for improved valuation study designs and more validity research.

There is a variety of nonmarket valuation methods that are available and presented in this chapter. However, no single method can be considered the best at all times and for all types of aquatic ecosystem valuation applications. In each application it is necessary to consider what method(s) is the most appropriate.

In presenting the various nonmarket valuation methods available for estimating monetary values of aquatic and related terrestrial ecosystem services, this chapter has also sought to provide some guidance on the appropriateness of the various methods available for a range of different services. Based on this review of the current literature and the preceding conclusions, the committee makes the following recommendations:

- There should be greater funding for economists and ecologists to work together to develop estimates of the monetary value of the services of aquatic and related terrestrial ecosystems that are important in policymaking.

- Specific attention should be given to funding research at the "cutting edge" of the valuation field, such as dynamic production function approaches, general equilibrium modeling of integrated ecological-economic systems, conjoint analysis, and combined stated-preference and revealed-preference methods.
- Specific attention should be given to funding research on improved valuation study designs and validity tests for stated-preference methods applied to determine the nonuse values associated with aquatic and related terrestrial ecosystem services.
- Benefit transfers should be considered a "second-best" method of ecosystem services valuation and should be used with caution, and only if appropriate guidelines are followed.
- The replacement cost method and estimates of the cost of treatment are not valid approaches to determining benefits and should not be employed to value aquatic ecosystem services. In the absence of any information on benefits, and under strict guidelines, treatment costs could help determine cost-effective policy action.

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5

Translating Ecosystem Functions to the Value of Ecosystem Services: Case Studies

INTRODUCTION

Valuing ecosystem services requires the integration of ecology and economics. Ecology is needed to comprehend ecosystem structure and functions and how these functions change with different conditions. Both ecology and economics are required to translate ecosystem functions into the production of ecosystem goods and services. Economics is needed to comprehend how ecosystem goods and services translate into value (i.e., benefits for people; see also Figure 1-3). The two preceding chapters discuss much of the relevant ecological and economic literature. Chapter 3 focuses on the relevant ecological literature on aquatic and related terrestrial ecosystem functions and services, while Chapter 4 focuses on the economic literature on nonmarket valuation methods useful for valuing ecosystem goods and services. In this chapter, the focus is on the integration of ecology and economics necessary for valuing ecosystem services for aquatic and related terrestrial ecosystems. More specifically, a series of case studies is reviewed (including those taken from the eastern and western United States; see Chapter 1 and Box ES-1 for further information), ranging from studies of the value of single ecosystem services, to multiple ecosystem services, to ambitious studies that attempt to value all services provided by ecosystems. An extensive discussion of implications and lessons learned from these case studies is provided and precedes the chapter summary.

Development of the concept of ecosystem services is relatively recent. Only in the last decade have ecologists and economists begun to define ecosystem services and attempted to measure the value of these services (see for example, Balvanera et al., 2001; Chichilnisky and Heal, 1998; Constanza et al., 1997; Daily, 1997; Daily et al., 2000; Heal, 2000a,b; Pritchard et al., 2000; Wilson and Carpenter, 1999). There is a much longer history of natural resource managers and economists evaluating "goods" produced by ecosystems (e.g., forest products, fish production, agricultural production). For example, in 1926, Percy Viosca, Jr., a fisheries biologist, estimated that the value of conserving wetlands in Louisiana for fishing, trapping, and collecting activities was $20 million annually (Vileisis, 1997). In the 1960s and early 1970s, pioneering work by Krutilla (1967), Hammack and Brown (1974), and Krutilla and Fisher (1975), among others, greatly expanded the set of "goods and services" generated by natural systems considered by economists to be of value to humans (e.g., clean air, clean water, recreation, ecotourism). Economic geographers and regional scientists (e.g., Isard et al., 1969) examined spatial relationships among natural and socioeconomic systems. Recent work on ecosystem services has broadened the set of goods and services studied to include water purification, nutrient retention, and flood control, among other things. It has also emphasized the importance of understanding natural processes within ecosystems (e.g., primary and secondary productivity, carbon and nutrient cycling, energy flow) in order to understand the production of ecosystem services. Yet, as discussed throughout this report, for the most part, the importance of these natural processes in producing ecosystem services on which people depend has remained largely invisible to decision-makers and the general public. For most ecosystem services, there are no markets and no readily observable prices, and most people are unaware of their economic value. All too often it is the case that the value of ecosystem services becomes apparent only after such services are diminished or lost, which occurs once the natural processes supporting the production of these services have been sufficiently degraded. For example, the economic importance of protecting coastal marshes that serve as breeding grounds for fish may become apparent only after commercial fish harvests decline. By then, it may be difficult or impossible to repair the damage and restore the production of such services.

Although there has been great progress in ecology in understanding ecosystem processes and functions, and in economics in developing and applying nonmarket valuation techniques for their subsequent valuation, at present there often remains a gap between the two. There has been mutual recognition among at least some ecologists and some economists that addressing issues such as conserving ecosystems and biodiversity requires the input of both disciplines to be successful (Daily et al., 2000; Kinzig et al., 2000; Loomis et al., 2000; Turner et al., 2003; Holmes et al., 2004). Yet there are few existing examples of studies that have successfully translated knowledge of ecosystems into a form in which economic valuation can be applied in a meaningful way (Polasky, 2002). Several factors contribute to this ongoing lack of integration. First, some ecologists and economists have held vastly different views on the current state of the world and the direction in which it is headed (see, for example, Tierney, 1990, who chronicles the debates between a noted ecologist and economist [Paul Ehrlich and Julian Simon]). Second, ecology and economics are separate disciplines, one in natural science and the other in social science. Traditionally, the academic organization and reward structure for scientists make collaboration across disciplinary boundaries difficult even when the desire to do so exists. Third, as noted previously, the concept of ecosystem services and attempts to value them are still relatively new. Building the necessary working relationships and integrating methods across disciplines will take time.

Some useful integrated studies of the value of aquatic and related terrestrial ecosystem goods and services are starting to emerge. The following section reviews several such studies and the types of evaluation methods used. This review begins with situations in which the focus is on valuing a single ecosystem service. Typically in these cases, the service is well defined, there is reasonably good ecological understanding of how the service is produced, and there is reasonably good economic understanding of how to value the service. Even when valuing a single ecosystem service however, there can be significant uncertainty about either the production of the ecosystem service, the value of the ecosystem service, or both. Next reviewed are attempts to value multiple ecosystem services. Because ecosystems produce a range of services that are frequently closely connected, it is often difficult to discuss the valuation of a single service in isolation. However, valuing multiple ecosystem services typically multiplies the difficulty of valuing a single ecosystem service. Last to be reviewed are analyses that attempt to encompass all services produced by an ecosystem. Such cases can arise with natural resource damage assessment, where a dollar value estimate of total damages is required, or with ecosystem restoration efforts. Such efforts will typically face large gaps in understanding and information in both ecology and economics.

Proceeding from single services to entire ecosystems illustrates the range of circumstances and methods for valuing ecosystem goods and services. In some cases, it may be possible to generate relatively precise estimates of value. In other cases, all that may be possible is a rough categorization (e.g., "a lot" versus "a little"). Whether there is sufficient information for the valuation of ecosystem services to be of use in environmental decision-making depends on the circumstances and the policy question or decision at hand (see Chapters 2 and 6 for further information). In a few instances, a rough estimate may be sufficient to decide that one option is preferable to another. Tougher decisions will typically require more refined understanding of the issues at stake. This progression from situations with relatively complete to relatively incomplete information also demonstrates what gaps in knowledge may exist and the consequences of those gaps. Part of the value of going through an ecosystem services evaluation is to identify the gaps in existing information to show what types of research are needed.

MAPPING ECOSYSTEM FUNCTIONS TO THE VALUE OF ECOSYSTEM SERVICES: CASE STUDIES

Despite recent efforts of ecologists and economists to resolve many types of challenges to successfully estimating the value of ecosystem services, the number of well-studied and quantified cases studies remains relatively low. The following section reviews cases studies that have attempted to value ecosystem services in the context of aquatic ecosystems. These examples illustrate different levels of information and insights that have been gained thus far from the combined approaches of ecology and economics.

Valuing a Single Ecosystem Service

This review begins with studies of the value of ecosystem services using examples that attempt to value a single ecosystem service. These cases provide the best examples of both well-defined and quantifiable ecosystem services and of services that are amenable to application of economic valuation methodologies. The best-known example of a policy decision hinging on the value of a single ecosystem service involves the provision of clean drinking water for New York City, which is reviewed first. Other examples include cases where ecosystems provide habitat for harvested fish or game species and cases where they provide flood control.

In all of the cases reviewed in this section, the ecosystem service is well-defined although there may be some scientific uncertainty surrounding quantification of the amount of the service provided. In some cases, adequate methods for valuing the single ecosystem service exist. Further, for some cases, such as the New York City example below, information about a single ecosystem service may prove sufficient to support rational environmental decision-making. In other cases, this will not be so, and further work to assess a more complete set of ecosystem services will be necessary. Under no circumstances, however, should the value of a single ecosystem service be confused with the value of the entire ecosystem, which has far more than a single dimension. Unless it is kept clearly in mind that valuing a single ecosystem service represents only a partial valuation of the natural processes in an ecosystem, such single service valuation exercises may provide a false signal of the total economic value of the natural processes in an ecosystem.

Providing Clean Drinking Water: The Catskill Mountains and New York City's Watershed

One of the best-studied water supply systems in the world is the one that provides drinking water for more than 9 million people in the New York City metropolitan area (Ashendorff et al., 1997; NRC, 2000a; Schneiderman, 2000). New York City's water supply includes three large reservoir systems (Croton, Catskill, and Delaware) that contain 19 reservoirs and 3 controlled lakes. This system, including all tributaries, encompasses a total area of 5,000 km^2 with a reservoir capacity of 2.2×10^9 m.^{3} This complex array of natural watersheds requires a wide range of management to sustain the water quality supplied to the reservoirs and aqueducts. Historically, these watersheds have supplied high-quality water with little contamination. However, increased housing developments with septic systems, combined with nonpoint sources of pollution such as runoff from roads and agriculture, have posed threats to water quality. Further significant deterioration of water quality would force U.S. Environmental Protection Agency (EPA) to require New York City to build a water filtration system[1] to ensure that drinking water delivered to consumers would meet federal drinking water standards. By 1996, New York City faced a choice: it could either build water filtration system or protect its watersheds to ensure high-quality drinking water.

The cost of building new, larger filtration system necessary to meet water quality standards was estimated to lie in the range of $2 billion to $6 billion. Moreover, the city estimated that it would spend $300 million annually to operate the new filtration plant. Together, the costs of building and operating the filtration system were estimated to be in the range of $6 billion to $8 billion (Chichilnisky and Heal, 1998).

Instead of investing in a water filtration facility, New York City opted to invest more in protecting watersheds. Maintaining water quality in the face of increased human population densities in the watershed required increased protection of riparian buffer zones along rivers and around reservoirs. These zones help to regulate nonpoint sources of nutrients and pesticides from stormwater runoff, septic tanks, and agricultural sources. In 1997 the city received "filtration avoidance status" from the EPA by promising to upgrade watershed protection. The 1997 Watershed Memorandum Agreement resulted from negotiations among the State of New York, New York City, the EPA, municipalities within the watershed, and five regional environmental groups. The agreement provided a framework for compliance with water quality standards and contained plans for land acquisition through mutual consent, watershed regulations, environmental education workshops, and partnership programs with community groups. For example, a farmer-led Watershed Agricultural Council provides programs for the approximately 350 dairy and livestock farms in the watershed to minimize nutrient input from agricultural runoff (Ashendorff et al., 1997).

Under this agreement, New York City is obligated to spend $250 million during a 10-year period to purchase lands within the watershed (up to 141,645 hectares). In this part of the overall response, the New York City Department of Environmental Protection land acquisition program purchases undeveloped land from willing sellers rather than relying on condemnation and the power of eminent domain. Property rights to develop land in the watershed rests in the hands of local landowners. In some cases these rights are regulated by local ordinances. New

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[1] In the late 1990s, the plan was to build one centralized plant for the Catskill/Delaware portion of the larger watershed (see NRC, 2000a for further information). However, it has since been determined that the Croton portion of the watershed has to build a separate filtration plant.

York City's 1953 Watershed Rules and Regulations give the city some authority over watershed development to limit water pollution. Decades-old resentment remains among some residents of upstate watersheds because earlier land acquisitions to build the reservoirs displaced entire communities. Moreover, recent concerns about security of the reservoirs have also polarized residents whose road access has been limited. Exactly what legal rights New York City has and what legal rights local municipalities and local landowners have to make decisions is not fully resolved. The long-term costs of riverbank protection, upkeep of sewage treatment plants by municipalities and overall maintenance costs of this approach remain uncertain.

On the other hand, a series of regulations prohibiting certain types of development in certain places (e.g., areas in close proximity to watercourses, reservoirs, reservoir stems, controlled lakes, wetlands) was agreed upon. The city together with the Catskill Watershed Corporation developed a comprehensive geographical information system to track land uses and to analyze runoff and storm flows resulting from precipitation. Runoff is sensitive to connections among stream network, and to the amount of impervious surface in the watershed (e.g., roads, buildings, driveways, parking lots), which results in increased peak flows that can cause flooding and bank erosion (Arnold and Gibbons, 1996; Gergel et al., 2002). To minimize these effects, new construction of impervious surfaces within 300 feet of a reservoir, rivers, or wetland is prohibited. Road construction within 100 feet of a perennial stream and 50 feet of an intermittent stream is also prohibited. Septic system fields cannot be located within 100 ft of a wetland or watercourse or 300 feet of a reservoir because these on-site sewage treatment and disposal systems do not work effectively in saturated soil. Septic fields also interfere with the natural nutrient processing in floodplains, wetlands, and riparian buffer zones along streams. Funds are available to subsidize upgrades of local wastewater treatment plants and septic systems throughout the watershed. There are 38 wastewater treatment plants in the watershed that are not owned by New York City. Overall, New York City projected that it would invest $1 billion to $1.5 billion in protecting and restoring natural ecosystem processes in the watershed (Ashendorff et al., 1998; Chichilnisky and Heal, 1998; Foran et al., 2000; NRC, 2000a). Incentives for landowners to improve riparian protection through conservation easements and educational outreach efforts were combined with management of state-owned lands to minimize erosion and protect riparian buffers.

In this case, it was not necessary to value all or part of the services of the Catskills watershed; it was merely necessary to establish that protecting and restoring the ecological integrity of the watershed to provide clean drinking water was less costly than replacing this ecosystem service with a new water filtration plant. As discussed in Chapter 4, Shabman and Batie (1978) suggest that a replacement cost approach can provide a "proxy" valuation estimation for an ecological service if the alternative considered provides the same service, the alternative compared is the least-cost alternative, and there is substantial evidence that the service would be demanded by society if it were provided by that least-cost alternative. In the Catskills case the proposed filtration plant would provide very similar services (more on this below). Of course, the city will have to provide clean water somehow. So these conditions are met and the cost of replacing the provision of clean drinking provided by the watershed with a filtration plant, less the cost of protecting and restoring the watershed, can be thought of as a measure of the ecosystem service value to New York City as a water purification tool. If, however, demand side management can reduce demand for water at less cost than it costs to provide the water via the filtration plant, then demand side management costs would provide the relevant avoided costs. Both methods, natural processes in watersheds and a water filtration plant, are capable of providing clean drinking water that meets drinking water standards.

This case also appears to provide clear environmental policy direction. For New York City, it is likely to be far less costly to provide safe drinking water by protecting watersheds, thereby maintaining natural processes, than to build and operate a filtration plant. Further, protecting watersheds to provide clean water also enhances provision of other ecosystem services (e.g., open space for recreation, habitat for aquatic and terrestrial species, aesthetics). As discussed throughout this report, such ecosystem services are arguably far harder to value economically. Since these values add to the value of protecting watersheds for the provision of clean water, which is the preferred option even without consideration of these additional values, it is not necessary to establish a value for these services for policy purposes. Thus, protecting watersheds can be justified on the basis of the provision of clean drinking water alone.

Despite the appearance of being a textbook case for valuing a single ecosystem service, several issues make the answer to ecosystem valuation less obvious than at first glance. The replacement cost approach assumes that the same service will be provided under either alternative. In reality, it is unlikely that watershed protection and filtration will provide identical levels of water quality and reliability over time because engineered systems can fail—especially during storms when heavy flows overwhelm the system. Likewise, natural watersheds can also vary in their effectiveness in response to severe storm flows or other disturbances (Ashendorff et al., 1997). Managed watersheds can require some maintenance costs to sustain ecosystem services such as clean up of accidental spills or fish kills to prevent pollution or control of invasive species such as zebra mussels (Covich et al., 2004; Giller et al., 2004). Both engineered and ecosystem approaches are vulnerable but they differ in the types of uncertainty associated with each investment.

New York City's watershed investment plan includes several maintenance costs such as thorough, multistaged monitoring of water quality and disease surveillance that triggers active management and localized water treatment. Baseline data on water quality and biodiversity of stream organisms in the watershed (e.g., aquatic insects) are being collected by the Stroud Water Research Center (2001) annually to determine if the city's recent management efforts are effective. By reducing the risk of contaminants from various sources, the city can minimize use of disinfectants at the final water treatment stages. Reducing chemical use saves money directly and it may also have health benefits since chlorination can produce halogenated disinfection by-products (e.g., chloroform, trihalomethane) in drinking water, especially in ecosystems with high levels of organic matter (Symanski et al., 2004; Villanueva et al., 2001; Zhang and Minear, 2002). Some of these by-products may be carcinogens. On the other hand, filtration may provide higher-quality drinking water because chlorination is not completely effective in killing pathogens, particularly when there are high levels of suspended materials (Schoenen, 2002).

Despite the regulations and the comprehensive framework contained in the city's watershed protection plan, considerable uncertainties exist about whether the plan can sustain high quality water supplies over the longer-term. Enforcement of the regulations and monitoring the rapid rate of suburban growth constitute a major challenge, and these development pressures in the area may increase the opportunity costs of watershed protection. Construction in the headwaters of streams, permitted under the plan, may result in increased runoff rates and erosion. Filling tributary channels with sediments can take place incrementally, with each step occurring at a small scale. Yet numerous small-scale changes may transform the watershed in detrimental ways over time without sufficient oversight and long-term planning. The U.S. Army Corps of

Engineers (USACE) has authority under Section 404 of the Clean Water Act to review permits. However, without site-by-site reviews of small projects (less than four hectares), allowable incremental alterations can have significant cumulative effects on small streams. Decreased stream density (stream length per drainage basin area) would occur if natural stream channels were replaced by pipes and paved over for development, resulting in loss of the essential ecological processes of organic matter breakdown and sediment retention (Meyer and Wallace, 2001; Paul and Meyer, 2001).

Additional uncertainties might impact decision-making, besides the adequacy of protection in the watersheds. Model uncertainty that arises from imperfect understanding of ecosystem function and the translation to ecosystem services is a major issue for most ecosystem valuation studies. In this case, there is model uncertainty because the hydrologic modeling used for determining water supplies is affected by the definition of spatial and temporal boundaries. For example, other municipalities in New York and New Jersey use water from the Catskills. Changes in water diversions from the Catskill Mountains can affect outflows to the Delaware River and modify salinities in the lower sections of the river used by Philadelphia (Frei et al., 2002). Given the additional uncertainties of future regional droughts, floods, and extreme temperatures, as well as acid rain and nitrogen deposition from atmospheric sources, planners must consider the range of intrinsic natural variability in decision-making. Planners can cope with aspects of model and parameter uncertainty by carefully monitoring land uses in the basin and incorporating environmental data into any new regulations that might be required. A long series of studies on nutrient budgets and acid deposition provides some essential baseline information for the Catskills (e.g., Frei et al., 2002; Lovett et al., 2000; Murdoch and Stoddard, 1992, 1993; Stoddard, 1994). Other locations may lack sufficient information, and thus, considerable sources of uncertainty will limit the analysis of complete replacement costs.

In this case, the provision of clean drinking water supplies through the protection of natural processes in watersheds rather than through the human-engineered solution of building a water filtration system offers an estimate of the value of restoring an ecosystem service that provides clear advice to a policy decision. Replacement costs for natural processes in watersheds providing clean drinking water are estimated to be in the neighborhood of $6 billion to $8 billion, which is far higher than estimates of the cost necessary to protect the watersheds. Because the policy question is relatively specific (i.e., whether to build a filtration plant or to protect watersheds), currently available economic methods of ecosystem service valuation are sufficient.

Even in this example however, obtaining a precise estimate of the value of the provision of clean water through watershed conservation is probably not possible given existing knowledge. First, it is not clear that the two methods, filtration and watershed protection, provide the same level of water quality and reliability. There are numerous dimensions to the provision of clean drinking water, such as the concentrations of various trace chemicals, carcinogens, and suspended solids, variance of the quality, and the adequacy of supply. It is unlikely that the two methods will deliver water that is identical in all of these dimensions under all conditions. Second, there is no guarantee that protecting watersheds will continue to be successful. Increased development pressure on lands outside the riparian buffer zones or inadequate enforcement may require building a filtration system at some point in the future. If the watershed protection plans prove to be insufficient in the future, the investments in protection will still likely reduce future costs of building filtration plants because the quality of the water to be treated will be enhanced through these land-use programs.

Finally, it should be emphasized that (1) the value of providing clean drinking water is only a partial measure of the value of ecosystem services provided by the watershed, and (2) replacement cost is rarely a good measure of the value of an ecosystem service. Even if water quality benefits alone did not justify watershed protection, such a finding would not justify abandoning efforts at watershed protection. To make that decision would require a broader effort to measure the value of the wider set of ecosystem services produced by Catskills watersheds. It is less clear that estimates to answer this broader question are sufficiently precise to provide policy-relevant answers (see Chapters 2 and 6 for more on framing). Replacement cost methods can be used as a measure of the value of ecosystem services only when there are alternative ways to provide the same service and when the service will be demanded if provided by the least cost alternative. Replacement cost does not constitute an estimate of value of the service to society. It represents the value of having the ability to produce the service through an ecosystem rather than through an alternative method.

Other Surface Water Examples

Other cities have used similar strategies to invest in maintaining the ecological integrity of their watersheds as a means of providing high quality drinking water that meets all federal, state, and local standards. Boston, Seattle, San Francisco, and Greenville, South Carolina, are other examples where the value of ecosystem services could be estimated using a replacement cost approach for building and operating water treatment plants that are roughly equivalent in the quality of drinking water supplied (NRC, 2000a). The costs of producing safe drinking water were traditionally derived from production cost estimates associated with engineering treatments. Filtration plants were built to remove organic materials, and then some form of chemical purification was used to control microorganisms. Engineers generally considered natural ecosystems such as rivers and lakes mostly from the viewpoint of volumes, transport systems, resident times, dilution, and natural "reoxygenation." In other words, they viewed many natural ecosystems as large pipes rather than as complex habitats for a diverse biota. Yet even viewed strictly through the lens of water supply systems, protecting natural processes within ecosystems may be superior to engineering solutions, and such a result may be sufficient for decision-making purposes. Replacement cost estimates for provision of clean drinking water, however, provide an estimate of just one source of value and should not be confused with the complete value of ecosystem services provided by watersheds. Further, as discussed in Chapter 4, replacement cost is a valid approach to economic valuation only in highly restricted circumstances—namely, that there are multiple ways to achieve the same end and the benefits exceed the costs of providing this end.

Provision of Drinking Water from Groundwater: San Antonio, Texas

In contrast with the Catskills case, there has been a lack of valuation studies to date on the economic value of the Edwards Aquifer (see also Box 3-5) that supplies drinking water to San Antonio as well as water for irrigation and other uses. Groundwater supplies approximately half of America's drinking water (EPA, 1999). It is relied on heavily in some parts of the arid West where surface waters are scarce. The long-term supply of groundwater is a concern in some of these areas (Howe, 2002; Winter, 2001). For example, depletion of the Ogallala Aquifer is creating great uncertainties about future water supplies throughout a large region of the central United States (Glennon, 2002; Opie, 1993). Similarly, depletion of groundwater aquifers in the Middle Rio Grande Basin is creating uncertainty about the future supply of drinking water for Albuquerque, New Mexico (NRC, 1997, 2000b). Aquifers generally provide high quality drinking water, but pollution lowers water quality in some areas, such as the Cape Cod Aquifer where there are threats from sewage and toxic substances leaching into groundwater from the Massachusetts Military Reservation (Barber, 1994; Morganwalp and Buxton, 1999).

The long-term sustainability of groundwater depends on matching extraction with recharge (Sanford, 2002). It is often difficult to predict the timing and rate of recharge because of complications of local geology, time lags, and climate uncertainties. Recharge of the porous karstic limestone that characterizes the Edward Aquifer occurs primarily during wet years when precipitation infiltrates deeply into the soils and underlying rock (Abbott, 1975). Drought conditions have complex effects on lowering recharge rates while simultaneously tending to increase the demand for water. The greatest source of uncertainty about groundwater recharge is the range of natural interannual variability in precipitation and land-use changes. Increasing demands from a growing population and the difficulty in predicting climate change raise questions about the adequacy of groundwater supplies in arid regions (Grimm et al., 1997; Hurd et al., 1999; Meyer et al., 1999; Murdoch et al., 2000).

Aquifer depletion has both economic and ecological consequences. The costs for deeper drilling and pumping increase as groundwater is depleted. Removal of water in the underground area may cause collapse of the overlying substrata. These collapses decrease future storage capacity below ground and may cause damage on the surface as areas subside, buckle, or collapse. In some areas, depleted groundwater may cause the intrusion of low-quality water from other aquifers or from marine-derived salt or brackish waters that could not readily be restored for freshwater storage and use.

Depletion of groundwater supplies creates uncertainty and generally is offset by supplies from surface waters. An interesting exception is San Antonio (the ninth largest city in the United States) that relies primarily on groundwater for its source of municipal water. An outbreak of cholera in 1866 from polluted surface waters prompted the City of San Antonio to switch to groundwater from the Edwards Aquifer. The aquifer is estimated to contain up to 250 million acre-feet of water with a drainage area covering approximately 8,000 square miles. The average annual recharge is estimated at approximately 600,000 acre-feet of water (Merrifield , 2000). Given this large supply, the Edwards Aquifer plays a major role in the economy of San Antonio and south-central Texas (Glennon, 2002). In some parts of this region, clean, free-flowing springs and artesian wells provide drinking water without the cost of pumping and with minimal treatment. San Antonio built its first pumping station in 1878. The U.S. Geological Survey (USGS) has monitored aquifer recharge rates since 1915 and water quality monitoring began in 1930. In 1970 the Edwards Aquifer was designated a "sole source aquifer" by the EPA under the Safe Drinking Water Act. Currently, more than 1.7 million people rely on the Edwards Aquifer for water. Industrial and agricultural demands on the Edwards Aquifer have increased, and the city has planned for new reservoir storage as part of its water supply several times over the last two decades. As the demand for water in the area has grown, concerns have arisen over both the quantity and the quality of groundwater available (Wimberley, 2001).

Depletion also raises the specter that adequate supply will not be available for future demand at any price. The $3.5 billion-a-year tourist industry in San Antonio is centered on the city's River Walk, which relies primarily on recycled groundwater (Glennon, 2002). Uncertainties over the long-term availability of water make long-term planning problematic and threaten long-term investments. For example, aquaculture companies (e.g., Living Waters Artesian Springs, Ltd.) expanded their catfish operations in March 1991, but subsequently closed in November 1991 because of concerns over pumping rates and the impaired water quality of return flows (i.e., high concentrations of dissolved nutrients) to surface- and groundwaters associated with the Edwards Aquifer.

Groundwater storage is critical in most aquatic ecosystems to provide persistence spring and stream habitats during dry seasons or during drought. Several springs (Comal, San Antonio, San Pedro) in the area began to dry up following a seven-year drought in the 1950s. Chen et al. (2001) used a climate change model to estimate the regional loss of welfare at $2.2 million to $6.8 million per year from prolonged drought. They estimated groundwater recharge based on historic data for recharge rates as influenced by precipitation and temperature. These researchers forecasted municipal and irrigation demand for five scenarios, including current condition and four different levels of climate change. Estimates of demand elasticity were based on models and methods used in other studies of arid regions. Given the projected reductions in available water, it would be necessary to protect endangered species in springs and groundwater, at an additional reduction of 9 to 20 percent in pumping that would add $0.5 million to $2 million in costs.

The economic value of organisms living in groundwater and in springs, wetlands, and downstream surface flows supplied by groundwater is difficult to estimate. However, their value is generally assumed to be high because of their many functional roles in maintaining clean water as well as their existence values. For example, many diverse microbial communities and a wide range of invertebrate and vertebrate species live in groundwater, springs, and streams (Covich, 1993; Gibert et al., 1994; Jones and Mulholland, 2000). Their main functions are breaking down and recycling organic matter that forms the base of a complex food web (Covich et al., 1999, 2004). Depletion of groundwater aquifers results in possible loss of habitat for endemic species protected by state and federal regulations. For example, the Edwards Aquifer-Comal Springs ecosystem provides critical habitat for several endangered and threatened species, including salamanders (the Texas blind salamander and San Marcos Spring salamander), fish (the San Marcos gambusia and fountain darter), and Texas wild rice (Glennon, 2002; Sharp and Banner, 2000). In all, 91 species and subspecies of other organisms that are endemic in this aquifer and its associated springs (Bowles and Arsuffi, 1993; Culver et al., 2000, 2003; Longley, 1986).

Most studies predicting groundwater supply focus on usable water quantities given drought frequencies and recharge. Land use is also important because it influences demand as well as runoff and recharge. As a result of water shortages in San Antonio, regulations controlling development were issued beginning in 1970. These regulations included rules for limiting economic development within the recharge zone. As noted previously, economic development often increases the extent of impervious surfaces that, in turn, cause more rapid runoff and loss of infiltration during and after precipitation events. Studies indicate that when impervious cover exceeds 15 percent of the surface of a watershed, there are adverse impacts on surface water quality and subsurface water recharge (e.g., Veni, 1999).

The quality of groundwater is also an issue. Increasing concerns about water pollution of the Edwards Aquifer led former (now deceased) Congressman Henry B. Gonzalez of San Antonio to propose the Gonzalez Amendment to the Safe Drinking Water Act of 1974. The amendment dealt with protection of sole source aquifers used for water supplies (Wimberley, 2001). Leachate from landfills, leaking petroleum storage tanks, and pesticides all pose contamination threats that could render groundwater unusable. In 1987, a regional committee was formed to determine how the aquifer could be further protected. Henry Cisneros, then mayor of San Antonio, chaired the committee and proposed a plan that limited total withdrawals and called for a reservoir construction program (the Applewhite Reservoir was proposed but ultimately not approved).

A severe drought in 1990 and above-average pumping combined with this to dry up two of the aquifer's major springs (Merrifield, 2000). In 1993, the Sierra Club sued the state under the Endangered Species Act for failure to guarantee a minimum flow of 100 cubic feet per second to Comal and San Marcos Springs (*Sierra Club vs. Lujan*, 1993 W.L. 151353). The State and the U.S. Fish and Wildlife Service entered into an agreement to resolve this conflict. The Texas legislature created the Texas Edwards Aquifer Authority to control pumping and reallocate water through market mechanisms (McCarl et al., 1999; Schiable et al., 1999). This approach reallocated water from lower economic uses (such as agricultural irrigation) to higher-valued uses (such as domestic and industrial water supplies and environmental and recreational uses). In 2000, the Edwards Aquifer Authority decided to ban the use of any type of sprinkler in the eight-county region whenever flow at Comal Springs declined to 150 cubic feet per second (cfs) or less. In September 2002, the USGS reported that the flow had declined to 145 cfs and the ban went into effect.

Groundwater is a renewable resource that provides both extractive use value and in situ value. In situ value refers to the value created by having a stock of groundwater in the aquifer. Extraction of groundwater generates current extractive use value but can result in lower in situ value if extractions rates exceed aquifer recharge rates. Efficient use of groundwater requires extraction only when extractive use value per unit exceeds in situ value per unit of groundwater. Most economic analyses, such as those discussed above, have focused on extractive use values because these are most readily quantified. Extractive use values include the value of water for municipal and agricultural uses as well as recreation. Characterizing the in situ value of groundwater is more difficult. Aquifer depletion imposes direct economic costs on water users by increasing pumping costs. Depletion can also impose costs through a loss of ecosystem services, such as processing of organic matter by diverse microbes and invertebrates, providing possible dilution of some types of surface-originating contaminants, and sustaining populations of rare and endangered species that are often restricted to very local habitats (Culver et al., 2000). Further, depleting the stock of groundwater means that water is less available for use, or for maintenance of ecosystem services in the future. With uncertain recharge because future precipitation is uncertain, there is an insurance value from maintaining adequate groundwater stocks. Maintaining adequate stocks helps avoid shortages during drought years, prevents land subsidence, and provides late summer supplies of water to springs and streams for sustaining fisheries and wildlife and for recreating uses (NRC, 1997). Estimating in situ values of groundwater requires a dynamic model that incorporates expected recharge rates, pumping costs, and demand through time. Dynamic renewable resource models of groundwater with uncertain recharge exist and could provide a basis upon which to estimate in situ values (Burt, 1964; Provencher, 1993; Provencher and Burt, 1994; Rubio and Casino, 1993; Tsur and Zemel, 1994), though uncertainties about local hydrology would make it difficult to know the correct model specification (model uncertainty).

The construction of water transfer pipelines and additional surface storage reservoirs in San Antonio is under consideration along with conjunctive storage (pumping water into subsurface storage associated with aquifers). Although surface water can substitute for groundwater for extractive uses, surface water and groundwater do not contribute to the same ecosystem functions nor do they provide the same set of ecosystem services. At present alternatives to continued reliance on groundwater are on hold because city voters rejected development of the proposed Applewhite Reservoir as an alternative water source.

Dependence on a sole source aquifer leaves communities subject to the risk that they will not have adequate water supply if it is depleted or polluted. As population and economic activity continue to increase in the San Antonio area, it seems unlikely that the Edwards Aquifer will be sufficient to meet future demand for water. Attempts to purchase water from surrounding counties and to build more storage have been under consideration for decades but have not yet materialized. While the establishment of a water market will help reallocate a fixed amount of water to high value uses, it does not guarantee that adequate supply will be available (Merrifield and Collinge, 1999). Weighing the benefits of extractive use of groundwater versus the value of water in situ for insurance against future drought and for maintaining natural ecosystem functions and the survival of endangered species poses difficult questions. Uncertainties about potential climate change, local hydrology, and the likely future value of ecosystem services, such as provision of drinking water and habitat necessary for the survival of endangered species, complicate the task of informing decision-makers about trade-offs between current extractive use value and in situ value of groundwater. Predictions about likely future aquifer recharge and water demand, as well as evidence about the value of other ecosystem services, such as habitat provision for endangered species, all would help in guiding decisions.

Valuation of Fish Production Provided by Coastal Wetlands and Estuaries

Coastal wetlands (e.g., seagrass meadows, marshes, mangrove forests) are increasingly recognized as providing economically valuable ecosystem services. One of the most important services provided by coastal wetlands is the provision of important habitat for many species of commercially harvested fish, crustaceans, and mollusks (Beck et al., 2001). Given their high diversity and productivity, coastal wetlands are often referred to as nurseries (Boesch and Turner, 1984; NRC, 1995).

The economic value of coastal wetlands as breeding and nursery grounds can be estimated using a production function approach (see Chapter 4 and Appendix C). In economic terms, a coastal wetland is like a production facility or factory that transforms inputs (nutrients, energy) into valuable outputs (fish, crustaceans, and mollusks). The production function approach applied to fisheries requires being able to estimate the increased quantities of various marketable species produced when coastal wetlands are preserved. Then, the value of the coastal wetland as breeding and nursery grounds can be estimated by calculating the increase in consumer and producer surplus due to the increased production. Barbier (2000) provides a review of production function approaches to economically valuing the ecological function of coastal wetlands as breeding and nursery grounds.

Estimates of value of coastal wetlands for fisheries production have ranged widely. For example, Barbier and Strand (1998) estimated that conversion of one square kilometer of mangrove in Campeche, Mexico, to other than natural uses reduced the value of annual shrimp harvest by more than $150,000 for 1980 to 1981. Such a large value argues for protecting the mangroves even when ignoring the value of other ecosystem services. On the other hand, Swallow (1994) found that loss of normal-quality wetlands reduced fishery values by an estimated $2.77 per hectare, or $277 per square kilometer. Swallow concluded that protecting normal-quality wetlands is not justified because the economic value of increased value of shrimp production is less than the value of agricultural development. Basing such a conclusion on the economic value of a single ecosystem service, however, is premature; only when the value of all ecosystem services provided by the wetland is less than the value of agricultural development can such a conclusion be justified.

A major difficulty with the production function approach in the context of coastal wetlands and fisheries is the complex nature of the ecological relationships involved. Subtle changes in nutrient cycles, water temperatures and water currents, and fluctuations in the populations of predators and prey, all can have a large influence on the number of fish that reach adulthood. Large variations in fish populations occur even with no apparent change in physical conditions.

The production function models of wetlands and fisheries employed by economists to date have assumed simple ecological relationships that ignore most of this complexity. Starting with Lynne et al. (1981), these models assume that the productivity of the systems is a simple nonlinear function of the area of coastal wetlands. Static production function models assume that productivity increases with the natural logarithm of area (Bell, 1989, 1997; Farber and Costanza, 1987; Lynne et al., 1981), or that the natural logarithm of productivity increases with the natural logarithm of area (Ellis and Fisher, 1987; Freeman, 1991). Dynamic production function models (Barbier and Strand, 1998) include effects of population stock size as well as area of coastal wetlands. Increasing coastal wetland area shifts the natural population growth function up (stock-recruit function) that defines population in one period as a function of the population in the previous period. However, both the static and the dynamic production function models do not account for other important environmental factors such as the aforementioned nutrient cycling, temperature, or currents, nor do they attempt to account for stochasticity in ecological conditions or in species populations. While these models are suggestive of increased fisheries productivity from wetlands, more work is needed before quantitative estimates of the value of increased productivity can stand up to critical review. An ongoing challenge will be to discern realistic ecological relationships between structure and function of coastal wetland ecosystems and fisheries productivity amid the complex and seemingly chaotic fluctuations in fishery stocks.

How fisheries are managed also influences estimates of value (Freeman, 1991). An optimally managed fishery typically generates far higher economic returns than does an open-access fishery. For example, Barbier and Strand (1998) estimated that the annual value of a square kilometer of mangrove was more than $150,000 in 1980 to 1981, but dropped to less than $90,000 in 1989 to 1990 when overfishing had depleted stocks, resulting in lower harvests. In addition, market prices, which depend on consumer preferences as well as production from other ecosystems, will affect estimates of value.

For commercially marketed outputs, well understood methods can be used to estimate the change in consumer plus producer surplus from a change in available resource stock. The major difficulty in applying the production function approach is the great uncertainty typically present in understanding the link between structure and function of coastal wetlands and productivity of fisheries. Complexity of ecosystems, chance events, and natural variability of populations all make it difficult to discern the input-output relationships that are necessary for estimating a production function. Assumptions about fisheries management and market conditions will also influence estimates of economic value.

Provision of Flood Control Services by Floodplain Wetlands

Flood control is an important ecosystem service provided by riverine and coastal floodplains. Floodplains absorb excess water during floods that otherwise might inundate and damage developed areas. In addition to providing flood control, floodplain ecosystems provide critical resources for plant and animal communities. Despite their importance, humans have attempted to replace or supplement natural flood control services provided by floodplains by building flood control structures (e.g., dams, reservoirs, levees, floodwalls). The magnitude of flood control infrastructure development is evidenced by the fact that as a result of the Mississippi River flood of 1927—which inundated 5.26 million hectares and forced 700,000 persons to relocate—Congress authorized $325 million for flood control works on the Lower Mississippi River, which at that time was the largest public works expenditure in U.S. history (Hey and Philippi, 1995; Wright, 2000). In fact, during the height of the flood control movement spanning 1936 to 1951, Congress spent more than $11 billion for flood control projects (Wright, 2000). Although development of this regionally engineered infrastructure has protected some areas of the United States from flood damage, it has also served to promote floodplain development. Such development ultimately exacerbates levels of flood damage during large precipitation events. Furthermore, flood control structures have often given farmers and city dwellers a false sense of protection.

In principle, flood control services provided by floodplain ecosystems can be clearly defined and quantified. They are an input into production of a valuable service, namely reducing the probability of damage from floods. In this sense, floodplain ecosystems perform a role in of flood control similar to that of coastal wetlands in fishery production—one valuation method is to estimate how changes in the ecosystem lead to changes in production of the service in question and then to value the change in the service. The simplest method for economically valuing floodplain ecosystems in providing flood control is to multiply estimates of the change in probability of floods of various magnitudes with and without floodplain conservation by the estimate of damage that floods of various magnitudes would cause. This method is essentially what insurance companies routinely do in assessing risks.

A complication in assessing flood control is that measures to prevent floods or ameliorate the damage may cause changes in human behavior. For example, if the risk of building in a floodplain is lowered, there is less reason to avoid floodplain development. Further, if those building in the floodplain do not have to pay full costs for damages from floods (e.g., they are provided with subsidized flood insurance or with disaster payments that reimburse damages from floods), then one might expect excessive development in floodplains. Insurance companies are no stranger to this phenomenon, which has been referred to as a "moral hazard." Conducting an assessment of the value of flood control services depends on assumptions about patterns of development and infrastructure. Assuming that existing buildings and infrastructure are fixed and immovable will result in a different answer than an approach that factors in a behavioral response. While doing the latter is more realistic, it is also more difficult.

Another complication in evaluating wetlands and floodplains in providing flood control is that the value of this service also depends on human-engineered infrastructure in the form of dikes, levees, or flood control dams. Floodplain ecosystems and dams are alternative ways to prevent floods, similar to watersheds as alternatives to filtration plants to produce clean water. Information relevant to the value of floodplains in providing flood control is given by *avoided costs* of human engineered flood control through dikes, levees, or flood control dams. For example, the USACE opted to purchase 3,440 hectares of floodplain wetlands in the upper portion of the Charles River watershed in Massachusetts. By protecting this land, the Corps estimated that 61.67 million cubic meters of water could be stored on the floodplain—similar to the capacity of a proposed dam. Purchase of the development rights to these floodplain wetlands cost $10 million, which was one-tenth of the $100 million estimated for the dam and levee project originally proposed (American Rivers, 1997; Faber, 1996). This natural wetlands flood control system was able to deal with large floods during 1979 and 1982. For a discussion of replacement cost as a method to estimate the value of an ecosystem service see the discussion of the Catskills watershed above.

The Napa River Flood Protection Project in California provides another example that includes both structural and nonstructural flood protection approaches. These range from residential and commercial development relocation, to road reconstruction and bridge removal, along with floodplain reconstruction of 80 hectares of seasonal wetlands, intertidal mudflats, and emergent marshlands. The $155 million cost of the project is a fraction of the estimated $1.6 billion that would have to be spent by Napa County to repair flood damage over the next 100 years if the project is not implemented. The project is projected to save the community $20 million annually (USACE, 1999).

Although much anecdotal information exists regarding how flood damage is related to alterations of natural floodplains and subsequent development in high flood risk areas, determining what percentage of total flood damage costs can be attributed to wetland drainage and floodplain alterations is difficult. For example, in the Upper Mississippi River basin, a strong relationship was found between flood damage and wetland destruction; areas having fewer wetlands due to wetlands drainage generally suffered greater flood damages. Likewise, in the Puget Lowlands in Washington State, water discharge events (with a recurrence interval of 10 years prior to urbanization) increased in frequency (to a recurrence interval of 1 to 4 years) after urbanization, with the increase in probability of flooding proportional to the degree of urbanization (Moscrip and Montgomery, 1997).

Wetlands and floodplains generate other services that benefit the public, such as wastewater reclamation and reuse, pollution abatement, aquifer recharge, and recreation. One study that attempted to estimate values for a range of ecosystem services in monetary terms is a study of the multipurpose Salt Creek Greenway in Illinois (Illinois Department of Conservation, 1993; USACE, 1978). The sum of the natural values of floodplain land, other than for flood control, was estimated at $8,177 per acre. The estimated value of regional floodwater storage was $52,340 per acre (Forest Preserve District of Cook County Illinois, 1988). Combining these estimates provides an estimated total value of preserved floodplain land of $60,517 per acre. Such high values indicate that preserving floodplain ecosystems was the best use of such land, far outstripping its value in agriculture or development. Demonstrating the magnitude of these values in a clear and convincing fashion would encourage sensible land use decisions that include the preservation of floodplains where their value is high (Scheaffer et al., 2002).

In general, the value of an ecosystem service will vary with its level of provision. For example, the preservation of an additional acre of floodplain wetlands will tend to be quite valuable when only a few acres of wetlands have been similarly preserved and the probability of flooding is high. In contrast, the value of preserving an additional acre of wetlands will tend to be smaller when many acres of wetlands have already been preserved and the probability of flooding is low. Estimates such as those provided in the preceding paragraph are stated in a way that makes it seem as if the value of an additional acre of floodplain wetlands is constant. Indeed, estimates of marginal changes are sometimes derived by equating them with the average value per unit over a large change. When marginal values are not constant however, this will result in biased estimates of marginal value.

Reasonably good information to estimating the value of floodplain ecosystems in providing flood control, at least in some cases exists in some case. Hydrologic models can be used to estimate the amount of water that a floodplain ecosystem can absorb during a flood. Economic values from lowering the risk of damages from floods can be estimated with reasonable precision and, in fact, are calculated by government agencies and private insurance companies on a regular basis. Trying to incorporate changes in human behavior or investments in flood control infrastructure are complications that can affect valuation estimates. As with the other cases of estimating the value of single ecosystem services, such estimates should not be confused with estimates of the value of the ecosystem itself, which would require estimates of a range of ecosystem services.

Summary

Studies that focus on economically valuing a single ecosystem service show promise of delivering results that can inform important environmental policy decisions. In some cases, the valuation exercise is clearly defined, there is sufficient natural science understanding and information available, and well-supported economic valuation methods can be applied to generate reliable estimates of value. The provision of drinking water for New York City by protecting watersheds in the Catskills is an example in which evidence of the cost of replacing an ecosystem service informed decision-making. In other cases, the valuation of ecosystem services has not advanced far enough to provide clear and compelling evidence for formulating policies that are likely to be accepted by competing interests. Although some information is available, more work is necessary before reasonably precise estimates of the value of in situ groundwater can be made in the case of the Edwards Aquifer. The impacts of drought and legal issues regarding endangered species and rights to groundwater make such economic valuation efforts quite complex. Similarly, while providing useful information, studies on the value of coastal wetlands for fishery production are in need of further refinement before a high degree of confidence can be attached to estimates of economic value. Even where there is reasonably good information and valuation methods are available, details about ecological functions, the dynamics of ecosystems, human institutions, and human behavior can make estimation of economic value a difficult task. However, the limited scope of valuing a single ecosystem service allows researchers to address many of these complications.

One danger inherent in the economic valuation of a single ecosystem service is mistaking this value for the value of the entire ecosystem. Ecosystems produce a wide range of services and the value of a single service will necessarily represent only a partial valuation of the entire ecosystem. Sometimes this partial valuation is enough for purposes of decision-making, as in the New York City example. Other times, as in the case of Swallow's (1994) integrated ecological-economic analysis of the impacts of wetlands conversion on coastal shrimp nursery habitat in North Carolina, it will not be enough. Although that particular study provides a reliable estimate of the economic costs of wetlands conversion in terms of loss of key hydrological function and consequent effects on shrimp nursery habitat, other important ecosystem services provided by wetlands were not considered or addressed. Thus, there is a danger that the study could be used to advocate too much conversion of wetlands with the concomitant loss of a multitude of ecosystem services.

Valuing Multiple Ecosystem Services

This section reviews three examples that estimate the economic value of multiple services from an ecosystem. As discussed throughout this report, ecosystems provide a wide range of services. Because of the interconnection of processes within an ecosystem, it may be difficult to isolate and study the production of one ecosystem service without simultaneously considering other services. Further, production of some ecosystem services may be in conflict with provision of others. In such cases, providing clear policy advice requires the simultaneous estimation of multiple ecosystem values. Expanding the range of ecosystem services covered brings the resulting estimates of economic value closer to providing an accurate estimate of the value of all ecosystem services. Nevertheless, these studies, although more comprehensive than single ecosystem service studies, still represent only partial estimates of the complete economic value of services generated by an ecosystem.

Fish Production, Irrigation Waters, Navigation, Flood Control, and Clean Drinking Water: The Columbia River Basin

The Columbia River basin is the fourth largest in North America, covering large portions of the States of Idaho, Oregon, and Washington and the Canadian province of British Columbia. The Columbia River provides a wide range of ecosystem services including hydroelectric power, water supply for municipalities and industries, irrigation for agriculture, transportation, recreation, fish production, and diverse aesthetic values. The basin is highly developed and contains a large number of dams, including 18 on the mainstem of the Columbia and Snake Rivers; most of the large dams are multipurpose (i.e., hydroelectric power generation, flood control, irrigation, recreation, municipal and industrial water supply). Besides hydroelectric power generation, a major economic benefit of the dams is storage of snowmelt runoff and diversion of water for irrigated crops during the growing season. Navigation is also enhanced by maintenance of sufficient river depths. The dams along the Lower Columbia and Snake Rivers allow barge transportation to Lewiston, Idaho, making it a port with access to the ocean despite being located 465 river miles inland.

However, the dams along the Snake River and the mainstem of the Columbia River have been at the center of a major controversy; on the one hand, dams provide a range of economic benefits as listed above; on the other hand, dams are blamed, at least in part, for declines of Columbia and Snake River salmon stocks. One study estimated that the number of wild adult salmon returning to the Columbia River was less than 10 percent of the presettlement numbers of 8 million to 10 million (NRC, 1996). Several fish stocks are listed on the federal threatened and endangered species list including: spring and summer-run chinook, fall-run chinook, sockeye, steelhead and bull trout in the Snake River; spring-run chinook, steelhead, and bull trout in the Upper Columbia; steelhead and bull trout in the Mid-Columbia; and chinook, chum, steelhead, and bull trout in the Lower Columbia. The dams have fundamentally changed the ecology of the river, altering it from free-flowing to a chain of reservoirs linked by rivers that impact both downstream migration of juvenile fish and upstream migration of spawning adults (Deriso et al., 2001; NRC, 1996; Schaller et al., 1999). These dams have also closed-off access to 55 percent of the drainage area and 31 percent of the stream miles of original salmon and steelhead habitat in the Columbia River basin (NRC, 1996).

However, dams are thought not to be the only reason for the decline in the wild salmon population in the Columbia River basin. Urban development, industry, agriculture, grazing, mining, forestry, the large-scale introduction of hatchery fish, fish harvesting, ocean conditions, and climate change are also implicated. Forestry and grazing practices that result in reduced streamside vegetation can increase water temperatures above beneficial levels for salmon (Beschta, 1997; Beschta et al., 1987; Platts, 1991; Rishel, 1982). In fact, failure to attain stream temperature standards is the most prevalent water quality violation in the Pacific Northwest (Wu et al., 2003). Water withdrawals for irrigation reduce instream flow and water diversions without screens lead to loss of juvenile fish (Jaeger and Mikesell, 2002; NRC, 1996). Removal of woody debris, changes in water velocity, and erosion causing increased siltation of streams also negatively impact salmon populations (Hicks et al., 1991; NRC, 1996). Furthermore, ocean and climate conditions influence salmon populations, including decade-long changes in ocean conditions that affect currents and upwelling in the Pacific Northwest (Hare et al., 1999; Nickelson, 1986); interannual variability in precipitation influenced by El Niño-Southern Oscillation and other periodic climate shifts (Hamlet and Lettenmaier, 1999a,b; Miles et al., 2000); and long-term climate change (Beamish and Mahnken, 2001; Beamish et al., 1999; Pulwarty and Redmond, 1997).

Decision-making about fisheries management, land management, and the operation of the hydroelectric dams involves calculations of the effect on salmon populations and on other valued ecosystem services. The effects of various alternative management actions on salmon stocks and on electricity generation, irrigated agriculture, navigation, and other economic activities have been analyzed in a number of ecological and economic studies (NRC, 2004). Debates on whether to remove hydroelectric dams on the Lower Snake River focused attention on the costs and benefits of dam removal. Several recent ecological and economic studies analyze the effects of the removal of dams (Budy et al., 2002; Grant, 2001; Gregory et al., 2002; Kareiva et al., 2000; Levin and Tolimieri, 2001; Poff and Hart, 2002; Schaller et al., 1999). The benefits of restoring migratory routes for fish to upper headwaters are widely appreciated. The costs of removing sediments that accumulate in reservoirs by dredging or by allowing sediments to be washed downstream and alter spawning substrates (by infilling gravels with fine mud) are difficult to quantify but are often significant. Furthermore, elimination of some dams that currently form barriers to fish migration (preventing non-native species from moving upstream and displacing native fish species) may be important costs, not benefits, in some rivers. The USACE estimated that forgone economic benefits that would occur with the removal of four dams on the Lower Snake River would be $267 million annually (USACE, 2002), though Pernin et al. (2002) derived far lower estimates of forgone benefits from dam removal. At present, there is no consensus on how costly dam removal would be or on how effective such actions would be for salmon recovery throughout the Columbia River Basin.

Studies have been undertaken of the costs and benefits of enhancing river flows or restoring more natural patterns of flow such as allowing more spring flooding to remove fine sediments to enhance spawning conditions (Adams et al., 1993; Fisher et al., 1991; Jaeger and Mikesell, 2002; Johnson and Adams, 1988; Moore et al., 1994, 2000; Naiman et al., 2002; Paulsen and Hinrichsen, 2002; Paulsen and Wernstedt, 1994; Wernstedt and Paulsen, 1995). Some of these studies include integrated ecological and economic models that build from biological models of fish populations to economic models of the valuation (Adams et al., 1993; Johnson and Adams, 1988; Paulsen and Wernstedt, 1995; Wernstedt and Paulsen, 1995). Studies by Johnson and Adams (1988) and Adams et al. (1993) estimated the value of increased flows in the John Day River in Oregon for recreational steelhead fishing. Those researchers estimated changes in fish population by combining a hydrologic and a biological model. They then combined this estimate using contingent valuation methods to derive an estimate of value for an increased fish population.

Economic studies that focus strictly on valuing recreational or sportfishing in the Pacific Northwest include Olsen et al. (1991) and Cameron et al. (1996); though other studies have valued salmon fishing in Alaska (Layman et al., 1996) and central California (Huppert, 1989). Valuation estimates vary depending on the location of the study and the methodology employed. Other studies have focused on costs of providing increased streamflows (Aillery et al., 1999; Jaeger and Mikesell, 2002; Moore et al., 1994, 2000). Jaeger and Mikesell (2002) noted that the costs of augmenting streamflows to increase the survival of native fish in the Pacific Northwest are likely to be "modest" (between \$1 and \$10 per capita per year within the region). Studies have also evaluated the costs and benefits of modifying habitat condition (Loomis, 1988; Wu et al., 2000) and decreasing stream temperatures (Wu et al., 2003). Another area of research is on the cost-effectiveness of fish hatcheries that were initially built to offset losses of migratory fish after dam construction (Bugert, 1998; Congleton et al., 2000; Levin et al., 2001; Lichatowich, 1999; Meffe, 1992). Populations of hatchery-reared fish are known to have different genetic composition and behaviors than wild populations of the same species, and in some cases, these hatchery-reared fish may compete with or breed with wild populations thereby diminishing the stocks of those populations best adapted for long-term survival in the wild (Fisher et al., 1991).

Efforts to rebuild salmon stocks have been going on for several decades. The Pacific Northwest Electric Power Planning and Conservation Act of 1980 created the Northwest Power Planning Council to create a plan "to protect, mitigate and enhance fish and wildlife, including related spawning ground and habitat, on the Columbia River and its tributaries while assuring the Pacific Northwest an adequate, efficient, economical and reliable power supply." Despite legal authority and expenditures of more than \$3 billion to date (Northwest Power Planning Council, 2001), salmon populations have not recovered.

In part, this failure is due to the lack of scientific understanding about what measures are likely to be effective in restoring salmon: "The list of central topics that we know too little about is surprisingly long. The topics include, for example, the survival of young fish between dams compared with their survival as they pass through and over dams; the relationship of survival of young fish to the flow rates of water in rivers; the effects on survival of various management practices including logging, grazing, irrigation, agriculture, and use of hatcheries, the influence of ocean conditions. . ." (NRC, 1996). Such pervasive uncertainty has led to calls for increased research effort to reduce critical uncertainties (NRC, 1996) and for adaptive management (Lee, 1993, 1999; Walters, 1986). Several studies have analyzed the value of reducing uncertainty by learning or better forecasting ability (Costello et al., 1998; Hamlet et al., 2002; Paulsen and Hinrichsen, 2002). At present, managers face a difficult challenge in making decisions under uncertainty (see also Chapter 6). Sometimes decisions cannot wait for science to provide clear evidence, but decision-making without clear evidence allows the management policies to be attacked as excessively risky. Such policies impose potentially high costs on contain sectors of society while lacking an adequate basis of scientific support to show that they will be either biologically effective or efficient (cost-effective). The fact that some consequences are irreversible (e.g., extinction) raises the stakes further.

Questions such as how to recover salmon populations and how to protect or restore other ecosystem services in the Columbia River basin have been, and likely will continue to be, contentious issues. The costs of recovery efforts for salmon are high, already topping several billion dollars (Northwest Power Planning Council, 2001). Changing the fisheries management, regional land use, or operation of dams could lead to fundamental changes in the functioning of the ecosystem, with consequent effects on the production of multiple ecosystem services, ranging from hydroelectric power generation to the existence value of salmon. At present, there are large gaps in the scientific understanding of the impact of such changes important elements of the ecosystem, particularly salmon populations. Even if those scientific controversies were resolved, difficult valuation questions would remain. Estimating existence value and spiritual value of salmon with currently available economic valuation methods is controversial (some would argue economic methods cannot fully capture such values; see also Chapter 2). The large and uncertain costs and benefits of alternative proposals, which will fall disproportionately on different groups within society, amplify the difficulty of decision-making. The political nature of this controversy will make it a difficult arena for ecosystem valuation to be viewed as rational, objective, and conclusive. Despite these challenges, it is important to try to impart good information to such debates.

Upstream Versus Downstream Water Use: Losses in Downstream Economic Benefits as a Result of Upstream Diversion from Dams

The development of the Hadejia-Jama'are floodplain in northern Nigeria is one of many examples worldwide where water diversion upstream (associated with dams) is negatively affecting economic activities downstream. Supporters of dams and water diversion projects typically point to the economic benefits created by such projects but often fail to consider costs imposed elsewhere. In this particular case, economists and hydrologists worked together to estimate both upstream benefits and downstream costs (Acharya and Barbier, 2000, 2001; Barbier, 2003; Barbier and Thompson, 1998). These studies are among the few integrated case studies to assess the impact of upstream water allocation on water availability and groundwater recharge downstream and to value the effects on irrigated agriculture and potable water supplies downstream.

Barbier and Thompson (1998) combined economic and hydrological analysis to compare the benefits of upstream diversion with losses of downstream floodplain benefits in terms of agriculture, fishing, and fuel wood. They found that fully implementing all existing and planned upstream irrigation projects results in losses of approximately $20 million (1989-1990 U.S. dollars) versus the case with no irrigation upstream. Full implementation of upstream irrigation project generated estimated benefits of approximately $3 million, while floodplain losses were estimated to be around $23 million. Acharya and Barbier (2000, 2001) analyzed impacts of a one meter drop in groundwater from lower water recharge in the floodplain on dry season agriculture and rural domestic water use in villages. They estimated annual losses of $1.2 million in irrigated dry season agriculture and $4.8 million in domestic water consumption for rural households. These analyses strongly suggest that expansion of existing irrigation schemes within the river basin is not economically desirable (Barbier, 2003).

In a very different setting, Berrens et al. (1998) reported similar conclusions about upstream diversions of water. The purpose of this study was to analyze the costs of imposing minimum instream flow regulations in the Colorado River to protect endangered fish species. However, instead of costs they found that imposing instream flow restrictions generated overall positive net benefits because it allowed more water to be used further downstream where it would be put to higher valued uses.

Cumulative alterations in hydrologic connections in the landscape exert major environmental and economic effects at different spatial scales (e.g., Pringle, 2001). In the last decade, ecologists have begun to identify and quantify the substantial environmental consequences of dams on local, regional, and even global scales (e.g., McCully, 2002; Pringle et al., 2000). However, relatively few integrated studies have evaluated economic consequences from hydrologic modifications and the resultant changes in provision of ecosystem services. Even at local scales, studies are conspicuously lacking that attempt to quantify the economic costs to downstream human activities from upstream water diversions such as those associated with dams. In many cases, damage assessments are attempted decades after a dam is completed so research is dependent on historical records to recall or reconstruct wetland environments and associated economic activities that once existed. For example, researchers are dependent on midden piles (i.e., a collection of biotic materials that can provide a paleoenvironmental history of an area) to assess the extent of shellfish production near the mouth of the Colorado River before dams diverted virtually all of its flow.

Fully evaluating the consequences of many projects, such as dams and water diversions, requires assessment of the change in value of ecosystem services that may play out at different spatial scales. Some of the consequences may occur far removed from the site of the project, such as consequences to downstream environments (floodplains, deltas, etc.). As the case studies of the Hadejia-Jama'are floodplain illustrate, a full accounting of downstream consequences can generate a different perspective of whether a project generates positive or negative net benefits.

Other well-known examples, such as water use in the Colorado River, the hypoxic zone in the Gulf of Mexico caused by high nitrogen runoff from Mississippi River drainage, and the drying of the Aral Sea due to upstream diversion of water, further illustrate the importance of considerations of downstream consequences. Ecosystem processes are often spatially linked, especially in aquatic ecosystems (see Chapter 3 for further information). Full accounting for the consequences of these actions on the value of ecosystem services requires understanding these spatial links and undertaking integrated studies at suitably large spatial scales to fully address important effects.

Food Production, Recreational Fishing, and Provision of Drinking Water from Lakes: Lake Mendota, Wisconsin

In many ecosystems it is difficult to isolate the economic value of a single good or service because of the complex connections among species and ecosystem functions. For example, food production such as a largemouth bass may seem obvious as an economic "good" derived from a lake ecosystem. Similarly, the recreational value of fishing may be measured by economic analysis as another good. However, much of an ecosystem's productivity may not produce a harvestable yield of interest to human consumers (algae or other aquatic plants). Furthermore, the type of fish (largemouth bass, lake trout, or carp) may also vary in value as products for either food or recreation. Although productivity is a fundamental measure of ecosystem functioning (see Box 3-1), it is different from what economists would typically use to evaluate human uses of ecosystem function. Generally, ecologists measure units of energy required for a species maintenance (respiration) and the energy converted to live matter (biomass) per unit area per unit time as the total productivity, whereas economists focus on harvestable amounts of certain desirable species as the valuable yield or one type of good produced by the ecosystem. Breakdown of dead organic matter through decomposition by microorganisms might be deemed an ecosystem service that maintains clean water in the lake, but its economic value is difficult to isolate from the recycling of nutrients needed for the productivity of plants and animals. Clean drinking water, food production, and recreation are all products of a lake ecosystem, but it is not easy to measure each one separately or to resolve conflicting views on which one is more or less important if trade-offs in management decisions are required. Removing excessive nutrients from a lake will improve drinking water quality (up to some point), but the resulting effect on fish production requires careful study of the entire food web.

Lake Mendota, located on the edge of the campus of the University of Wisconsin, is probably the most thoroughly studied medium-sized lake (>4,000 hectares) in the world (e.g., Brock, 1985; Kitchell, 1992; Lathrop et al., 1998, 2002). In the early 1980s, the combined decline of walleye populations and recreational fishing together with concerns over unpredictable outbreaks of noxious and sometimes toxic Cyanobacteria (blue-green algae) in the lake, led to a joint research effort that demonstrated that water quality and food web management could be successfully integrated. This research effort focused on the following issues: (1) trade-offs between increased stocking for walleye and northern pike fishing or managing for bass or perch (distinctly different goods for different groups of people); (2) effects of increased water clarity (following removal of algae by grazing zooplankton) on deep light penetration that can result in increased growth of submerged aquatic plants (macrophytes provide critical habitat structure used by juvenile fish to avoid predators, but some can become weedy and reduce dissolved oxygen in shallow, nearshore lake regions during late summer and winter when the dead plants decay); and (3) effects of improved water quality (clear water with lower concentrations of dissolved nutrients) that may reduce fish productivity and result in lower recreational fishing harvest levels. Finding the right balance of the production of various ecosystem goods and services is challenging, especially since what happens in the lake ecosystem depends on management decisions for the surrounding land as well. Inflowing waters from agricultural sources and municipal sewage treatment plants can provide excessive nutrients without appropriate land and municipal wastewater management. Conventional management approaches often focus on one sector at a time. However, management to address the problems of one sector may increase problems in other sectors if important interconnections are ignored. Successful management requires understanding the linkages between sectors and may require interdisciplinary teams to address complex multisector issues.

Economic analyses of ecosystem services of Lake Mendota (Stumborg et al., 2001) and similar lake ecosystems have considered costs and benefits of managing eutrophication relative to recreation, real estate values, drinking water quality, and other site-specific attributes (Boyle et al., 1999; Brock and de Zeeuw, 2002; Carpenter et al., 1999; D'Arge and Shogren, 1998; Wilson and Carpenter, 1999). These studies illustrate the unique aspects of Lake Mendota that constrain benefits transfer of results to other lakes. They also highlight the considerable uncertainties in lake management. Significant sources of uncertainties are related to high levels of temporal variability in lake ecosystem dynamics, surrounding land-use changes, and hydrological variables. For example, regional droughts greatly reduce inflows, increase residence times of nutrients, and often decrease transport of suspended sediments that affect water quality by altering turbidity and light regimes, as well as influencing nutrient input, transport, and cycling (Kitchell, 1992). Land clearing for development generally increases peak flows of runoff, increases bank erosion of tributaries that drain into lakes, and greatly increases turbidity. Thus, despite intensive programs to remove nutrients from point sources such as sewage treatment plants, continued input of nutrients from diffuse, nonpoint sources (e.g., fertilizers from agricultural runoff, soil erosion, septic tanks) remains a major challenge in many watersheds (NRC, 2000).

Aquatic ecologists manipulated fish and zooplankton species to regulate algal production and restore clear water to lakes. Some lakes were covered with green scum and characterized by fish kills resulting from deoxygenation during warm-water periods in late summer. Ecologists learned that successive, small increments of phosphorus additions to lakes were critical to eutrophication in many situations. The ratio of phosphorus to nitrogen was also found to alter the species composition of the planktonic algae. Low values of phosphorus led to the dominance of lake waters by green algae that were readily consumed by grazing zooplankton and fish. Incremental nutrient additions caused lakes to flip from one state (clean water) to another (green, turbid water) that altered ecosystem services and lowered real estate values of surrounding property (Carpenter et al., 1999; Wilson and Carpenter, 1999).

Although harvesting fish was known to remove nutrients, especially phosphorus, and to alter pathways of food webs to minimize algal blooms, the effects of large-scale applications of this approach to managing water quality in Lake Mendota and other lakes remained unknown until a number of field experiments and models were completed (DeMelo et al., 1992; Gulati et al., 1990; Kitchell, 1992; Reed-Anderson et al., 2000). The concept of removing some dissolved nutrients from the open waters by optimizing their incorporation into green algae that is later consumed by zooplankton, and then by juvenile fish, was widely understood to work in small ponds but was not often tested in lake ecosystems. Excretion of nutrients by grazers and predators can increase nutrient turnover and productivity, but understanding and stabilizing the balance of different consumer species in food webs remains complex. Lake management efforts use a combination of biomanipulation of food webs (Shapiro, 1990), diversions of some tributaries that have high nutrient loadings, and nutrient removal technologies that focuses on point sources. This combined management approach provides an opportunity to examine trade-offs between alternative investments in water pollution control and recreational fisheries management.

Summary

As the case studies in this section illustrate, aquatic ecosystems produce multiple services, many of which are closely interconnected. These interconnections sometimes make it difficult to analyze one service in isolation. For example, a dam that diverts water from a river or increases nutrient input to a lake, may alter ecosystem structure and function in fundamental ways, thereby causing changes in the production of a range of ecosystem goods and services. Thus, increasing the number of services to be economically valued necessarily increases the complexity of the valuation exercise and will likely increase the set of specialized skills and experience needed. Deriving a unified assessment of economic value requires integrating disciplinary skills. This integration becomes increasingly difficult both on an intellectual level and on a practical level as the number of services is increased. The interconnection of ecosystem services may take place on a spatial or temporal scale, as well. As the Hadejia-Jama'are floodplain example illustrates, there are links between the provision of ecosystem services at upstream and downstream sites. Finally, it will often be the case that there are trade-offs among the production of different services. For example, reduced nutrient input into a lake may increase recreational values by decreasing algal blooms and turbidity, but it may also lower total fish productivity. Building a dam will change a section of free-flowing river into a lake, which may result in a decrease in the population of some fish species (e.g., salmon) and in opportunities for river recreation (e.g., canoeing, kayaking, whitewater rafting) while increasing populations of lake-adapted fish species and lake-based recreation (e.g., sailing, waterskiing). Trade-offs among ecosystem services increase the likelihood of sociopolitical debates because different groups are likely to place different relative values on different services. Natural variation, such as interannual differences in flood and drought frequencies and intensities, further complicates issues associated with reaching agreement on trade-offs among different ecosystem services. Although economic valuation of multiple ecosystem services is more difficult than valuation of a single ecosystem service, interconnections among services may make it necessary to expand the scope of the analysis.

Valuing Ecosystems

This section reviews three cases that in some sense attempt to cover the economic value of all ecosystem services either for a single ecosystem or, more ambitiously, for the entire planet. The policy context of these three sets of studies is quite different. The first case study in this section reviews valuation studies done for the purpose of natural resource damage assessment for the *Exxon Valdez* oil spill. The second case, concerning the Florida Everglades, reviews studies that support what is probably the most expensive attempt at ecosystem restoration undertaken to date. The final case study by Costanza et al. (1997) represents the most ambitious attempt at valuation of ecosystem services to date. Its scope is nothing less than the value of ecosystem services for the entire planet (i.e., "the value of everything").

Exxon Valdez *Oil Spill*

In March 1989, the *Exxon Valdez* oil tanker spilled 38,000 metric tons of crude oil (about one-fifth of its total cargo) into Prince William Sound in south-central Alaska. This accident inflicted large-scale environmental damage. Approximately 2,100 km of shoreline were impacted, with 300 km heavily or moderately impacted and 1,800 km lightly or very lightly oiled. Much of this coastline consists of gravel beaches into which oil penetrated to depths as great as one meter. The carcasses of more than 35,000 birds and 1,000 sea otters were found after the spill, but this is considered to be a small fraction of the actual death toll since most carcasses sink. The best estimates are that the spill caused the deaths of 250,000 seabirds, 2,800 sea otters, 300 harbor seals, 250 bald eagles, up to 22 killer whales, and billions of salmon and herring eggs. While lingering injuries continue to plague some species, others appear to have recovered. Knowledge of the fate of the 38,000 metric tons of oil lost by the *Exxon Valdez* is imprecise; however, it is estimated that 30-40 percent evaporated, 10-25 percent was recovered, and the rest remained in the marine environment for some period of time (Shaw, 1992).

Following the accident, both private groups and governments sued Exxon for damages caused by the oil spill. Commercial fish interests pursued their own damages under federal and state law because they had a direct economic stake in the resource. Federal, state, and tribal governments serve as the legal trustees for public resources. The State of Alaska and the federal government sued for damages to public natural resources. Damage to public resources included lost recreational opportunities, diminished passive use values, and diminished use by Native peoples.

To prepare for possible trial in these cases, private parties, the State of Alaska, the federal government, and Exxon commissioned research bearing on the question of damages caused by the oil spill. Recognized researchers in a number of fields were recruited to undertake this research. The research was conducted for the purposes of litigation and took place in a highly charged atmosphere with billions of dollars of potential liability on the line. It was subject to intense scrutiny and generated heated debates over methods and results, particularly about validity and reliability of nonuse values estimated using contingent valuation methods. Although the State of Alaska and the federal government settled with Exxon over damages to public resources in 1991, debates about the validity and reliability of contingent valuation estimates of nonuse values raised by the affair continued. Some analysts extended these critiques to applications of contingent valuation to estimate use values. A conference sponsored by Exxon held in 1992 presented research papers that were quite critical of contingent valuation estimates of nonuse values (these papers were subsequently published in Hausman, 1993). In response to the ongoing controversy over the use of contingent valuation in natural resource damage assessment, the National Oceanic and Atmospheric Administration (NOAA) convened a blue-ribbon panel to assess the validity of contingent valuation applications to nonuse values, resulting in a widely cited NOAA panel report (NOAA, 1993).

Researchers used a variety of valuation techniques to assess the dollar value of damage from the *Exxon Valdez* oil spill to an array of public resources. Economic studies were conducted on recreational fishing losses (using a travel-cost model), impacts on tourism, replacement costs of birds and mammals, and a contingent valuation study of lost passive nonuse values. Studies of sportfishing activity and tourism indicators (i.e., vacation planning, visitor spending, canceled bookings) all indicated decreases in recreation and tourism activity. A major study using contingent valuation was undertaken to estimate losses in (nonuse) values from the oil spill for people who did not visit or directly use the resources of Prince William Sound. There were also studies of lost value from commercial fishing. Commercial fishing losses, although part of the economic measure of damage to the ecosystem, were not part of the public resource injuries. Recreational fishing losses were counted as part of the public resource injuries.

Recreational fishing losses were estimated by two different teams, one representing Exxon and one representing the State of Alaska. Both teams used a random utility travel-cost model to estimate forgone use values but they arrived at estimates that differed by an order of magnitude. Hausman et al. (1992, 1993) estimated losses at $2.6 million to $3.2 million in the first year after the oil spill (1989) depending on the specific model used. This damage estimate would be expected to decline in future years as salmon stocks recovered from the spill. Carson and Hanemann (1992) estimated losses as high as $50 million per year. These differences occurred largely because Hausman et al. (1992, 1993) assumed 16,000 fewer recreational trips per year while Carson and Hanemann assumed 180,000 fewer trips. Hausman et al. (1992, 1993) also estimated lost recreational use values for hunting and hiking or viewing as well as a gain in recreational use value for pleasure boating (due to more trips taken to observe the aftermath of the spill). In total, they estimated "lost interim use values" due to the oil spill of $3.8 million in 1989.

An extensive contingent valuation study (Carson et al., 1994) estimated a loss of $2.8 billion in passive nonuse values by people who did not use or anticipated using Prince William Sound in the future. That estimate was derived from a national in-person survey that asked respondents about their willingness to pay to prevent the ecological harm of an oil spill of the magnitude of the *Exxon Valdez*. The survey found that median household willingness to pay to avoid similar injury to the marine ecosystem of the Prince William Sound region was $31 per household—which results in a value of $2.8 billion when summed across all households in the United States. However, it can be argued that this estimate was conservative and that the value of the ecological damage was far higher. For example, the persons surveyed were informed that ecological damages included 75,000 to 150,000 seabirds, 580 sea otters, and 100 harbor seals, compared to best estimates of 250,000 seabirds, 2,800 sea otters, and 300 harbor seals. Survey respondents were also told that no long-term damage would occur to the ecosystem and that wildlife populations would return to previous densities within three to five years. In addition, willingness to pay was used as the measure of damages, rather than willingness to accept estimates, which typically are higher (Hanemann, 1991; see also Chapters 2 and 4). On the other hand, Hausman et al. (1993) were quite skeptical of estimates of nonuse values of several billion dollars when their estimate of use value was only several million dollars.

The replacement costs study identified a per-unit replacement cost of various seabirds and mammals, as well as eagles (Brown, 1992). For example, the market price or the costs of relocating otters vary from $1,500 to $50,000 per otter. Replacement costs cannot be added to the public and private losses noted above, however, because these are expenditures to restore both the ecological services of the ecosystem and the aspects of these services enjoyed by humans (e.g., viewing wildlife and fishing).

A market model was used to evaluate private economic losses to commercial fisheries. Cohen (1995) estimated that the upper bound of the accident's first-year social costs was $108 million. Second-year effects may have been as high as $47 million. Although estimates of economic losses to commercial fisheries are typically far less controversial than estimates of nonmarket values, there remain a number of sources of uncertainty. Cohen (1995) was not able to fully consider the numerous sources of variability inherent in the marine environment that may have contributed to harvest volume impacts but were provisionally attributed to the oil spill. In addition, efforts to distinguish effects of the oil spill on the value of harvest from other potential influences were hindered by inadequacies in economic data on supply responses of other U.S. commercial fisheries and the Japanese commercial fish market (Cohen, 1995). The analysis did not attempt to analyze economic harm to other components of south-central Alaska's regional economy (e.g., fish processing and service sectors) or the extent to which the oil spill contributed to changes in the overall economic climate in south-central Alaska (Cohen, 1995).

Natural resource damage assessments require accurate assessment of the dollar value of damages to ecological resources. However, difficulties in understanding ecosystems, the production of services, and the values of those services is likely to lead to imprecise estimates. A precise determination of the damages caused by the *Exxon Valdez* oil spill is constrained by the dynamic interaction of numerous biological and economic variables (Cohen, 1995; Paine et al., 1996; Shaw, 1992). It is difficult to measure the full impact of the oil spill, to predict the time path of ecosystem recovery, and the extent of recovery that will ultimately occur. Furthermore, it is difficult to disentangle the effects of the oil spill from other environmental changes. Therefore, some unavoidable uncertainty will remain in attempts to quantify the link between the oil spill and changes in the provision of ecosystem services valued by humans. On top of this, valuing changes in the ecosystem involves both use values and passive nonuse values, the latter being notoriously difficult to estimate with much precision. However, even valuing damages to marketed commodities (e.g., the value of lost commercial fishing), where traditional uncontroversial market methods were used, proved difficult and a source of disagreement. Although studies of the value of ecosystem services can generate useful information, the degree of imprecision of the resulting estimates of values leaves plenty of room for arguments in court in natural resource damage assessment cases.

Restoration of the Florida Everglades

The Comprehensive Everglades Restoration Plan (CERP) is a framework (see also Box 3-6) and guide to restore the water resources of central and south Florida including the Everglades. This plan covers an area of 18,000 square miles and is predicted to take more than 30 years to implement. It is designed to regulate the quality, quantity, and distribution of water flows (CERP, 2001). The Florida Everglades ecosystem is one of the most endangered wetland complexes in the United States. More than one-half of the original marshes contained in this highly productive and diverse ecosystem have been drained. The remaining area is dissected by 2,253 km of canals that transport water loaded heavily with nutrients from fertilizer and waste runoff from urban and agricultural lands. The Everglades provides habitat for 14 endangered or threatened species including the Florida panther (*Felis concolor coryi*), wood stork (*Mycteria americana*), and Florida Everglades snail kite (*Rostrhamus sociabilis plumbeus*).

The hydrologic connectivity (Pringle, 2003) between many different ecosystems within the Everglades makes quantifying the changes in ecosystem services due to restoration an extremely complex issue. The Everglades provide recharge water for aquifers across the state. Water flow through the Everglades also affects the salinity and biological integrity of connecting marine waters of Florida Bay. The effects of hydrologic alterations on these interconnected ecosystems are still subject to dispute. These and related issues have served as the basis of several previous National Research Council reports (e.g., NRC, 2002a,b). For example, the effectiveness of regional aquifer storage and recovery[2] as a component of the CERP Plan is limited (NRC, 2002a). While aquifer storage and recovery have many advantages, disadvantages include low recharge and recovery rates relative to surface storage. Likewise, ecological impacts of altered hydrologic flow scenarios into Florida Bay also require more study (NRC, 2002b).

The Florida Everglades includes 4 national parks and preserves, 13 national wildlife refuges, 2 national marine sanctuaries, 17 state parks, 10 state aquatic preserves, and 5 wildlife management areas. Everglades National Park was created in 1947 to protect the approximately 20 percent of the remaining wetlands and is thus a vestige of the original Everglades ecosystem (which once included what is presently the Everglades Agricultural Area, the Water Conservation Area, and western portions of coastal urban areas). Large-scale drainage efforts over the last several decades have led to rapid agricultural, commercial, and residential growth (Englehardt, 1998) to the extent that native flora and fauna of the Everglades and adjacent interconnecting systems are imperiled. Efforts to restore hydrologic function (i.e., flows) to the region are complicated by the magnitude and extent of human modification of the landscape.

Waters of the Kissimmee River flow south into Lake Okeechobee (the second-largest freshwater lake in the United States) and then into agricultural fields through an extensive system of flood control canals and reservoirs. Eventually the waters flow into the Everglades and into mangrove forests and estuaries on the Atlantic and Gulf Coasts. The Kissimmee was once a broad (1-2 miles wide), 103-mile-long river that meandered through an extensive network of floodplain wetlands (20,000 hectares). The ecosystem provided habitat for more than 300 fish and wildlife species, including resident and over-wintering waterfowl, a diverse wading bird community, and 13 game fish species. Channelization of the Kissimmee and drainage of approximately two-thirds of the floodplain wetlands were undertaken in the 1960s by the U.S. Army Corps of Engineers to improve flood protection and to provide drainage for agriculture. This has damaged the river-floodplain ecosystem, resulting in a 92 percent reduction in over-wintering waterfowl and negative effects on the native fish community (Englehardt, 1998). Moreover, agricultural drainage waters contain elevated phosphorus concentrations and have caused enrichment of Lake Okeechobee and the Everglades. Algal blooms have resulted in dramatic reductions in dissolved oxygen which has led to the death of many aquatic species; for example, nesting bird populations have decreased by 90 percent over the past 60 years.

One aspect of the CERP is to reestablish historic geomorphic and hydrologic conditions so that the Kissimmee River will once again be connected with its floodplain. This is being accomplished by back-filling the central portion of the dredged flood control canal (mainstem Kissimmee) and reestablishing side channels and backwaters (Toth, 1996). The restoration effort is also attempting to reduce phosphorus levels in the ecosystem by constructing stormwater treatment areas (large constructed wetlands). Other efforts to restore the Everglades include increasing water flows through the region, mimicking historic flow patterns, cleaning up polluted waters (e.g., Guardo et al., 1995), and purchasing private lands to protect them from development.

The economic valuation of restoration alternatives for the Everglades involves many challenges, primarily due to the complexity of the ecological systems (Davis and Ogden, 1994; Englehardt, 1998; Toth, 1996). Although restoration efforts promise to increase habitat for a

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[2] Pyne (1995) defines aquifer storage and recovery as "the storage of water in a suitable aquifer through a well during times when water is available, and recovery of the water from the same well during times when it is needed."

wide variety of species, it is difficult to predict *how* different species will respond to changes in water quantity and quality. For example, ongoing restoration of the Everglades is dependent on numerous computer models to understand ecosystem processes, test alternatives, and evaluate restoration performance (Sklar et al., 2001). Landscape models used for restoration include hydrologic models, transition probability models, gradient models, distributional mosaic models, and individual-based models. When several landscape models are combined, they have the potential to contribute to water management and policymaking for Everglades restoration (Sklar et al. 2001); however, they have shortcomings based on their inherent assumptions and lack of important information. Although this is one of the most studied ecosystems in the world, much additional ecological knowledge is necessary (Kiker et al., 2001) to improve existing models and develop new ones. Curnutt et al. (2000) developed spatially-explicit species index models to predict how a number of species and species groups (e.g., cape seaside sparrow, snail kite, a species group model of long-legged wading birds) would respond to different hydrological restoration management alternatives. While no one scenario was beneficial to all species, the model allowed assessment of relative species responses to alternative water management scenarios.

Englehardt (1998) evaluated ecological benefits and impacts of proposed and alternative restoration plans in monetary terms. Current plans for restoration involve discharge of phosphorus-enriched water from artificial wetlands (stormwater treatment areas) to relatively pristine Everglades marshes for 3-10 years, risking conversion of the ecosystem to a eutrophic cattail marsh. Uncertain benefits and impacts were analyzed probabilistically, following principles of net present value analysis. This analysis indicated that alternative "bypass plans" would avoid the loss of up to 1,200 hectares of sawgrass marsh at a cost that is probabilistically justified by the value of the ecosystem preserved. This type of analysis can help clarify trade-offs but is complicated by the realities that restoration alternatives may have competing ecological benefits and losses over time. Again, there is also often a lack of scientific understanding and agreement (Englehardt, 1988).

Aillery et al. (2001) provide an analysis of trade-offs between restoration and agricultural economic returns to the Everglades Agricultural Area under alternative water retention targets. They developed a model linking economic and physical systems (including agricultural production, soil loss, and water retention). Effects of water retention scenarios (such as groundwater retention and surface water storage development) on production returns and agricultural resource use were estimated. Not surprisingly, the results suggest that small increases in water retention can be achieved with minimal losses in agricultural income, while agricultural returns decline more significantly with higher water retention targets.

To date there have been no attempts at a comprehensive economic valuation of the Everglades restoration efforts. Given the hydrological, ecological, and economic complexities of South Florida, a complete accounting of values is unlikely anytime in the near future. However, advances in our understanding of hydrological, ecological, and economic relationships could be of great help in guiding future restoration efforts. Such data can be useful in comparing the net benefits of alternative management policies even if an overall estimate of ecosystem values remains elusive.

The Value of Everything: Multiple Services in Multiple Ecosystems

In an ambitious and controversial paper, Costanza et al. (1997) attempted to estimate the total economic value of the services provided by all ecosystems on earth. The paper received a great deal of attention, not all of it favorable. A follow-up briefing article in *Nature* the following year stated that "The paper was a box-office success but was panned by the critics" (Nature, 1998).

In the paper, Costanza et al. (1997) estimated values for 17 ecosystem services[3] from 16 ecosystem types including wetlands, forests, grasslands, estuaries, and other marine and terrestrial ecosystems. To derive estimates of the economic value of ecosystem services, Costanza et al. (1997) began with existing estimates of the productivity of a hectare for each ecosystem type for each service and a willingness to pay estimate for the service. Multiplying these estimates generated a per hectare value of the ecosystem service for each ecosystem type. They then aggregated across all services to establish a value per hectare for each ecosystem type. Finally, they multiplied this per-hectare value by the number of hectares of each ecosystem type and summed across ecosystem types to derive the total value of ecosystem services. For the bottom line, they estimated that the annual value of ecosystem services for the earth ranged from $16 trillion to $54 trillion, with a mean estimate of $33 trillion. This value was notably higher than the value of global GDP (gross domestic product) at the time ($18 trillion).

Critics have pointed out a number of serious flaws that lead to conclusions that the estimate has little scientific merit (e.g., Bockstael et al., 2000; Toman, 1998) while some attacked the approach as a meaningless exercise. If the question is the value of the life support system of the planet, there can be only one of two answers depending upon whether a willingness to pay or a willingness to accept approach is used. Willingness to pay should be bounded by global ability to pay (i.e., global GDP, or $18 trillion). If willingness to accept is used, then as Toman (1998) concludes, $33 trillion is "a serious underestimate of infinity."

Other criticisms focused on problems with the methods and assumptions used in the paper. The paper itself has a long list of "sources of error, limitations and caveat" (Costanza et al., 1997). Obviously, there will be large data gaps in any such exercise. In addition, aggregation issues pose particular trouble in this study. According to Bockstael et al. (2000),

> ...Simple multiplication of a physical quantity by 'unit value' (derived from a case study that estimated the economic value for a specific resource) is a serious error. Small changes in an ecosystem's services do not adequately characterize, with simple multipliers, the loss of a global ecosystem service. Values estimated at one scale cannot be expanded by a convenient physical index of area, such as hectares, to another scale; nor can two separate value estimates, derived in different contexts, simply be added together.

A similar aggregation problem occurs in ecology, "A linear aggregation rule treats each change as if it could be made independent of the other constituent elements. In doing so, it assumes independence within and across the ecosystems being considered, and it ignores the possible effects of feedback cycles" (Bockstael et al., 2000). The approach used by Costanza et al. (1997) also assumes that ecosystem service production is "scale-free" in the sense that

[3] These 17 services, in order of importance, were nutrient cycling (accounting for over 50 percent of the total value), cultural values, waste treatment, water supply, disturbance regulation, food production, gas regulation, water regulation, recreation, raw materials, climate regulation, erosion control, biological control, habitat and refugia, pollination, genetic resources, and soil formation.

provision per unit area is constant no matter how big or small the ecosystem under consideration. Other papers (see also Chapter 3) since have stressed the importance of more focused analysis that matches the scale of analysis for ecosystem valuation to the scale of management questions (Balmford et al., 2002; Daily et al., 2000).

However, even some harsh critics of the paper have concluded that it served a useful role in getting more attention on the values of ecosystem services. One prominent economist said the paper was "a recklessly heroic attempt to do something futile" but that it was "very useful—it stirred things up a lot." (Nature, 1998)

Summary

In one sense, attempting to economically value all ecosystem services can be viewed as the correct approach to take because it offers a complete accounting. It would certainly be advantageous to have evidence on *all* benefits and costs prior to decision-making because anything less will be partial and incomplete and risks giving incorrect advice to decision-makers. Yet trying to attain the "value of everything" through a complete and reliable accounting of all ecosystem services cannot be done with current understanding and methods and is unlikely to be accomplished anytime soon. Problems arise because knowledge of the translation from ecosystem function to ecosystem services is often incomplete as is the translation from services to values. For studies of the value of a single ecosystem service, and to some extent for studies of the value of multiple ecosystem services, attention can be directed toward services that are easier and relatively straightforward to value, such as the economic value of reducing the likelihood of flood damage or providing clean drinking water without filtration. In the case of the *Exxon Valdez* and the Florida Everglades restoration however, many of the important values are linked to the existence of species or the existence of the ecosystem itself in something akin to its original (pre-human-altered) condition. Valuing such services presents difficult challenges even when ecological knowledge is relatively complete. In addition, aggregation issues can cause problems in comprehensive approaches to ecosystem service valuation, particularly when scaling up the valuation exercise to cover multiple ecosystems.

IMPLICATIONS AND LESSONS LEARNED

This chapter has reviewed a number of applications of ecosystem valuation ranging from economic valuation of a single ecosystem service to attempts to value all services for an ecosystem and even for the entire planet. The valuation of ecosystem services is still relatively new and requires the integration of ecology and other natural sciences with economics. Such integration is not easy to accomplish. Still, examples of approaches and interdisciplinary studies that provide such integration indicate successful beginnings. Some of the lessons emerging from the case studies reviewed in the previous sections are discussed below.

Extent of Ecological and Economic Information for Valuing Ecosystem Services

As examples in this chapter have shown, the ability to generate useful information about the value of ecosystem services varies widely across cases. For some policy questions, enough is known about ecosystem service valuation to help in decision-making. A good example is the value of providing drinking water for New York City by protecting watersheds in the Catskills rather than building more costly filtration system. As other examples make clear, knowledge and information may not yet be sufficient at present to estimate the value of ecosystem services with enough precision to answer policy-relevant questions.

The inability to generate sufficiently precise and reliable estimates of ecosystem values for purposes of informing decision-making may arise from any combination of the following three reasons: (1) there may be insufficient ecological knowledge or information to estimate the quantity of ecosystem services produced or to estimate how ecosystem service production would change under alternative scenarios; (2) existing economic methods may be unable to generate reliable and uncontroversial estimates of value for the provision of various levels of ecosystem services; and (3) there may be a lack of integration of ecological and economic analysis.

Much of the difficulty in generating reliable estimates of the value of ecosystem services derives from the fact that ecosystems are complex and dynamic and our understanding of them is typically incomplete or flawed. Learning how such ecosystems evolve and change as inputs to the system change can be a slow process (perhaps not even as fast at the system itself is changing). The example of the Everglades and the difficulty in designing a restoration plan aptly illustrate problems inherent in attempting to understand and manage aquatic ecosystems because the links from ecosystem condition and function to the production of goods and services may be hard to decipher. Other examples reviewed include fish production in coastal wetlands and salmon production in the Columbia River, where changes in ocean currents, flow of nutrient, water temperature, precipitation patterns, disease prevalence, predator and prey populations, and other factors can impact fish populations. Although an increase in fish population from one year to the next could be related to a beneficial change in management strategy, it may also be due to changes in ocean conditions or other causes. In other cases, it is not necessary to understand the entire ecosystem in order to be able to estimate the production of an ecosystem service of interest with reasonable precision, such as the degree of flood control provided by wetlands. However, without adequate ecological understanding of ecosystem structure and function, it will not be possible to predict the level of some ecosystem services provided or the way provision levels may change under alternative management options.

Other difficulties arise because some ecosystem services are notoriously difficult to value. As stated previously, it is clear that people place value on such things as the continued existence of species, wilderness, beautiful scenery, and restoring ecosystems to a pre-human-altered condition. Ignoring such values, essentially assigning a value of zero to them, is clearly incorrect. What value should be assigned, however, is often far from clear and subject to debate. Estimating existence values and other nonconsumptive or nonuse values is among the most difficult challenges in environmental economics. For entire ecosystem valuation efforts, such as the *Exxon Valdez* case or the Everglades restoration, estimating such values cannot be avoided because they may account for a significant fraction of total economic value. The development and application of nonmarket valuation approaches have advanced significantly over the past two decades (see Chapter 4). There remains controversy, both within the economics profession and outside it, regarding the reliability of economic valuation methodologies (contingent valuation in particular) for environmental goods and services. For some ecosystem services such as valuing commercial fish harvests or the reduction of flood damage, the valuation exercise is more straightforward and uncontroversial. Difficulties may remain in knowing the level of services provided (e.g., how many fish are produced by coastal wetlands) or in obtaining relevant data (e.g., costs of fish harvesting), but there is relatively little disagreement about the utility of existing valuation methodology. One method, however, deserves particular mention and caution.

Using replacement or avoided cost to value an ecosystem service is justified under a restricted set of circumstances—namely, when there are alternative ways of providing the same service and the value of the service exceeds the cost of providing it, such as the provision of drinking water for New York City by increasing the protection of watersheds in the Catskills. However, this approach is sometimes applied when these conditions do not hold, thereby generating numbers that may bear no relation to the actual economic value of ecosystem services. For example, tallying up the large sum of money necessary to restore Prince William Sound to something close to its pre-spill condition does not necessarily imply that the economic value for services provided by the ecosystem is anywhere close to this cost.

Even when ecologists understand a system reasonably well and economists can apply widely accepted valuation methods, an effort at valuing ecosystem services may still fail if ecologists and economists fail to integrate their approaches. Unless the correct questions are asked at the outset, ecological information may not be of particular use for generating estimates of the production of ecosystem services in a useful form for economists to apply valuation methods. For their part, economists may apply valuation methodologies to cases that are not built on solid ecological grounding. It is important for ecologists and economists to talk at the outset of the valuation exercise to design a unified approach. Although it is easy enough to state or even recommend that ecologists and economists need to work together on integrated studies, accomplishing such integration is often difficult because of institutional constraints and reward structures that are largely disciplinary-based. Advances in interdisciplinary efforts may be risky or professionally unrewarding, especially for junior faculty members. It is important to overcome some of the institutional barriers that prevent ready and effective collaboration between ecologists and economists. Explicitly interdisciplinary programs, such as Dynamics of Coupled Natural and Human Systems as part of the Biocomplexity in the Environment Program[4] at the National Science Foundation (NSF), represent a move in the right direction. Expanding "Schools of the Environment" at universities, where faculty from different disciplines interact routinely in addressing environmental issues, is another way to overcome disciplinary barriers.

As discussed throughout this report, the adequacy of information in providing estimates of the economic value of ecosystem services that are policy relevant depends in large part on what policy question is asked. If the relevant policy question (or questions) can be answered by a relatively narrow evaluation of ecosystem services, the value of ecosystem services can likely be estimated with a relatively high degree of confidence with existing methods. For example, it is possible to answer questions about whether to conserve watersheds to provide clean water is worthwhile, as in the Catskills, or to conserve floodplains for flood control, as in the Salt Creek Greenway in Illinois. However, if the questions were reframed to identify the complete value of

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[4] The NSF Dynamics of Coupled Natural and Human (CNH) Systems Program emphasizes quantitative understanding of short- and long-term dynamics of natural capital, including how humans value and influence ecosystem services and natural resources, and considering uncertainty, resilience, and vulnerability in complex environmental systems. Further information is available on-line at *http://www.nsf.gov/od/lpa/news/publicat/nsf0203/cross/pma.html.*

the conservation of watersheds or floodplains, there is insufficient information available on which to generate a reliable and credible answer. The issue of the effect of framing in terms of the policy context is also discussed in Chapters 2 and 6.

Scope of Coverage, Spatial and Temporal Scale

Aquatic ecosystems produce a broad range of ecosystem services. Typically, however, ecological and economic information suitable for estimating reasonably precise values for ecosystem services exists for only a relatively narrow range of services. Lack of natural science (often ecological) information or understanding, or imprecision of valuation estimates for certain services, limits the ability to obtain precise estimates of economic value over the entire range of services provided by an ecosystem. In addition, there is considerable variation in ecosystem structure and function across space and time. As a consequence, the value of services from a particular ecosystem at a particular time may not necessarily be a good predictor of the economic value of services for other ecosystems or even the same ecosystem at a different time. Such ecosystem idiosyncrasies make benefits transfer problematic (see Chapter 4 for a discussion of benefits transfer). For these reasons, measures of the economic value of ecosystems services will continue to be partial and incomplete, at least for the foreseeable future. Some limit on the scope and scale of analysis is inevitable, but just where to set the boundaries for analysis is an important question.

The difficulty in obtaining estimates of economic value for the full range of ecosystem services presents analysts with a problematic trade-off. While relatively precise estimates of the value of ecosystem services may be derived for a fairly narrow set of services, an ecosystem valuation study that analyzes only a partial list of services may be insufficient for policy purposes. For example, suppose a development would destroy a wetland. If relatively uncontroversial estimates of ecosystem service value such as flood reduction and increased fishery production do not exceed the value of development, it may be necessary to estimate values for a wider array of ecosystem services to inform the decision. However, when there are large uncertainties associated with estimates of value of these other ecosystem services, even collecting information on a wider set of ecosystem service values may not yield a clear recommendation about whether it is better to protect the wetland or allow development.

A second difficulty with limiting the scope of coverage of an ecosystem valuation study is the interconnection of processes within an ecosystem. Changing the inflow of nutrients into a lake will change ecosystem function and result in changes in fish productivity, recreational opportunities, and other ecosystem services. When there is a conflict between the provision of different ecosystem services—for example, hydroelectric power generation and fish production, the analysis should include the potentially conflicting ecosystem services if it is to be of use in policy decisions. Further, there may be cascading effects in which changes in one part of an ecosystem can ripple through the ecosystem, causing additional effects that may be difficult to foresee. For example, removal of a top predator may cause an increase in small predators, changes in the herbivore prey base, with consequent changes in vegetation. It may be difficult to predict a priori how ecosystem functions and services will change when a predator is removed.

The preceding paragraphs strongly favor a more complete scope of coverage and a systems approach to valuing ecosystem services. However, expanding the scope of services covered by the analysis not only increases the workload and range of expertise necessary to design and conduct the analysis, but it will also likely to force analysts to estimate values for services whose production is poorly understood or for which valuation methods may generate imprecise estimates. There are no case studies that include a broad range of ecosystem services for which the value of these services can be estimated within a narrow range with much confidence.

In addition to questions about the scope of services studied, analysts will face difficult issues about the proper spatial and temporal scales. Spatial heterogeneity also limits the utility of benefits transfer, in which the estimates of value generated for one ecosystem are applied to other ecosystems. On the other hand, analyzing every ecosystem in detail can be prohibitively expensive and time consuming. In generating estimates of the economic value of ecosystem services across larger spatial scales, some method of extrapolation may be unavoidable, but such extrapolations bear careful scrutiny.

Interconnections in the production of ecosystem services across whatever spatial boundaries are chosen are virtually inevitable. A real danger of being too narrow in spatial scale is that important linkages in the production of ecosystem services or in the value of those services will be ignored. For example, focusing on upstream benefits from dams in the case of the Hadejia-Jama'are floodplain in northern Nigeria, while ignoring downstream losses, would give an incorrect assessment of the net benefits of dams and water diversions. Besides obvious physical interconnections, other types of interconnections may create important linkages in the production of ecosystem services. One mechanism that creates important interconnections across ecosystems occurs when multiple conditions contribute to the level of service provided. For example, protecting the summer habitat for neotropical migrant birds may be for naught if their winter habitat is destroyed. Protecting coastal wetlands in Louisiana as fish breeding grounds will be more or less valuable depending on the level of nitrogen export from Mississippi River drainage and the extent of the hypoxic zone. Another interconnection may occur with the existence of ecological thresholds and cumulative effects (as discussed in Chapter 3). Stress may be tolerated with little damage to an ecosystem service until a threshold is reached, at which point system function might change drastically, giving rise to a large change in ecosystem services. A classic example is the change in a shallow lake from oligotrophic to eutrophic conditions. A study of the consequences of increased nutrient export from a single stream into a lake may show that there is no change in economic value of the ecosystem services produced by the lake. However, the cumulative effects of increasing nutrient export from all streams into the lake could be sufficient to trigger a regime shift, causing a large change in the value of ecosystem services.

There may be interconnections between ecosystem services on the valuation side even when no biophysical connections exist between ecosystems. The marginal value of an ecosystem service typically depends on the quantity of service supplied rather than being constant (e.g., demand curves generally slope downward). So, for example, a collapse in fish harvest in one ecosystem will tend to increase the economic value of fishery production from other ecosystems. In all valuation studies, some assumption must be made about the level of related ecosystem services produced elsewhere. In addition, the value of particular ecosystem services may also be a function of the level of provision of other ecosystem services or other human-produced services. In other words, there may be important complementarity or substitutability among services.

Most existing valuation techniques used by economists work well for valuing marginal changes but may be more problematic for valuing larger changes. Market price is an accurate signal of the marginal change in value for a small change in the quantity of a marketed good. However, to estimate the change in value from a nonmarginal change in quantity requires information about how price changes with quantity (i.e., the shape of the demand curve), information that may not be readily available. There are similar difficulties for nonmarketed services. For example, it is difficult obtain values for nonmarginal changes in hedonic studies (see Chapter 4). Changes in ecosystem structure and function, and hence in the provision of ecosystem services, however, may require nonmarginal valuation, such as with regime shifts (e.g., oligotrophic to eutrophic conditions in lakes) or large-scale disturbances. For nonmarginal changes, it is not valid simply to multiply the change in provision of the ecosystem service by an estimate of the marginal value of the service under current conditions to derive an estimate of the total change in economic value. Estimates of changes in total value must account for changes in marginal values as conditions change. Failure to take this fact into account can lead to serious errors—as for example, in claiming that diamonds are of greater value than water, based on the fact that the price of diamonds (which are scarce) is high while the price of water (which is not scarce in some places) is low.

Because of biological or physical connections and the dependence of marginal value on conditions, great care must be exercised when estimates of value derived at one scale of analysis are applied at a different scale. Typically, there are no simple rules for aggregating values from small scales to larger scales. Some of the most pointed criticisms of the Costanza et al. (1997) study involved aggregation issues.

The temporal scale to be considered also presents challenges to the economic valuation of ecosystem services. Just as ignoring downstream effects in a spatial sense generates an incorrect assessment of net benefits, ignoring the future costs or benefits of decisions will result in an incorrect assessment of the present value of net benefits. For example, ignoring the loss of future benefits when stocks of groundwater are depleted or when the population of a commercially valuable species such as salmon declines will not provide adequate signals of the value of conserving such resources. The difficult issue of comparing present and future values arises when the consequences of a decision impact not only present but also future conditions. A common approach in economic studies is to discount future values. However, there is concern about discounting, especially for decisions having long-term consequences that will have repercussions for decades, centuries, or even longer (see Chapters 2 and 6 for further information). Assessing future consequences necessarily introduces uncertainty into the valuation of ecosystem services. Numerous events that affect ecosystems (e.g., disease outbreaks, fire patterns, weather) and human systems (e.g., innovation, changes in preferences, political change) cannot be predicted in advance. Knowing that ecosystem conditions may change or that values may shift places a premium on the ability to learn and adapt through time and to avoid outcomes with irreversible consequences (or consequences that can be reversed only at great expense). Adaptive management (see Chapter 6) and avoiding difficult-to-reverse decisions prior to reducing uncertainty arose in the context of managing salmon in the Columbia River basin.

The estimate of value of ecosystem services typically depends on a number of current conditions both in the ecosystem itself and in other interconnected systems, many of which are not explicitly stated. A change in fundamental underlying conditions, such as with climate change or an invasive species, may result in large changes in the estimated value of ecosystem services.

Finally, although there is great danger that studies will be partial and incomplete, as discussed in this section, there is also the possibility that the economic value of some ecosystem services will be counted more than once. When value is attributed to coastal wetlands as an input to fishery production, it cannot also be attributed to increased fishery production as an output. Unless studies are carefully designed and executed, such "double-counting" issues may arise.

SUMMARY: CONCLUSIONS AND RECOMMENDATIONS

This chapter has reviewed a series of case studies that value ecosystem services from aquatic and related terrestrial ecosystems, with a focus on their integration of ecology and economics. The case studies varied from those valuing a single ecosystem service, to multiple ecosystem services, to ambitious attempts to value all services from an ecosystem and even the entire planet. Many of the topics and issues addressed in this chapter directly respond to the committee's statement of task (see Box ES-1). An extensive summary of implications and lessons learned from these reviews is provided in the previous section and no attempt is made to resummarize that section here.

Based on the case studies reviewed in this chapter and the various implications and lessons learned, the committee makes the following specific conclusions regarding efforts to improve the valuation of ecosystem services:

- Studies that focus on valuing a single ecosystem service show promise of delivering results that can inform important policy decisions. In no instance, however, should the value of a single ecosystem service be confused with the value of the entire ecosystem, which has far more than a single dimension. Unless it is understood clearly that valuing a single ecosystem service represents only a partial valuation of the natural processes in an ecosystem, such single service valuation exercises may provide a false signal of total value.
- Even when the goal of a valuation exercise is focused on a single ecosystem service, a workable understanding of the functioning of large parts or possibly the entire ecosystem may be required.
- Although valuation of multiple ecosystem services is more difficult than valuation of a single ecosystem service, interconnections among services may make it necessary to expand the scope of the analysis.
- Ecosystem processes are often spatially linked, especially in aquatic ecosystems. Full accounting of the consequences of actions on the value of ecosystem services requires understanding these spatial links and undertaking integrated studies at suitably large spatial scales to fully cover important effects. In generating estimates of the value of ecosystem services across larger spatial scales, extrapolation may be unavoidable but should be applied with careful scrutiny.
- The value of ecosystem services depends on underlying conditions. Ecosystem valuation studies should clearly present assumptions about underlying ecosystem and market conditions and how estimates of value could change with changes in these underlying conditions.

Building on these preceding conclusions, the committee provides the following recommendations:

- There is no perfect answer to questions about the proper scale and scope of analysis in ecosystem services valuation. Decisions about the scope and scale of analysis should be dictated by a clearly defined policy question.
- Estimates of value should be placed in context. Assumptions about conditions in ecosystems outside the ecosystem of interest should be clearly specified. Assumptions about human behavior and institutions should be clearly specified.
- Concerted efforts should be made to overcome existing institutional barriers that prevent ready and effective collaboration among ecologists and economists regarding the valuation of aquatic and related terrestrial ecosystem services. Furthermore, existing and future interdisciplinary programs aimed at integrated environmental analysis should be encouraged and supported.

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6
Judgment, Uncertainty, and Valuation

INTRODUCTION

Some aspects of the economic valuation of aquatic and related terrestrial ecosystem services inevitably involve investigator judgments, and some are unavoidably uncertain. This chapter aims to identify the needs for investigator judgments and how they arise, how such judgments should be made, and how they should be presented to environmental decision-makers. It also seeks to describe the sources and types of uncertainty, indicate which are most significant, and suggest how analysts and decision-makers can and should respond. More specifically, this chapter provides a review of issues related to framing, methodological judgments, and peer review; the sources and management of uncertainty and how these relate to valuation and policymaking considerations; and a summary of the chapter and its conclusions and recommendations. Although unavoidable, uncertainty and the need to exercise professional judgment are not debilitating to ecosystem services valuation. It is important to be clear, however, when such judgments are made, to explain why they are needed, and to indicate the alternative ways in which judgment could have been exercised. It is also important that the sources of uncertainty be minimized and accounted for in ways that ensure that one's conclusions and resulting decisions regarding ecosystem valuation are not systematically biased and do not convey a false sense of precision.

PROFESSIONAL JUDGMENTS

The following sections describe cases in which investigators had to use professional judgments in ecosystem valuation regarding issues of: (1) how to frame a valuation study; (2) how to address the methodological judgments that have to be made during the study (such as the choice of a discount rate); and (3) how to use peer review to identify and evaluate these judgments.

Framing

Perhaps the most important choice in any ecosystem services valuation study is the selection of the question to be asked and addressed. This report has previously described the importance of a careful selection of the question in several case studies including the Catskills watershed and the *Exxon Valdez* oil spill (see Chapter 5). In the Catskills study (see also NRC, 2000), a critical decision was made early on to not attempt to value the entire suite of services provided by the watershed but rather to focus on the service of water purification. More specifically, the issue was whether the restoration of the Catskills watershed would be more cost-effective than constructing a new drinking water filtration system as a way of addressing New

York City's drinking water quality problems. This definition of the issue was determined by policymakers not by the analysts.

This very specific and policy-oriented focus meant that it was not necessary to identify and attempt to value all of the services provided by the watershed, but rather to ascertain whether the cost of restoring its water purification services exceeded or was less than the known cost of a replacement for them. As discussed in Chapter 5, this focus greatly simplified the valuation task because a full economic valuation of the services of the watershed would have required the following: (1) that all sources of value be identified, such as water purification, tourism, support of biodiversity, esthetic values, recreational fishing, streamflow stabilization, and so on; (2) that each of these services be quantified; and (3) that each service be valued. It was not even necessary to establish the restoration cost exactly, but only to compare it to the cost of the alternative (i.e., construction of a drinking water filtration system). Since the outcome of this comparison was that the cost of restoration was less than that of the alternative, New York City decided to spend more than one billion dollars on increased protection and restoration of the watershed (NRC, 2000). It is worth emphasizing that no aspects of the services of the Catskills ecosystems were valued to reach this conclusion; watershed restoration costs were compared to those of an alternative source of the desired service. If this answer had been different—if, for example, the cost of restoration had exceeded the cost of a new water filtration system—it might still have been appropriate to restore the watershed. However, in that case, a complete economic justification of such a decision would have required the valuation of a sufficient number of services of the Catskills watershed to show that the total economic value exceeded the costs of restoration, and offered New York City an attractive return on its investment. Such a valuation exercise would have been an order of magnitude more complex. Thus, not only was the question framed in a way that simplified the analysis, but the existing data were conducive to supporting the simplest possible outcome. The decision tree (provided in Figure 6-1 below) illustrates this point—investigation of the New York City watershed followed the upper part of this decision tree, leading to a conclusion that avoided two complex steps that would otherwise have been required.

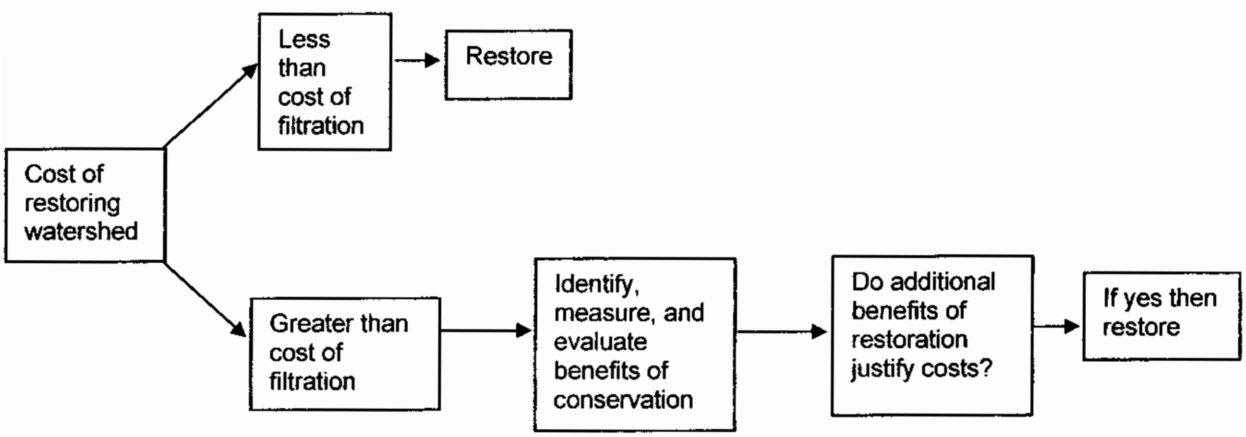

FIGURE 6-1 Decision tree for Catskills watershed study.

The *Exxon Valdez* case presents a different situation (Carson et al., 2003; Hanemann, 1994; Portney, 1994) as legal liability issues required estimates of damages to natural resources. A complete economic valuation of the costs of the massive oil spill would have required the following: (1) identification of all of the categories of impacts of the spill such as loss of fish catch, loss of tourist revenues, deaths of many species of birds, fish, mammals, and invertebrates; (2) quantification of all of these types of impacts (e.g., how much revenue from fishing and tourism was lost, how many animals of each type were killed.); and (3) valuation of each of these losses. Clearly, completing all three stages of such an ecosystem valuation study presents a massive and challenging task.[1] Although numerous studies were commissioned by Exxon, the State of Alaska, the federal government, and other interested parties, a clear answer to the question of the dollar value of damages to ecosystem services caused by the oil spill was not produced (Portney, 1994). As noted in Chapter 5, there are difficulties in quantifying the link between the oil spill and changes in ecosystem services as well as difficulties in valuing such changes—especially when considering nonuse values such as existence value. There was no naturally privileged and simple way of framing this issue in the *Exxon Valdez* case because all aspects of the damages were relevant to disputes about compensation.

These two cases illustrate the importance of how a valuation study is framed, and how the frame used derives from the specific context within which an ecosystem valuation issue is raised. They also illustrate that the way an issue is posed may make a huge difference in the complexity of the valuation problem to be addressed.

In addition to determining the question to be asked and the complexity of the analysis required, psychologists have shown that how an issue is framed frequently affects the way in which people make judgments about that issue and the subsequent answers they give to questions about the issue (Kahneman and Tversky, 2000; Machina, 1987). One classic illustration concerns the difference between the way people react to a policy that can alternatively be described as either saving lives or losing lives. Suppose that 100 people are threatened by a fatal disease but a policy intervention may save half of them. This situation could be described by stating that if this policy is followed, 50 of 100 people will die. Alternatively, one could also accurately state that this policy will save the lives of 50 of the 100 people who would otherwise die. Not surprisingly, the latter description is usually found to elicit a much more positive response and a higher "willingness to pay" (see more below) that is due entirely to the differences in the way the issue is framed. In one case, the emphasis is on saving lives, while the other is on losing lives.

A similar phenomenon has been noted in the description and interpretation of event probabilities (Kunreuther et al., 2001). Suppose that a natural disaster has a 1 in 100 chance of occurring each year. One could accurately state that over a 20-year period there is a 1 in 5 chance of such an event occurring. However, the latter way of presenting the same event probability almost always produces a stronger negative reaction. For example, people are typically willing to pay more for disaster insurance if the data is presented in the second way than in the first.

In the context of valuing aquatic ecosystems and their services, framing effects could matter in the choice between whether to emphasize what will be lost or what will be preserved. If an environmental policy will result in half of an existing wetland is being lost, should this be

[1] It is important to note that under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) legislation the federal government was only allowed to sue for public damages, which exclude loss of tourist revenues and business profits. See Hanemann and Strand (1993) for further information.

presented as half being lost or half being saved? Should an analyst emphasize the number of birds or fish saved as the result of a policy measure or the number that will die in spite (or because) of the measure? One might be tempted to answer that the correct solution is to present all relevant information and allow individuals to select based on what is important to them. Although in some cases this might be possible, in many cases the volume of relevant data will be so large that it is virtually impossible to present it all in a completely even-handed way. In such cases, some element of selection and framing will be unavoidable.

The choice between willingness to pay (WTP) and willingness to accept (WTA) as measures of the value of an ecosystem good or service (see also Chapters 2 and 4) is also a choice about how an issue is framed. This choice is normally thought of as depending on where the property rights lie (Hanemann, 1991). If the recipients of an ecosystem service have a right to that service, then the loss from removing it or allowing it to be lost is what they would be willing to accept as compensation. Unlike WTP, this measure is not bounded by their wealth. If on the other hand there is no inherent right to an ecosystem good or service, then its value to people is better measured by their willingness to pay for it. Certainly, there are situations in which the underlying ownership rights are not clear and it is therefore not obvious as to which measure is the better one. For example, do polluters have a right to pollute water, or do individuals have a right to clean water? The answers to such questions determine whether clean water is most appropriately valued by WTP or WTA compensation for its loss. These are likely to result in very different valuation estimates, and unfortunately the methods of eliciting them are also rather different (see Chapter 4).

In fact, methods of eliciting willingness to pay are better developed than those for eliciting willingness to accept. Indeed the experience of some investigators in this area is that subjects in contingent valuation studies are more comfortable with questions about what they are willing to pay than with questions about willingness to accept, as deciding what to pay for a good or service is an everyday human activity whereas one is rarely called upon to decide what to accept.[2] In such cases, the analyst should ideally report both sets of estimates in a form of sensitivity analysis. However, the committee recognized that in some cases this may effectively double the work and in such situations a second best alterative is to carefully document the ultimate choice made and clearly state that the answer would probably have been higher or lower had the alternative measure been chosen.

The previously described Catskills watershed example (NRC, 2000) provides a good illustration of the possible ambiguity of property rights and the consequent ambivalence about whether willingness to pay or to accept is the more appropriate measure of value. Did the upstream communities have the right to pollute, at least within some limits, or did New York City have the right to clean water? The answers were governed by the legislative framework, in particular the federal Clean Water Act (see footnote 1, Chapter 1), which makes a sharp distinction between point source pollution and nonpoint source pollution—the former being strictly regulated, the latter less so. It also became clear during the discussions about conserving the Catskills watershed that the answer could change as a part of the ongoing negotiations. This was made clear when the State of New York introduced the possibility of using eminent domain legislation to compulsorily allow the purchase of areas of land deemed critical. The cost to New York City of restoring the watershed was affected by these considerations because they determined how much had to be paid to landowners in the watershed to help persuade them to

[2] Michael Hanemann, University of California, Berkeley, personal communication, August 2004.

reduce polluting activities. These payments would obviously be higher, given better-established landowners' "rights to pollute."

There are cases in which the ability to present an environmental policy recommendation in several different frames may be important to decision-makers because it allows them to seek and obtain support from different constituencies. For example, a recommendation to use tradable air emission permits to limit emission of a pollutant can be presented as an extension of the use of market mechanisms to those who may be predisposed to support such measure because of their belief in the market mechanism. It can also be presented as a limitation on pollution to "environmentalists," who may be disposed to support such a measure because it results in a net reduction in air pollution. The fact that a particular environmental policy appeals to several different constituencies often stems from the ability to frame it in different ways. Cross-constituency support for a measure may mean that there is widespread agreement on the measure; it may also indicate that it can be seen from several different perspectives and is framed differently to appeal to different groups.

These preceding examples suggest that framing unavoidably affects both the question that is asked in an ecosystem valuation study, and therefore the type and level of analysis needed to answer it, and the way in which people respond to any given issue. Framing in the second of these senses introduces an element of subjectivity into an ecosystem valuation analysis. Rarely, if ever, will a completely objective presentation of the issues be attainable. Analysts must be aware of this and sensitive to the different ways of presenting data and issues, and make a serious attempt to address all perspectives in their presentations. Failure to do so could undermine the legitimacy of an ecosystem valuation study.

Framing in the first sense—that is, determining the question to be asked in a valuation study such as the Catskills and *Exxon Valdez* studies—represents a legitimate and appropriate attempt to fit the analysis conducted to the precise decision to be made. In the Catskills case, it was appropriate and logical to ask whether watershed restoration could meet the same needs at a lower cost. In the *Exxon Valdez* case, investigators used the information available from the impact and injury studies being conducted by the State of Alaska to present the issues to respondents and so to frame the issues. The investigators attempted to be conservative in summarizing the conclusions of these studies and were constrained by the fact that the economic and ecological studies were being conducted somewhat in parallel. Because they did not desire the survey respondents to rely on information they had individually gleaned from the media, the investigators went out of their way to describe the effects of the spill, albeit in a succinct manner. Furthermore, the investigators chose to avoid duplicating the impact and injury studies that had already been completed. Instead they relied on the presentation and discussion of these studies in the media and other public fora to have created an informed public who could use this discussion to place values on the avoidance of a similar event. Such an approach does raise questions about how informed the sample used in the *Exxon Valdez* contingent valuation study was, about the soundness of their understanding of the impact of the oil spill on the local ecosystem, and about the sensitivity of the values people placed on preventing ecosystem damage to possible further information about the issues.

Additional Methodological Judgments

In most ecosystem valuation studies, the analyst will be called on not only to frame the study but also to make additional judgments about how the study should be designed and conducted. Typically, these will address issues such as whether, and at what rate, future benefits and costs should be discounted (see Chapter 2 for further information); whether to value goods and services by what people are willing to pay or what they would be willing to accept if these goods and services were reduced or lost; and how to account for and present distributional issues arising from possible policy measures. In many cases, different choices regarding some of these issues will make a substantial difference to the final valuation. For example, many environmental restoration projects have projected lives of a century or more, and over such long periods, even small differences in discount rates can result in order-of-magnitude differences to the present value of a stream of net benefits (Heal and Kriström, 2002). In such cases, the appropriate response is undoubtedly for the analyst to present figures on the sensitivity of the results to alternative choices.

In the case of choice of discount rate, it is a straightforward matter to present a table of results showing how valuation varies with the discount rate selected. For cases in which a measure has significant distributional impacts, it is incumbent on the analyst to identify and describe these impacts, providing details of the groups that gain and lose from the policy, and the extents of these gains and losses. The analyst may also provide an estimate for the aggregate value of an environmental policy if benefits and costs to all recipients are weighted equally and then indicate how this would change if different distributional weights were to be used (see Layard and Walters, 1994).

Another illustration of the importance of methodological judgments comes in the choice of an objective in an economic project evaluation. There are usually several possibilities in making this selection. The conventional approach is to follow the utilitarian route of choosing the project that generates the greatest net total benefit. In this approach, the analyst calculates all of the gains and losses to the different groups in society and then totals them, with the project having the highest total gains deemed the best. In the process of adding up benefits over different groups, the analyst might apply different weights: for example, weighting gains and losses to indigent groups more than those to the affluent. Of course, in adding up gains and losses that occur at different dates, the analyst may weigh by discount factors (see Chapter 2 for further information).

An alternative approach is to follow the Rawlsian route;[3] in this case the analyst focuses exclusively on the impact of the policy measure on one social group, this poorest group in society. In such cases, the "best" policy is defined as the one that does best by the poorest group in society. These two different approaches, the utilitarian and the Rawlsian, often lead to significantly different outcomes (Heal, 1998). The ultimate choice depends, among other things, on which approach the analyst believes best reflects the values of the group for whom the study is being undertaken. If the client is society as a whole, are its values better reflected by utilitarian or Rawlsian goals? Similar to situations in which WTP or WTA is used in ecosystem valuation study, ideally the analyst will present the results of both approaches and explain how and why they differ. However, the reality is that this may greatly increase the complexity of the

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[3] American philosopher John Rawls' chief work, *A Theory of Justice* (1971) discussed liberty and equality in the context of a social contract. Rawls stated that inequalities in the distribution of wealth and income only become just when they can work in favor of the worst-off segment of the society.

ecosystem valuation study. If time and resources allow only one approach, then it is reasonable to expect a clear explanation of how the choice was made and some discussion of alternatives.

Peer Review

The unavoidable need to make professional judgments in ecosystem valuation activities through choices of framing and methods suggests that there is a strong case for peer review to provide input on these methodological issues before study design is complete and relatively unchangeable. Although most significant ecosystem valuation studies will be reviewed by external reviewers on completion and/or publication, the committee believes that external review by peers and stakeholders could also be particularly valuable at a much earlier stage, when key judgments for the study have tentatively been chosen but there remains a legitimate opportunity for revision. Outside review at these earlier stages can make the difference between a valuation study that is widely accepted and one that is regarded as controversial or misleading (NRC, 1996).

UNCERTAINTY

The following sections discuss the major sources of uncertainty in the economic valuation of aquatic ecosystem services and how policymakers and analysts should respond.

Levels of Uncertainty: Risk and Ambiguity

The almost inevitable uncertainty facing analysts involved in ecosystem valuation can be more or less severe depending on the availability of good probabilistic information. A favorable case would be one in which, although there is uncertainty about the magnitudes of various parameters, the analyst nevertheless has good probabilistic information. That is, there is a distribution of possible magnitudes—with means, standard deviations, and other aspects of the distributions available—and these distributions are based on statistical data that are sufficiently extensive to allow some confidence in their predictions. An illustration of such a case is provided by insurance companies, which typically have many years of actuarial data on the death rates of people with different characteristics and thus can calculate the expected number of deaths in a population with some confidence.

An alternative and common scenario in ecosystem valuation is one in which there is really no good probabilistic information about the likely magnitudes of some variables and what is available is based only on expert judgment. To continue the insurance analogy, this would likely be the position of an insurance company currently trying to assess the risk it faces if it provides terrorist insurance for owners of prominent buildings in major cities. There is no database of events on which the company can draw, and important decisions will have to be based solely on experts' assessments of the risks. Environmental policymakers find themselves in this situation when making decisions about climate changes because there is no database that allows an estimation of the consequences of increasing concentrations of greenhouse gases. Thus, such decisions should be based on the analyses of expert groups such as the

Intergovernmental Panel on Climate Change (IPCC).[4] Analysts are in a similar position when evaluating changes designed to restore functionality in complex ecosystems such as the Florida Everglades.[5]

Situations such as the first of these, where there are reliable probabilities describing the unknown magnitudes, are described as characterized by *risk*—and the word risk in this context refers to situations in which reliable estimates of the probabilities are available. In contrast, the term *ambiguity* describes situations in which there are no data-based probabilities. Obviously, making good decisions is harder under conditions of ambiguity than under conditions of risk (Machina, 1987).

One way in which decision-makers can attempt to bridge the gap between risk and ambiguity is to assign subjective probabilities to the different possible outcomes. A subjective probability is one that is not based on repeated trials and observed occurrence frequencies, which is the classical interpretation of a probability, but rather on strength of belief in the likelihood of an outcome. So, in situations where there are no objective frequency-based probabilities, such as the consequences of the accumulation of greenhouse gases in the atmosphere, one could ask experts to present their best judgments about the likelihood of different outcomes by probability distribution. These would be subjective probabilities. Such judgments provide probability-like numbers to use in situations in which there are no data to provide frequency-based probabilities. One might, of course, end up with as many different subjective probabilities as there are different experts (Nordhaus, 1994; Roughgarden and Schneider, 1999.)

Model Uncertainty

Model uncertainty arises for the obvious reason that in many cases the relationships between certain key variables are not known with certainty (i.e., the "true model" of an important phenomenon or process will not be known). To take a biogeochemical example, the relationship between the nature of riparian tree cover in a watershed and the purification of water by that watershed may never be known. How do the amount and extent of water purification depend on the types of plant communities in a watershed and the successional stage of those communities? This is an example of the relationships discussed in Chapter 3 between ecological structure and function and the provision of ecosystem goods and services to the community. This relationship is often poorly understood and inevitably a source of uncertainty in ecosystem valuation efforts. In fact, in most studies of the value of aquatic ecosystems, this will be the largest single source of uncertainty because our understanding of how the structure of an ecosystem is affected by human activities and of how these effects translate into changes in ecosystem services is often rudimentary (see, for example, the Columbia River case study in Chapter 5 for further information).

On the economic side, an analyst might not know how society's WTP for an ecosystem service depends on the way in which that service is provided. For example, how does the degree of visible cleanliness, or the degree of development and crowding affect the value that is placed

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[4] The IPCC was organized by the United Nations to provide scientific, technical, and socioeconomic data on the impacts and options for adaptation and mitigation in climate change. Further information is available on-line at *http://www.ipcc.ch*, last accessed June 14, 2004.

[5] Such groups include, for example, the South Florida Ecosystem Task Force (see *http://www.sfrestore.org* for further information).

on a particular waterbody? What are the functional forms that relate the value that people place on a body of water to the parameters describing the state of that waterbody? In economic terms, what is clear is that investigators often do not know the form of the demand function for an ecosystem service. Difficulties in estimating societal values of an ecosystem's services are especially acute for nonuse values such as the existence value that individuals may have for preserving species or intact ecosystems.

As discussed in Chapter 3, a particularly important issue in evaluating environmental policies designed to change the functioning of ecosystems is the existence of thresholds at which the qualitative behavior of an ecosystem changes. There is, for example, some evidence that many streams can absorb nitrate pollution up to a certain level with little or no effect on their biochemistry, but that beyond a certain level of nitrate input, their capacity to neutralize nitrates is exhausted and their biochemistry changes sharply (Lovett et al., 2001). The discussion of Lake Mendota in Chapter 5 also illustrates this effect. In such a situation, assuming a linear or even smooth response of the behavior of the system to outside influences could lead to massive errors in forecasts of the impacts of these influences. Model uncertainties about qualitative changes in ecosystem behavior are particularly important in ecosystem valuation. These should always be of concern to analysts who should establish a range for the main sources of uncertainty whenever possible.

It is clear from the preceding examples that given the imperfect knowledge of the way people value natural ecosystems and their goods and services, and our limited understanding of the underlying ecology and biogeochemistry of aquatic ecosystems, calculations of the value of the changes resulting from a policy intervention will always be approximate.

Parameter Uncertainty

Parameter uncertainty is one level below model uncertainty in the logical hierarchy of uncertainty in the valuation of ecosystem services. Even if the mathematical form of a relationship between important variables were known, one could—and in all probability would—still be uncertain about the values of the parameters in this functional form. For example, assume that an analyst knew with certainty that the value individuals place on a lake take the form $V = A^x B^y C^z$, where A, B, and C are characteristics of the lake such as water clarity, fish populations, and cleanliness; x, y, and z are parameters; and V is the value placed on the lake. Even if the functional form were known, the exact values of the parameters x, y, and z of the function would still not be known. At best, statistical estimates of these could be obtained, giving expected values of the parameters and distributions of possible errors about these parameters.

Most commonly, an analyst seeking to value the service or services of a particular ecosystem is subject to both model and parameter uncertainty in that he or she is not sure of the true model and conditional on the choice of model, faces further uncertainty about the values of parameters in the model.

Reducing Uncertainty: (Quasi) Option Values and Adaptive Management

Although there is considerable uncertainty regarding the value of ecosystem services, there is often the possibility of reducing this uncertainty over time through learning. Learning can be either active (the result of actions such as research designed to generate new knowledge), or passive (the byproduct of actions taken for other purposes or simply of the passage of time). Regardless of its source, the possibility of reducing uncertainty in the future through learning can affect current decisions, particularly when the impacts of these decisions are irreversible (Arrow and Fisher, 1974; Demers, 1991; Epstein, 1980; Henry, 1974). With learning, a "quasi-option value" has to be incorporated into the analysis, beyond the inclusion of expected net benefits that reflects the value of the additional flexibility. (From now on, this is collectively referred to as just "option value"; see also Chapter 2.) This flexibility allows future decisions to respond to new information as it becomes available.[6]

If the destruction of a natural system is irreversible, and if its value is currently unclear but may become better known in the future, then preserving it now allows the destroy or conserve issue to be revisited at a time when decision-makers are better informed; whereas destroying the ecosystem forces a permanent choice without the benefit of better knowledge. It follows that with the possibility of learning, in a cost-benefit analysis the measurement of the benefits of ecosystem protection through ecosystem valuation should consider the possibility of learning and, in consequence, making a better decision at a later date (i.e., it should incorporate the option value; Arrow and Fisher, 1974; Hanemann, 1989; Henry, 1974).[7]

The incorporation of option value in cost-benefit analysis still entails a balancing. Although the flexibility created by preservation and by the opportunity to revisit the decision adds to the benefits of preservation, this balancing does not necessarily imply that preservation will in all cases be justified by this criterion. The benefits of ecosystem preservation (including the value of retaining the flexibility to respond to new information) will not necessarily exceed the associated costs. At present, there is little guidance about the importance of option values in ecosystem valuation. Similarly, only a limited amount of empirical work has been done to date on estimating the magnitude of option value. There is a need for further research in both of these areas in the context of ecosystem valuation.

Adaptive Management

A natural extension of the observation that better decisions can be made if one waits for additional information is the use of adaptive management, which is a relatively new paradigm for confronting the inevitable uncertainty arising among management policy alternatives for large complex ecosystems or ecosystems in which functional relationships are poorly known. Although advanced in the late 1970s and 1980s (Holling, 1978; Walters, 1986;), adaptive

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[6] However, it is not universally true that learning in the future makes increased flexibility more desirable. For discussions of the conditions under which this holds, see Epstein (1980), Freixas and Laffont (1984), Gollier et al. (2000), and Graham-Tomasi (1995).

[7] See Fisher and Hanemann (1986) for an empirical application of the concept of option value in the extinction of species.

management (AM) has recently only been applied by natural resource managers.[8] A key component of adaptive management is active learning by introducing new management policies to learn more about the system's behavior and thereby reduce uncertainty. Typically, there may be an effort to implement environmental management actions as "experiments" in order to "learn by doing," with the experiments designed to reduce critical uncertainties about the ecosystem's behavior. The usual goal of ecosystem management is to manage for resiliency (i.e., capacity for self-renewal) while optimizing benefits to society. Possible economic benefits are often a part of the mix of information that stakeholders or government officials use to select management actions. Actually implementing potentially beneficial policies thus winnows the uncertainty in system response, albeit in a reversible and experimental sense. Adaptive management therefore provides for a mechanism for learning systematically about the links between human societies and ecosystems. In contrast, the learning that occurs in economic models with option values is purely passive—information about the value of an environmental system is acquired with the passage of time. If one believes that additional information could be influential in selecting the best environmental policy option, then adaptive management is a natural step from the passive concept of an option value associated with gaining information to the concept of managing the ecosystem to learn and so reduce uncertainty. When an adaptive management approach is possible, which will not always be the case, the option value associated with conservation is likely to be increased because of the enhanced rate of information acquisition.

Adaptive management often uses explicit dynamic modeling or conceptual models of large complex ecosystems. These computer models are useful for two purposes. First, building an explicit numerical model requires a clear statement of what is known and what is assumed, which helps to expose broad gaps in data and understanding that are easily overlooked in verbal and qualitative assessments. Second, even crude models can help "screen" policy options and eliminate those that are simply too small in scale to be important or would be unacceptably risky given uncertainty about directions of response in key policy indicators (Walters et al., 2000). Proponents of adaptive management have long emphasized the importance of such modeling (Holling, 1978; Walters, 1986). Adaptive management is not a tool for ecosystem valuation or a method of valuation per se, nor does it require valuation. Rather, by reducing uncertainty and illuminating relationships within the ecosystem and between the ecosystem and human actions, it aids management and decision-making and may make economic valuation easier and more accurate.

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[8] Adaptive management is an integrated, multidisciplinary approach for confronting uncertainty in natural resource issues. It is adaptive because it acknowledges that managed resources will change as a result of human intervention, surprises are inevitable, and uncertainties will emerge. Active learning is the way in which the uncertainty is winnowed. Adaptive management acknowledges that policies must satisfy social objectives, but also must be continually modified and flexible for adaptation to these surprises. Adaptive management therefore views policy as hypotheses; that is, most policies are really questions masquerading as answers...and management actions become treatments in an experimental sense. For more information on AM and adaptive management, see: Gunderson et al., 1995; Holling, 1978; Lee, 1993; NRC, 2002, 2004; and Walters, 1986.

DECISION-MAKING AND DECISION CRITERIA UNDER UNCERTAINTY

Decision Criteria

Just as there are different types of uncertainty, so there are also different ways in which an analyst can allow for uncertainty in the support of environmental decision-making. A central issue is how to account for the range of possible outcomes (the variability of outcomes) that is an inevitable result of uncertainty. A widely used criterion for decision-making is to choose the alternative that yields the greatest expected value of the benefits. This rates as equal all distributions of outcomes that have the same mean even if they have very different higher moments and so ignores information about variability. However, this approach can be adopted only if the possible values of the relevant variables are known and associated probabilities can be assigned; otherwise, expected values cannot be computed. Thus, in order to adopt the objective of maximizing expected net benefits in ecosystem valuation, one has to be able to assign probabilities, either objective probabilities from past experience or subjective probabilities (for general discussion, see Machina, 1987).

The unpredictability of the outcome of an environmental policy under uncertainty means that while the outcome could be excellent, it also has a chance of being poor. In general, faced with the choice between policies that generate the same expected value but with different ranges of outcomes, most people would choose the policy with the lowest variability, implying that they are "risk averse." The extent of their risk aversion determines what they would be willing to pay to avoid a risk and replace it by a certain outcome. If people are very risk averse, an environmental policy that delivers a modest outcome with some certainty might be preferred to one that may deliver a truly outstanding outcome but may also deliver a very poor result. In such situations, an analyst has to decide whether to build some measure of risk aversion into the analysis and, if so, how much. There are studies of the degree of risk aversion displayed by individuals in financial markets (see Chetty, 2003, and references therein), but because risk aversion for a given person may vary with the magnitude of the risk and because it varies across people, these are not necessarily the appropriate values to use in environmental studies. In a heterogeneous population the analyst will have to make an assumption about the level of risk aversion that is appropriate for the group as a whole. In general, this is a matter in which the best solution is to state clearly that the assumption about the degree of risk aversion will affect the outcome and to conduct sensitivity analyses to indicate how this assumption impacts the outcome of the study (Heal and Kriström, 2002). If contingent valuation methods are used, it may be possible to inform subjects of the uncertainties associated with estimates presented in the study, so that their valuations reflect their own degrees of risk aversion.

A key assumption in ecosystem valuation models is that individuals seek to maximize their utility and that they will be indifferent to changes that leave their utility unchanged. Under uncertainty, the assumption is that they maximize their expected utility, which is simply the expected value of the utilities they would realize under the possible outcomes. Although widely used in economic analyses, the expected utility assumption has been controversial since in some contexts its predictions are not consistent with observed behavior (Machina, 1987). Alternative theories of behavior under uncertainty have been proposed, including prospect theory

(Kahnemann and Tversky, 2000).[9] These alternatives introduce psychological responses (such as feelings of loss aversion and regret) into models of choice. This modifies the arguments and structure of the individual's utility or payoff function, but maintains the assumption that there is a payoff function that individuals seek to maximize. Thus, these alternative theories retain the basic assumption that individual behavior is based on self-interest.

Under the assumption that individuals seek to maximize their expected utility, the value of ecosystem protection is typically defined as the amount an individual would be willing to pay to ensure that protection occurs, which is then a measure of the dollar value or benefit of protection. The ecosystem valuation process is designed to provide an estimate of this measure. In the context of uncertainty, both WTP and WTA have to be interpreted as expressing preferences over uncertain outcomes and, in particular, as reflecting individuals' aversions to the risks they perceive to be associated with the options available. To the extent that valuations reflect individuals' attitudes toward risk and those individuals are accurately informed of the uncertainties associated with a project, there is no need for the analyst to make further allowance for risk aversion.

If society is extremely risk averse, the objective of maximizing the expected value of the aggregate utility can be replaced by an objective known as "maximin." The intent in such cases is to focus on the worst possible outcome, the minimum, and then seek the policy option that makes this as favorable as possible, or maximizes it (hence, the name; for a discussion, see Arrow and Hurwicz, 1972; Maskin, 1979). By way of illustration, consider an aquatic ecosystem that, among other services, provides flood control to a residential area. It is possible that decision-makers believe that the loss of human life through floods is the worst possible outcome and must be prevented at all costs. Such a belief would be appropriately represented by maximin preferences, which would lead the analyst to select the project that minimizes the loss of life from flooding. Focusing exclusively on the worst possible outcome is justified only if there are good reasons to suppose that society is really risk averse and is willing to sacrifice considerable possible benefit from a policy to avoid any chance of a bad outcome. Technically, the maximin objective can be seen as a limiting case of the expected utility objective as the degree of risk aversion increases without limit. There are also arguments that suggest that the maximin may be an appropriate choice of objective in some cases of ambiguity, that is, cases in which there are no objective or subjective probabilities (Arrow and Hurwicz, 1972; Maskin, 1979). Implementing the maximin criterion does not require probabilities; it requires only that the worst possible outcome be identified, so it is particularly suited to problems for which no probabilities are available.

Recent literature on this topic (e.g., Ghirardato et al., 2002) has extended this concept to a broader analysis of decision-making with ambiguity and suggests, in outline, that under quite general conditions a decision-maker faced with ambiguity should look for the worst possible outcome, then for the best possible outcome, and then rank projects and policies by a weighted average of these. Obviously, using the maximin criterion in ecosystem services valuation is a special case because all of the weight in the weighted average is placed on the worst case. A logical extension of this line of thinking leads to concepts such as the precautionary principle and the idea of a safe minimum standard, which are discussed next.

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[9] Prospect theory differs in two key respects from expected utility theory, (1) the payoff is not linear in probabilities, overweighting low probabilities and underweighting large ones, and (2) outcomes are evaluated with respect to a reference point rather than with respect to their absolute value (see Kahneman and Tversky, 1979 for details; for a general review see Machina, 1987).

The Precautionary Principle and Safe Minimum Standard

Another approach to environmental decision-making under uncertainty is embodied by the precautionary principle. Notably, the 1992 Rio Declaration (Article 15) (see Gollier et al., 2000) stated: "Where there are threats of serious and irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." Alhough the precautionary principle has been attacked as a vague concept lacking a precise definition, the essence of the precautionary principle is clear and is that the burden of proof should be to demonstrate that changes do not cause irreversible environmental damage, rather than proving that a change is dangerous. Most economists, if asked to think of a justification for the precautionary principle in decision-making, would probably couch it in terms of learning, especially about the validity of a scientific model, irreversibilities, and option values. The option value linked to conserving an ecosystem whose change is irreversible is in effect a reward for cautious behavior, although it certainly does not imply that conservation is always appropriate. Gollier et al. (2000) note that the precautionary principle can also be given a formal justification in environmental decision-making without invoking irreversibilities, just by assuming that there is cumulative damage from a stock of pollutant and possible learning over time about the consequences of the pollutant.

There has been extensive discussion of irreversibility, learning, option values, and the precautionary principle in the context of policy toward climate change. Since the basic decision framework is similar to that in ecosystem conservation and valuation, it is useful to review briefly some of the more relevant conclusions from this literature. Notable references include Fisher and Narain (2002), Gollier et al. (2000), Kolstad (1996a,b), Pindyck (2000), among others.

One of the conclusions to emerge from this discussion is that, while there may be an option value associated with ecosystem conservation, it is also possible that there is a value associated with not adopting conservation policy measures that require significant investments. The point is that if an environmental policy requires investment in fixed capital and there is some uncertainty about the appropriateness of the policy, and so about the value of the associated investment, there may be a benefit from delaying its adoption so as to benefit from learning about the value of the investment. Thus, if one is unsure of how effective a policy measure is and it requires a long-term and unchangeable commitment, it may be appropriate to wait to implement it until there is more information and the value is clear.

This implies that in discussions of the conservation of an ecosystem whose destruction would be irreversible and whose conservation would require an investment in fixed capital, then there is an option value argument for conserving the ecosystem and also an option value argument for delaying implementation of the conservation policy until it is clear whether the associated investment in fixed capital is in fact appropriate. In such a case, there are two opposing option values and which is larger is an empirical question. An example of an effectively irreversible policy would be the construction or removal of a dam or of a system of canals, which cannot readily be undone once implemented.

One recommendation that emerges from this discussion is that under conditions of uncertainty and learning, there should be a preference for environmental policy measures that are flexible and minimize the commitments of fixed capital or that can be implemented on a small scale on a pilot or trial basis. In effect, this is adaptive management and the option value stays on one side of the equation.

In their study of Lake Mendota, Carpenter et al. (1999; see also Chapter 5) set out a quite different approach. In an intensive agricultural region, such as the Midwest of the United States, phosphorus is often applied as a fertilizer to the land and some runs off into nearby streams and lakes, including Lake Mendota. In sufficient concentrations, phosphorus can cause a change in the normal biological state of the lake that results in a potentially locally stable state of eutrophication in which the lake is unproductive for most human uses. Eutrophication of a lake can be reversed, albeit slowly. The response of a lake to phosphorus concentration is highly nonlinear and the concentration depends not only on the runoff but also on temperature and rainfall. How should the runoff of phosphorus over time be managed in order to maximize the expected discounted value of benefits net of the costs of phosphorus mitigation? In this regard, Carpenter et al. (1999) modeled the dynamics of the interacting lake and surrounding agricultural systems as a nonlinear dynamical system with several different locally stable states, one of which (eutrophication) is highly undesirable. Avoiding this state in agriculturally intensive regions is costly, so there are trade-offs to be made. Further, the stochasticity of the weather means that the problem has to be viewed in probabilistic terms. A particularly relevant conclusion that these authors (Carpenter et al., 1999) reached follows:

> An important lesson from this analysis is a precautionary principle. If phosphorus inputs are stochastic, lags occur in implementing phosphorus input policy, or decision makers are uncertain about lake response to altered phosphorus inputs, then phosphorus input targets should be reduced. In reality, all of these factors—stochasticity, lags, uncertainty—occur to some degree. Therefore, if maximum economic benefit is the goal of lake management, phosphorus input levels should be reduced below levels derived from traditional limnological models. The reduction in phosphorus input targets represents the cost a decision maker should be willing to pay as insurance against the risk that the lake will recover slowly or not at all from eutrophication. This general result resembles those derived in the case of harvest policies for living resources subject to catastrophic collapse... We believe that the precautionary principle that emerges from our model applies to a wide range of scenarios in which maximum benefit is sought from an ecosystem subject to hysteretic or irreversible changes.

Although Carpenter et al. (1999) mention the precautionary principle, they do not define it or state it in an operational way in the context of managing Lake Mendota. Rather, the precautionary principle is implied to be a recommendation that phosphorus levels should be below that recommended by traditional limnological models, this being a cost that decision-makers must shoulder to avoid the risk of eutrophication. Thus, this is not a concept that can be made operational without further work, and indeed it seems possible that much of what is at issue in this case is captured in economists' concepts of risk aversion and option value, which were not explicitly developed in the model of Carpenter et al.

The precautionary principle is widely cited by the environmental community as a justification for erring on the side of conservation in situations of uncertainty. However, it is not clear that the precautionary principle brings anything new to the decision criteria frameworks usually used by economists. As stated above, many of the concerns that drive people to articulate the precautionary principle are addressed by existing economic approaches to environmental decision-making but under different names. With learning and irreversibility, option values may tilt decisions in the direction of environmental conservation, more so if learning can be actively pursued through an adaptive management approach, and especially if there is a chance of a significantly negative outcome from environmental impacts. In such cases, risk aversion will normally move decisions in the same direction.

Related in some ways to the precautionary principle is the concept of a "safe minimum standard," which introduces a class of choices in which decision-makers seek to maintain populations or ecosystems at levels deemed necessary to ensure their continued existence. The most striking example in the United States is the Endangered Species Act (ESA). As originally passed, the ESA explicitly prohibited actions that would reduce the survival chances of an endangered species, whatever the economic costs of this prohibition.[10] Thus, the ESA mandated conservation irrespective of economic costs when the very existence of a species was threatened. The intent of the ESA was clearly to take species survival decisions out of the realm of economics, asserting the primacy of an ethical imperative to prevent extinction over any cost-benefit calculations. The ESA was subsequently amended to include a provision for balancing extinction against the economic costs of its prevention.[11] As amended, the ESA is consistent with the safe-minimum standard approach, under which a minimum population is protected unless it is too costly to do so. However, the consideration of costs can only be invoked in extreme cases. As a result of the ESA, when the survival of a species is at stake, one generally does not have to place an economic value on its continuation because legislators have determined that this is infinite and outweighs any possible costs. The Clean Water Act also contains provisions that explicitly set the attainment of public health-related standards outside of the range of economic valuation, mandating that they be met whatever the cost.

These preceding examples illustrate situations in which U.S. society reacts to uncertainty about ecosystem services by specifying safe minimum standards (i.e., not causing conditions that would drive a species to extinction, not damaging human health) for impacts on or changes in these systems. Rather than calculate the expected costs and benefits of different levels of impacts and choosing the best, society specifies a bound on the permissible impacts. Of course, with ambiguity rather than risk, and thus no probabilities with which to work, it may be impossible to calculate expected costs and benefits so that standard cost-benefit analysis in such cases is hardly applicable.

Choosing one bound or safe minimum standard over another requires some justification and supporting analysis. One possible line of argument relates to thresholds in ecosystem behavior in response to stress (see Chapter 3). If stresses above a certain level are believed to lead to sharp deterioration in an ecosystem, this may provide a strong case for restricting impacts below this critical level. Yet even this argument relies implicitly on the idea that the costs of ecosystem stress rise sharply and are therefore likely to exceed benefits at some threshold—an argument that cannot be made plausibly without some idea of the magnitudes of the costs and benefits and of the associated margins of error. Once a safe minimum standard is chosen, however, valuation is not needed, but valuation may be needed in setting the safe minimum standard (Berrens, 1996; Berrens et al., 1998; Bishop, 1978; Ciriacy-Wantrup, 1952; Farmer and Randall, 1998; Palmini, 1999; Randall and Farmer, 1995; Ready and Bishop, 1991).

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[10] In *Tennessee Valley Authority vs. Hill,* the Supreme Court upheld that the Endangered Species Act of 1973 was intended by Congress to ". . . halt and reverse the trend toward species extinction at whatever the cost."

[11] In 1978, the ESA was amended to "take into consideration economic impact, and other relevant impact" of listing and designation of critical habitats. See *http://endangered.fws.gov* for further information about the ESA.

ILLUSTRATIONS OF THE TREATMENT OF UNCERTAINTY

This section briefly illustrates how uncertainty could be treated in ecosystem services valuation studies, with reference to the Catskills watershed in New York (also discussed earlier in this chapter) and the Edwards Aquifer case studies provided in Chapter 5. The section begins with an introduction to evaluating and assessing uncertainty through "Monte Carlo"[12] simulations and indicates how this approach could be applied to provide a more complete description of the consequences of uncertainty regarding the inputs to the valuation process.

Monte Carlo Simulation

A sophisticated way of incorporating uncertainty in the output of an ecosystem services valuation study is to use Monte Carlo simulation. This method can provide an estimate of the probability distribution of possible values that is derived from uncertainty about the underlying parameters and relationships. A prerequisite for such an analysis is some probabilistic information about the elements of the valuation.

By way of illustration, assume that a policy intervention is being evaluated that would conserve an ecosystem at some cost in terms of forgone residential development, which was the case in the Catskills watershed in New York. Assume further that there are two elements to the benefits, (1) the quantity of clean water assured because of the policy intervention and (2) the price at which this water should be valued. Call these Q and P respectively, where both are uncertain. On the cost side there is a present cost of C_p and a continuing cost of C_f per year in the future while the benefits continue into the future. If all values were known with certainty, then the net present value of the project would be represented by the following formula if the time horizon is fifty years and the discount rate is r:

$$NV = \sum_{t=1}^{T=50} \left(PQ - C_f\right)\left(1+r\right)^t - C_p$$

If the parameters of this expression are known only with some degree of uncertainty, then NV is a random quantity and an analyst would like data on its distribution. Suppose that the uncertainty is about P, Q, and C_f with r and C_p being known, and that the analyst possesses probability distributions over these uncertain variables. That is, for each of the uncertain variables there is a density function that provides the probability that the variable is within any interval. An analyst can then conduct a Monte Carlo simulation by picking a series of values for the uncertain variables as random numbers chosen according to their density function and for each set values for P, Q, and C_f computing the value of NV. This simulation is repeated many times with a different set of randomly-chosen values of P, Q, and C_f each time. The result will be a set of values for NV. As the number of repetitions of this process increases, the distribution of this set will approach that of the uncertain value of NV. An analyst can therefore obtain from

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[12] Monte Carlo methods have been practiced for centuries, but under more generic names such as "statistical sampling." The "Monte Carlo" designation was popularized by early pioneers in the field during World War II because of the similarity of statistical simulation to games of chance and because Monte Carlo (the capital of Monaco) was a well known center for gambling and similar pursuits. For further information about the history, development, and use of Monte Carlo simulation methods, see *http://csep1.phy.ornl.gov/mc/node1.html*.

this process approximations to the mean and standard deviation of the values of *NV* that are compatible with what is known about the uncertain parameters *P*, *Q*, and C_f.

In practice an analyst will use computer programs written for Monte Carlo simulation for this process, and will need only to input into these information about the distributions of the uncertain parameters and a formula indicating how these are used to compute the value. Of course, and as has been emphasized previously, obtaining probabilistic information about parameter values is not straightforward and on many occasions it will be necessary to use subjective probabilities for this purpose. A potential complication is that in some cases the distributions of the various parameters will not be independent; rather, these will be drawn from a joint distribution. For example, in the illustration above, price *P* and quantity *Q* will not be independent—high prices will tend to be associated with low quantities and vice versa. In such cases the analyst will have to specify joint rather than independent distributions, which is a somewhat more demanding task.

There is little doubt that if resources and sufficient information are available for a Monte Carlo approach, and if the analyst is able to supply the required probabilistic information, this approach provides decision-makers a better appreciation of the range of possible outcomes that are consistent with what is known or believed to be known concerning ecosystem services valuation. EPA has already applied Monte Carlo methods to some studies (EPA, 1997), and Jaffe and Stavins (2004) have reviewed these and conducted their own analyses. Although these previous applications were not in the context of ecosystem services valuation, they illustrate the feasibility of using Monte Carlo analysis to evaluate environmental policies and suggest that these methods could be applied in ecosystem valuation studies as well.

Catskills Watershed and Edwards Aquifer Cases Studies

In the Catskills case, and as noted previously, the key issue is to compare the cost of watershed restoration with the cost of the alternative to provide the service of water purification (NRC, 2000). While the costs of the alternative—construction of a drinking water filtration system) are relatively certain, whereas the cost of increased watershed protection and restoration is uncertain, as is the effectiveness of a given level of restoration in restoring ecosystem services. The poorly understood link from ecosystem structure and function to services is again the cause of the problem. Uncertainty about the effectiveness of watershed restoration, however, can in this case be subsumed into uncertainty about costs, so that the main issue can be treated as uncertainty about the cost of restoring the ecosystem service of water purification to a level needed by New York City.

The first step in dealing with uncertainty in this case will be to obtain information about the possible costs of watershed restoration. Ideally, a probability distribution over possible costs can be obtained. It may be that the analyst feels able to provide this information without further research, but in many cases this will require modeling the restoration process and then using ecological models to link the final state of the system post-restoration to the levels of ecosystem services provided. This will provide an estimate of the cost of restoring a given level of ecosystem services. Because the parameters of the restoration process will typically be uncertain, as will those of the ecological models, it would therefore be desirable to use Monte Carlo simulation to study the distribution of restoration costs and service levels. In doing this, the uncertainty associated with the links between ecosystem structure and function on the one hand and ecosystem services on the other are central. At issue is how far one must restore the watershed, in terms of area, land use, and vegetation, in order to provide water purification services at the level required by New York City. There are no existing models that can be readily enlisted to answer this question in a routine way. Monte Carlo simulation will provide a probability distribution over the costs of restoration to an appropriate level. Then, if the decision-maker is risk neutral, the next step is to compare the expected cost of the restoration with the cost of the alternative (i.e., construction of a water filtration system). If some degree of risk aversion is appropriate, then to the expected cost of restoration should be added a risk premium that depends on the degree of risk aversion of the decision-maker and the standard deviation and higher moments of the probability distribution of possible restoration costs, and this total is to be compared with the cost of the alternative.

In the absence of a probability distribution for the restoration costs, the best approach is probably to construct three scenarios for restoration costs: a best case, worst case, and expected case. These might, for example, amount to \$1 billion, \$2.2 billion, and \$1.6 billion. If the restoration cost is less than the replacement cost for each cost value, the choice is simple—restoration is preferable to the alternative. This would be the case provided that the worst-case restoration cost is less than the cost of a new filtration system (i.e., less than about \$8 billion; NRC, 2000).

A more complex case would arise when the range of restoration costs crosses the cost of replacement—for example, when the three restoration cost estimates are \$1.5 billion, \$9 billion, and \$2.5 billion with a replacement cost of \$8 billion. If probabilities were available to attach to these numbers, then an expected cost could be calculated and adjusted to allow for risk aversion, and the risk-adjusted expected restoration cost could be compared with the replacement cost.

In the case of the Edwards Aquifer—which provides water to San Antonio, Texas—uncertainty arises from several sources, one of which is our inability to forecast recharge rates for the aquifer. The dynamics of the aquifer can be written as:

$$S_t - S_{t-1} = R_t - C_t$$

Here, S_t is the stock of water in the aquifer at date t and R_t and C_t are the recharge and consumption rates, respectively. The consumption rate is relatively predictable and indeed can be controlled to some degree by limitations on water use, whereas the recharge rate depends on weather, which is inherently stochastic. There may also be a trend in the recharge rate associated with changing patterns of rainfall as a result of climate change and another resulting from land development in the intake region of the aquifer, which by increasing the amount of impervious surface can reduce the amount of water collected in the aquifer at any given level of rainfall. There are several other factors that aquifer managers have to take into account, including whether the structure of the aquifer may be damaged if water stocks are drawn down too low, and whether there are any endangered species that live in the aquifer and can be harmed by low water levels. The lowest level to which the water stock has fallen to date is an important variable because this can affect the health of aquifer-specific species. The precise ways in which the structure of the aquifer and the prospects of any endangered species depend on the minimum water level is far from clear, so this relationship is an additional source of uncertainty.

How should these considerations affect the value that resource managers place on water in the aquifer? If managers are risk averse, the recognition of uncertainty will tend to increase the value of water stocks in the aquifer. The fact that in a stochastic world there is a chance of little or no rainfall in the coming years and therefore of little or no replenishment of the water stock in the aquifer means that current stocks might possibly have to last through a long dry period, which adds to the value of having a slightly higher stock. Thus, the marginal value of a unit of water will be higher because of the risk. Likewise, the possibility of damage to endangered species or to the structure of the aquifer because of low water levels increases the value of existing water stocks, because in addition to providing more water for consumption, a higher stock will lower the risk of damage from a future low stock level.

The value of the aquifer considering uncertainty about future replenishment can be approximated by Monte Carlo simulation, using the equation for the dynamics of the aquifer with alternative future replenishment patterns that draw probabilistically from a distribution of future replenishment rates. It is also worth noting that if the structure of an aquifer can be damaged irreversibly by letting the water level fall too low, then there may be an option value to be associated with the preservation of water levels above a minimum. This is the type of context in which such values are applicable—there is a possible irreversible change, as well as the opportunity to learn more about the aquifer system's responses over time.

These two cases indicate that it is conceptually straightforward to see how the analyst should allow for uncertainty in valuation studies. Application of the concepts requires that the uncertainty be characterized to some extent and that the analyst understands decision-makers' attitudes toward uncertainty. Even if a characterization of the uncertainty is not available, it will often be possible, as in the case of the Edwards Aquifer, to state clearly what the qualitative impact of uncertainty will be—whether it will raise or lower a value—even though it may not be possible to measure the extent of this change.

SUMMARY: CONCLUSIONS AND RECOMMENDATIONS

The valuation of aquatic and related terrestrial ecosystem services inevitably involves investigator judgments and some amount of uncertainty. Although unavoidable, uncertainty and the need to exercise professional judgment are not debilitating to ecosystem valuation. It is important to be clear however when such judgments are made, to explain why they are needed, and to indicate the alternative ways in which judgment could have been exercised. It is also important that the sources of uncertainty be acknowledged, minimized, and accounted for in ways that ensure that a study's results and related decisions regarding ecosystem valuation are not systematically biased and do not convey a false sense of precision.

There are several cases in which investigators have to use professional judgment in ecosystem valuation regarding how to frame a valuation study, how to address the methodological judgments that must be made during the study, and how to use peer review to identify and evaluate these judgments. Of these, perhaps the most important choice in any ecosystem services valuation study is the selection of the question to be asked and addressed (i.e., framing the valuation study). The case studies discussed in this chapter illustrate the fact that the policy context unavoidably affects the framing of an ecosystem valuation study and therefore the type and level of analysis needed to answer it. Framing also affects the way in which people respond to any given issue. Analysts need to be aware of this and sensitive to the different ways of presenting data and issues, and make a serious attempt to address all perspectives in their presentations because failure to do so could undermine the legitimacy of an ecosystem services valuation study.

In most ecosystem valuation studies, an analyst will be called on to make various methodological judgments about how the study should be designed and conducted. Typically, these will address issues such as whether, and at what rate, future benefits and costs should be discounted; whether to value goods and services by what people are willing to pay or what they would be willing to accept if these goods and services were reduced or lost; and how to account for and present distributional issues arising from possible policy measures. In many cases, different choices regarding some of these issues will make a substantial difference to the final valuation.

The unavoidable need to make professional judgments in ecosystem valuation activities through choices of framing and methods suggests that there is a strong case for peer review to provide input on these issues before study design is complete and relatively unchangeable. There are several major sources of uncertainty in the valuation of aquatic ecosystem services and options for the way policymakers and analysts can and should respond. Model uncertainty arises for the obvious reason that in many cases the relationships between certain key variables are not known with certainty (i.e., the "true model" will not be known). Chapter 3 discusses the relationship between ecological structure and function and the provision of aquatic ecosystem goods and services to the community; however, this relationship is often poorly understood and will be the greatest single source of uncertainty in many studies of the value of aquatic ecosystems. On the economic side, an analyst might not know the extent to which society's willingness to pay for an ecosystem service depends on the way in which that service is provided. Parameter uncertainty is one level below model uncertainty in the logical hierarchy of uncertainty in the valuation of ecosystem services.

The almost inevitable uncertainty facing analysts involved in ecosystem valuation can be more or less severe depending on the availability of good probabilistic information and the amount of ambiguity. A favorable case would be one in which, although there is uncertainty about some key magnitudes of various parameters, the analyst nevertheless has good probabilistic information. An alternative and common scenario in ecosystem valuation is one in which there is really no good probabilistic information about the likely magnitudes of some variables, and what is available is based only on expert judgment.

Just as there are different types of uncertainty in ecosystem valuation, there are also different ways and decision criteria that an analyst can use to allow for uncertainty in the support of environmental decision-making. One of these is the use of Monte Carlo simulations as a method of estimating the range of possible outcomes and the parameters of its probability distribution. A key assumption in ecosystem valuation models is that individuals seek to maximize their utility and that they will be indifferent to changes that leave their utility unchanged. Under uncertainty, this implies they maximize their expected utility. Although widely used in economic analyses, the expected utility assumption has been controversial, since in some contexts its predictions are not consistent with observed behavior. Alternative theories of behavior under uncertainty have been proposed, including prospect theory and regret theory.

The outcome of an environmental policy choice under uncertainty is necessarily unpredictable, and risk aversion is a measure of what a person is willing to pay to avoid an uncertain outcome. In a heterogeneous population, the analyst will have to make an assumption about the level of risk aversion that is appropriate for the group as a whole. If society is extremely risk averse, then the objective of maximizing the value of the aggregate expected utility can be replaced by an objective known as maximin. Focusing exclusively on the worst possible outcome is justified, however, only if there are good reasons to suppose to which society is really risk averse and is willing to sacrifice considerable potential gain from a policy to avoid any chance of a bad outcome. Implementing the maximin criterion does not require probabilities; it requires only that the worst possible outcome be identified, so it is particularly suited to valuation conditions for which no probabilities are available. A logical extension of this line of thinking leads to concepts such as the precautionary principle and the idea of a safe minimum standard, which are summarized below.

Although there is considerable uncertainty regarding the value of ecosystem services, there is often the possibility of reducing this uncertainty over time through passive and/or active learning. Regardless of its source, the possibility of reducing uncertainty in the future through learning can affect current decisions, particularly when the impacts of these decisions are (effectively) irreversible, such as the construction or removal of a dam. With learning, an option value that needs to be incorporated into the analysis as part of the expected net benefits that reflects the value of the additional flexibility. This flexibility allows future decisions to respond to new information as it becomes available. It follows that with the possibility of learning, in a cost-benefit analysis the measurement of the benefits of ecosystem protection through ecosystem valuation should consider the possibility of learning (i.e., should incorporate the option value). At present, only a limited amount of empirical work has been done on estimating the magnitude of option value. A natural extension of the observation that better decisions can be made if one waits for additional information is through the use of adaptive management. Adaptive management provides a mechanism for learning systematically about the links between human societies and ecosystems, although it is not a tool for ecosystem valuation or a method of valuation per se.

Another approach to environmental decision-making under uncertainty is embodied by the precautionary principle as articulated in the 1992 Rio Declaration (Article 15). The precautionary principle is widely cited by the environmental community as a justification for erring on the side of conservation in situations of uncertainty. However, it is not clear that the precautionary principle brings anything new to the decision criteria frameworks usually used by economists. With learning and under conditions of irreversibility, option values may similarly move environmental policy decisions in the direction of environmental conservation, more so if learning can be actively pursued through an adaptive management approach and especially if there is the chance of a significantly negative outcome from environmental impacts. In such cases, risk aversion will normally move environmental decisions in the same direction. While there may be an option value associated with ecosystem conservation there may also be an option value associated with not adopting conservation policy measures that require significant investments.

Related in some ways to the precautionary principle is the concept of a safe minimum standard, which introduces a class of choices in which decision-makers seek to maintain population or ecosystem levels sufficient for survival. Under this approach, the presumption is that the necessary population size should be maintained, unless the costs of doing so are prohibitively high. The most striking example of this in the United States is the ESA.[13] Choosing one bound or safe minimum standard over another requires some justification and supporting analysis. Once a safe minimum standard is chosen, however, valuation is not needed, but valuation may be needed in setting the safe minimum standard.

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[13] In this case there is a provision for the economic costs of conservation of endangered species to be taken into account when these costs are very high.

Based on these conclusions, the committee makes the following recommendations regarding judgment and uncertainty in ecosystem valuation activities and methods and approaches to effectively and proactively respond to them:

- Analysts must be aware of the importance of framing in designing and conducting ecosystem valuation studies so that the study is tailored to address the major questions at issue. Analysts should also be sensitive to the different ways of presenting study data, issues, and results and make a concerted attempt to address all relevant perspectives in their presentations.
- The decision to use WTP or WTA as a measure of the value of an ecosystem good or service is a choice about how an issue is framed. If the good or service being valued is unique and not easily substitutable with other goods or services, then these two measures are likely to result in very different valuation estimates. In such cases the analyst should ideally report both sets of estimates in a form of sensitivity analysis. However, the committee recognizes that in some cases this may effectively double the work and in such situations a second best alternative is to document carefully the ultimate choice made and clearly state that the answer would probably have been higher or lower had the alternative measure been selected and used.
- Because even small differences in a discount rate for a long-term environmental restoration project can result in order-of-magnitude differences to the present value of net benefits, in such cases, analyst should present figures on the sensitivity of the results to alternative choices for discount rates.
- Ecosystem valuation studies should undergo external review by peers and stakeholders early in their development when there remains a legitimate opportunity for revision of the study's key judgments.
- Analysts should establish a range for the major sources of uncertainty in an ecosystem valuation study whenever possible.
- Analysts will often need to make an assumption about the level of risk aversion that is appropriate for use in an ecosystem valuation study. In such cases, the best solution is to state clearly that the assumption about risk aversion will affect the outcome and conduct sensitivity analyses to indicate how this assumption impacts the outcome of the study.
- There is a need for further research about the relative importance of, and estimating the magnitude of, option value in ecosystem valuation.
- Under conditions of uncertainty, irreversibility, and learning, there should be a clear preference for environmental policy measures that are flexible and minimize the commitment of fixed capital or that can be implemented on a small scale on a pilot or trial basis.

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7
Ecosystem Valuation: Synthesis and Future Directions

The committee's statement of task (see Box ES-1) identifies a number of specific questions regarding economic methods for valuing the services of aquatic and related terrestrial ecosystems. Chapter 2 sets the stage for the subsequent chapters with a general discussion of the meaning and sources of value, with a decided emphasis on the economic approach to valuation. Chapter 3 then discusses the relationship between ecosystem services and the more widely studied ecosystem functions; it addresses the types and measurement of ecosystem services and the extent of our current understanding of these services. Chapter 4 reviews the principal and currently available nonmarket economic valuation methods. These two chapters assess what is currently known about the underlying ecology (Chapter 3) and the economics (Chapter 4) necessary for conducting ecosystem valuation. Existing efforts in ecology and economics are then discussed through an examination of several case studies in Chapter 5. That chapter also provides an extensive discussion of implications and lessons to be learned from past attempts to value a variety of ecosystem services. Uncertainty and judgments that arise when conducting an ecosystem valuation study and affect the measurement of values are discussed in Chapter 6.

The purpose of this final chapter is to synthesize the current knowledge regarding ecosystem valuation in a way that will be useful to resource managers and policymakers as they seek to incorporate the value of ecosystem services into their decisions. The chapter begins with a list of premises that underlie the committee's view of ecosystem valuation. This is followed by a synthesis of the major conclusions that emerge from the preceding six chapters. The committee then presents a checklist or set of guidelines for use by resource managers or policymakers when conducting or evaluating ecosystem valuation studies. This checklist identifies a number of factors to consider and questions to ask in improving the design and use of such studies. Finally, this chapter identifies what the committee feels are the most pressing recommendations for improving the estimation of ecosystem values As noted previously, although the focus throughout this report is on those services provided by aquatic and related terrestrial ecosystems, the various conclusions and recommendations provided in this report and final chapter are likely to be directly or at least indirectly applicable to valuation of the services provided by any ecosystem.

GENERAL PREMISES

There are several general premises that the committee feels accurately reflect the current state of knowledge about the value and valuation of aquatic ecosystem services. These premises frame the more detailed discussion of major conclusions that follows. The key links embodied in these premises are illustrated in Figure 7-1, which is a more detailed version of Figure 1-3.

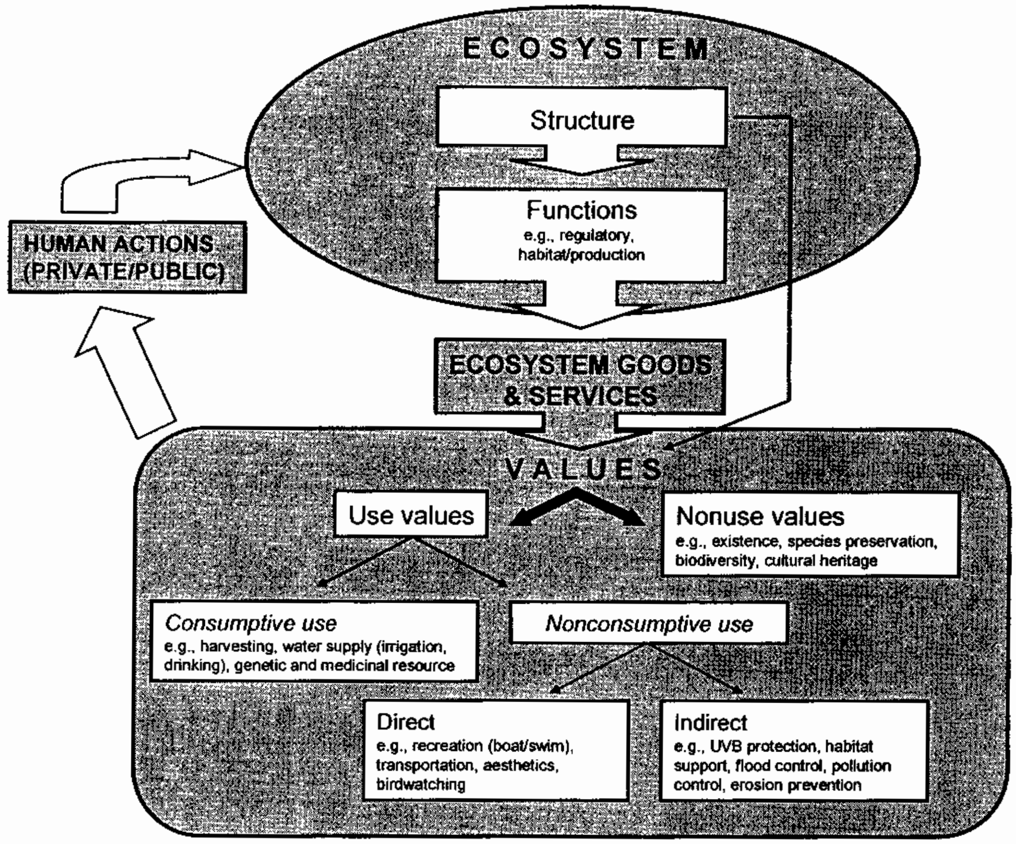

FIGURE 7-1 Connections between ecosystem structure and function, services, policies, and values.

1. Ecosystem structure along with regulatory and habitat/production functions produce ecosystem goods and services that are valued by humans. Examples include production of consumable resources (e.g., water, food, medicine, timber), provision of habitat for plants and animals, regulation of the environment (e.g., hydrologic and nutrient cycles, climate stabilization, waste accumulation), and support for nonconsumptive uses (e.g., recreation, aesthetics).

2. In addition, many people value the existence of aquatic ecosystems for their own sake, or for the role they play in ensuring the preservation of plant and animal species whose existence is important to them. This value can stem from a belief that these species or ecosystems have intrinsic value or from the benefits that humans get from their existence, even when that existence is not directly providing goods or services used by human populations. In some cases, this "nonuse" value may be the primary source of an ecosystem's value to humans.

3. The total economic value of ecosystem services is the sum of the use values derived directly from use of the ecosystem and the nonuse value derived from its existence.

Use value can be decomposed further into consumptive uses (e.g., fish harvests) and nonconsumptive uses (e.g., recreation).

4. Human actions affect the structure, functions, and goods and services of ecosystems. These impacts can occur not only from the direct, intentional use of the ecosystem (e.g., for harvesting resources, for boating), but also from the unintentional, indirect impacts of other activities (e.g., upstream agriculture). Human actions are, in turn, directly affected by public policy and resource management decisions.

5. Understanding the links between human systems and ecosystems requires the integration of economics and ecology. Economics can be used to better understand the human behavior that impacts ecosystems, while ecology aids in understanding the physical system that is both impacted and valued by humans.

6. Nearly all policy and management decisions imply changes relative to some baseline and most changes imply *trade-offs* (i.e., more of one good or service but less of another). Protection of an ecosystem through a ban on or reduction of a certain type of activity implies an increase in ecosystem services but a reduction in other services provided by the restricted activity. Likewise, allowing an activity that is deemed detrimental implies a reduction in some ecosystem services but an increase in the services generated by the allowed activity.

7. Information about these trade-offs—that is, about the value of what has been increased (what is being gained) as well as the value of what has been decreased (what is being forgone or given up)—can lead to better decisions about ecosystem protection. Since decisions involve choices, whenever these choices reflect how "valuable" the alternatives are, information about those values will be an important input into the choice among alternatives.

8. Because aquatic ecosystems are complex, dynamic, variable, interconnected, and often nonlinear, our understanding of the services they provide, as well as how they are affected by human actions, is imperfect and linkages are difficult to quantify. Likewise, information about how people value ecosystem services is imperfect. Difficulties in generating precise estimates of the value of ecosystem services may arise from insufficient ecological knowledge or data, lack of precision in economic methods or insufficient economic data, or lack of integration of ecological and economic analysis.

9. Nonetheless, the current state of both ecological and economic analysis and modeling in many cases allows for estimation of the values people place on changes in ecosystem services, particularly when focused on a single service or a small subset of total services. Use of the (imperfect) information about these values is preferable to not incorporating any information about ecosystem values into decision-making (i.e., ignoring them), since the latter effectively assigns a value of zero to all ecosystem services.

10. There is a much greater danger of underestimating the value of ecosystem goods and services than over-estimating their value. Under-estimation stems primarily from the failure to include in the value estimates all of the affected goods and services and/or all of the sources of value, or from use of a valuation method that provides only a lower bound estimate of value. In many cases, this reflects the limitations of the available valuation methods. Over-estimation, on the other hand, can stem from double-counting or from possible biases in valuation methods. However, it is likely that in most applications the errors from omission of relevant components of value will exceed the errors from over-estimation of the components that are included.

SYNTHESIS OF MAJOR CONCLUSIONS

The preceding general premises collectively imply that ecosystem valuation can play an important role in policy evaluation and policy and resource management decisions. The following section provides a synthesis of the major conclusions regarding ecosystem valuation that emerge from the previous chapters. **It is important to note that this is not intended to replicate or simply restate individual chapter summaries or the conclusions and recommendations of the individual chapters; rather, it is intended to integrate and summarize the broad themes that emerge from these chapters.** The synthesis is organized around these three sets of related questions:

1. What is meant by the *value* of ecosystem services? What components of value are being measured?
2. Why is it important to *quantify* the value of ecosystem services (i.e., to undertake *valuation*)? How will the values that are estimated (i.e., the results of the valuation exercise) be used?
3. How should these values be measured? What methods are available for quantifying values, and what are their advantages and disadvantages?

What Is Being Measured?

There is growing recognition of the crucial role that ecosystems play in supporting human, animal, plant, and microbial populations. There are several published inventories or classification schemes for the goods and services provided by aquatic ecosystems (see Chapter 3). Commonly recognized services include water purification, flood control, waste decomposition, animal and plant habitat, transportation, recreation, hydroelectricity, soil fertilization, and support of biodiversity. However, the complexity of ecosystems remains a barrier to quantifying the links from ecosystem structure and functions to the goods and services that humans value. In addition, although there is now widespread recognition that ecosystem services are "valuable," simply recognizing them as valuable may be insufficient as a guide to environmental policy choice. What is required is some way of comparing these services to other things that are also considered valuable. Without this, the value of ecosystem goods and services will not be given proper weight in policy decisions.

The concept of value, however, has many interpretations. Some notions of value are biocentric; others are anthropocentric. Some are based on usefulness (instrumental value) through contributions to human well-being (utilitarian values); others are based on inherent or intrinsic value and rights. There is a large and growing literature, much of it in the field of philosophy, devoted to defining the nature and sources of such value. To the extent that they represent dimensions that are important to people (and hence affect how they view alternative choices), all types of value can play an important role in environmental decision-making.

Given the committee's charge, this report focuses on the economic concept of value, which is generally defined in terms of the satisfaction of human wants, making it an anthropocentric and utilitarian approach. The economic definition of value postulates a potential substitutability between environmental goods or services and other goods or services that people value. It does not capture intrinsic values that stem from moral premises, although it does capture the value people place on the existence of a species or ecosystem for its own sake. For this reason, the economic concept is not an all-inclusive concept of value. Nonetheless, it is broadly defined to include not only the value derived from direct use of an ecosystem service (use value), but also nonuse values such as existence and bequest values. It thus includes the value of protection "for protection's sake," provided that protection for its own sake is viewed as desirable by some humans. Economic value should not be confused with the much narrower concept of market or commercial value, which reflects only payments made or received through market transactions. In general, economic value includes many components of value that have no commercial or market basis, including the values individuals place on preservation of ecosystems or species, even when that preservation has no apparent use value.

Economic *valuation* is then the process of quantifying the economic value of a particular *change* in the level of a good or service. A benefit of the use of economic valuation is that it provides a process that is grounded in economic theory and information that can be used to evaluate the trade-offs that inevitably arise in environmental policy choices. By using a common metric (normally monetary) to value changes, it allows a comparison of possible changes and hence facilitates a choice among them. The use of a monetary metric (e.g., dollar equivalent) for quantifying values is based on the assumption that individuals are willing to trade the change being valued for more or less of something else that can be represented by or bought with the metric (i.e., fewer dollars). It thus assumes that the good being valued is in principle substitutable or replaceable by other goods and services.

The economic approach to valuation does not, however, imply a unique measure of the value of a change. The economic value of a change can be defined in two alternative ways: (1) as the amount an individual or group is willing to pay to secure the change (willingness to pay) or (2) as the amount they would have to be compensated to forgo the change (willingness to accept [compensation]). These alternative measures imply different allocations of property rights and have different implications for the role of the income of those affected individuals and groups. In particular, willingness to pay is limited by ability to pay. Although contexts exist in which these two measures can be expected to yield similar values, it is nevertheless the case that without close substitutes for the service that is changing, the two can be expected to yield substantially different values. For unique ecosystems, such as the Florida Everglades, close substitutes are not available and hence the two measures can be expected to differ substantially. Usually, the willingness-to-accept measure, which is not constrained by income, yields a greater value for an improvement than does the willingness-to-pay measure. Economic theory suggests that willingness to accept is appropriate for valuing the removal of a service to which people have a right, whereas willingness to pay is appropriate for valuing the provision of a new service or more of an existing service in a situation where there is no right to receive this service, although in practice most economic valuation exercises use methodologies that measure only willingness to pay. Nonetheless, because willingness to pay provides a lower bound for willingness to accept, it is a sufficient measure for cases in which willingness-to-pay estimates exceed the value of alternatives.

Policy decisions made today and the human actions that they affect can impact an aquatic ecosystem not only now but also far into the future. The temporal dimension of policy impacts stems both from the potential effect on behavior (e.g., inducing long-term behavioral changes or irreversible decisions) and from the dynamic nature of aquatic ecosystems. As a result, the changes that result from a contemporary policy choice and the valuation of those changes must include not only current impacts but future impacts as well. In addition, aggregate value estimates require an aggregation of values over time. This is done typically through the use of discounting and the calculation of net present values. Much of the controversy surrounding the use of discounting stems from a misunderstanding of the distinction between two alternative forms of discounting: utility discounting and consumption discounting. In particular, even when it is desirable to weigh the well-being of all generations equally (implying a zero utility discount rate), it would still be appropriate to use a positive or negative discount rate for the benefits or costs associated with changes in ecosystem services, if the general availability of these services is expected to change over time. It is important to note, however, that because they are conducted at the present time, all valuation exercises measure the values or preferences of the current generation. To the extent that the preferences of future generations differ, those differences would not be captured in the value estimates.

Why Conduct Ecosystem Valuations?

Why or when might it be important to have an estimate of the value of a change in ecosystem goods or services? As concluded above, such estimates can inform and improve environmental policy and management decisions. Again, simply stating that something has value is insufficient as a basis for policy choice. Rather, it is necessary to have a ranking of alternatives, and estimates of the values of the changes implied by different options can contribute to such a ranking. However, the specific role that valuation plays and its contribution to such processes depends on the specific way in which it will be used (i.e., on the "policy frame"). In particular, the nature of the ecosystem valuation exercise (i.e., how it is conducted and how it is used) will depend on the specific context or problem. One can distinguish between different types of valuation exercises, each of which potentially implies a different type of valuation question, different information needs, different scopes (i.e., types of ecosystem services), and different spatial and temporal scales.

One possible context in which economic valuation plays a key role is in the measurement of damages from ecosystem degradation that has already occurred as a result of some human action. This is a measure of the value of the ecosystem services that have been diminished or lost. Perhaps the most common example of this is natural resource damage assessment (NRDA), which is used to determine the amount of compensation the party responsible for the damages must pay. In this context, a point estimate of damages (rather than a distribution of possible damages) is needed. In addition, it is necessary to have a measure of *total* damages. A partial measure based on a subset of ecosystem services is not sufficient, since as noted previously, not valuing some services is equivalent to assigning those services a zero value.

Rather than valuing a change in ecosystem services that has already occurred, one might instead be interested in valuing a change that could occur. Such a change would typically be linked to a specific policy under consideration. Economic valuation has been used in an attempt to place an estimate on the value of *all* ecosystem services, not as part of a specific policy evaluation, but rather as a means to demonstrate the importance of these services. However, as noted above, economic valuation is designed to estimate the value of a *change* in the provision of services, and the techniques are normally most reliable when applied to relatively small (marginal) changes. Hence, application to very large changes (e.g., "with" and "without" scenarios) often implies an inappropriate use of the techniques.

Some valuation studies do focus on changes in ecosystem services, but still not in the context of a specific policy evaluation. For example, studies can estimate the value of a *hypothetical* change in an ecosystem services (such as a 10 percent increase in commercial fish catch rate). Most economic valuation exercises to date have been of this type. Such analyses do not require a linkage of ecological and economic models, however, because the ecological processes or responses that might generate the hypothetical change are not part of the analysis. Although greatly simplifying the analysis, the use of hypothetical scenarios makes it difficult to link the value estimates with predicted policy impacts.

Ecosystem valuation is most useful as an input into environmental decision-making when the valuation exercise is framed in the context of the specific policy question or decision under consideration; however, this presents several challenges. Such an analysis should have the following components: (1) a way of estimating the *changes* in ecosystem structure and functions that would result from implementation of the policy, (2) a way of estimating the *changes* in ecosystem services that result from the changes in structure and function, and (3) a way of estimating the value of these changes in ecosystem services (see Figure 7-1). This requires an integration of ecological and economic methods and models. The physical impacts of the policy should first be determined, and this should then be translated into a value (e.g., a willingness to pay or willingness to accept compensation for that change). Without this linkage, either it will not be possible to evaluate a specific policy (e.g., it will only be possible to consider hypothetical changes in ecosystem services) or else the subjects of the valuation exercise (e.g., the people whose values are elicited) must implicitly supply their own subjective ecological model (i.e., their own beliefs about the likely effect of the policy on the ecosystem). Thus, the values that are elicited will depend on what these individuals *think* the link between the policy and ecosystem services will or should be.

In the context of aquatic ecosystems, the impact of a given policy on ecosystem services is particularly difficult to estimate, because these ecosystems are complex, dynamic, variable, interconnected and often nonlinear. In addition, linking changes in ecosystem services to values is also difficult, because many of these services are not traded in markets and a large part of the value may stem from nonuse value. However, this task may be easier when applied on a very local scale rather than a regional or global scale, and when it is focused on a subset of services rather than trying to incorporate an exhaustive list of ecosystem services.

Whether the results of a more narrowly focused analysis are sufficient will depend on the specific environmental policy context and the decision criteria that will be used to choose among policy alternatives. Different criteria require different types of information about values. Two contexts in which valuation plays a large role are benefit-cost analysis and cost-effectiveness analysis.

Many federal statutes and regulations require benefit-cost analyses as part of regulatory policy analysis or allow a consideration (as opposed to a comparison) of benefits and costs. In either case, information about the values of changes in ecosystem services needs to be included in the measures of such benefits and costs. In some cases, a partial measure of benefits (i.e., estimating the value of changes in some subset of services) may be sufficient. If a partial measure of benefits exceeds costs, then it is not necessary to have a measure of total benefits because the additional information (i.e., values associated with the additional ecosystem services) would not change the results of the benefit-cost analysis. However, if focusing on only a subset of services yields a benefit measure that is less than cost, it is necessary to consider the value of other services not previously included to see whether inclusion of these benefits changes the results of the analysis.

Economic valuation can also be an important input into environmental policy choice when a particular service (such as water purification) must be provided and one way to provide it is through protection, preservation, or restoration of ecosystem services. In this context, the valuation exercise may simply be part of a cost-effectiveness analysis designed to determine the least-cost means of providing the required good. In such cases, the valuation exercise would only require estimation of the replacement cost—the cost of the next-best alternative means of providing the required service (e.g., the cost of a new water filtration plant instead of watershed protection; see also Chapters 5 and 6). In this case, the willingness to pay for the ecosystem service is the amount saved by not having to provide the good or service through alternative means. It is important to emphasize that this does *not* give a measure of the overall value of the ecosystem service, since it reflects only the costs saved by providing the service through ecosystem protection or restoration rather than through an alternative means. In such a context, the value of the ecosystem service is not the cost savings but rather the willingness to pay (or accept compensation) for the improvement in water quality resulting from the protection or restoration of the ecosystem service.

How to Value Ecosystem Services?

Given a decision on what is to be valued and why, the third and last major question to be addressed is how to conduct the economic valuation. The ability to generate useful information about the value of ecosystem services varies widely across cases for at least two reasons. First, knowledge of the link from ecosystem structure and functions to the provision of ecosystem services varies. Some ecosystems, as well as some types of aquatic services, are better understood than others. Second, some types of values (such as nonuse values) are more difficult to estimate than others. For some ecosystem services, such as commercial fish harvests or flood control, the valuation exercise is rather straightforward and uncontroversial. For others, the translation of physical changes in structure or function into values is much more difficult and, in some cases, controversial.

A variety of existing methods can be applied to measuring the economic value of ecosystem services. Some of these methods are based on observed behavior (revealed-preference methods), while others are based on survey responses (stated-preference measures).

Stated-preference methods do not seek to infer values from behavior. Rather, they seek to elicit information about values through survey responses. The two primary types of stated-preferences methods are contingent valuation and conjoint analysis. Contingent valuation was developed to estimate values for goods or services for which neither explicit nor implicit prices exist. Conjoint analysis is conceptually similar to contingent valuation, although it focuses on individual attributes and asks respondents for rankings of alternatives rather than direct statements relating to value. In either case, statistical methods are used to estimate economic values from the stated choices or ranks. Since valuation questionnaires often pose a cognitive problem for respondents, the use of focus groups, individual interviews, and pre-tests can help to ensure that the questionnaires and responses reflect the intended purpose. Although stated-preference methods have come under substantial criticism because they are not based on actual behavior, inclusion of these types of quality control mechanisms in a study design would reduce potential biases and should help in their acceptance and use in environmental decision-making.

Revealed-preference methods, on the other hand, use observed behavior to measure or infer economic values. The main revealed-preference methods that have been used to value ecosystem services are travel-cost, averting behavior, hedonic, and production function models. The travel-cost approaches can capture only the value of ecosystem services that stem from use of a particular site, for example, for recreational fishing. To the extent that an ecosystem change affects recreational fishing at one or more locations (e.g., through a change in fish quantity or quality), the value of the impact on recreational fishing can be estimated using the travel-cost approach. However, the effect of this change on other ecosystem services would not be included in the value estimates derived from the travel-cost method.

Averting behavior models are best suited for valuing ecosystem services related to human health or the provision of related services such as clean water. The premise is that people will change their behavior and invest money to avoid undesirable health outcomes. If degradation of an ecosystem leads to a reduction in the provision of a service such as clean water, the expenditure that individuals would be willing to undertake to avoid the related health impacts—for example, investing in filtration treatment technologies or purchasing alternative water sources—provides a measure of the value of what is lost as a result of the degradation. Application of this valuation approach is currently limited to cases in which the ecosystem service directly impacts individuals, they are aware of any degradation of the ecosystem and its impact on the services provided, and activities can be undertaken to avoid or reduce the negative impacts resulting from the degradation.

The basic premise of the hedonic approach to ecosystem valuation is that the ecosystem services realized by living in a particular location are one attribute that contribute to the value of a house in that location and thus affect its price. Information about how the variation in services across locations (e.g., differences in observable water quality) affects housing prices can be used to infer the value that individuals place on changes in the level of these ecosystem services. Once again, however, the resulting measure of value is only a partial measure, since it captures only the component of value realized as a result of living at a particular location.

All of the above revealed-preference methods have been applied to the valuation of some component or subset of aquatic ecosystem services. In general, however, these applications have not relied on the direct linking of ecological and economic models discussed above. In some cases, the application was to an observed environmental degradation (such as a fish advisory or a water contamination episode). In others, the value of a hypothetical change in ecosystem services was estimated, using information about values derived from observed variations in ecosystem services across space or time. As noted above, decoupling the economic and ecological modeling greatly simplifies the valuation exercise. However, such analyses do not provide value estimates that can readily be used directly in policy evaluation and decision-making. What is needed for this purpose is a modeling framework that links the policy to changes in ecosystem structure and functions, which in turn affects the ecosystem services that people value.

The last revealed-preference approach, the production function approach, applies integrated ecological and economic modeling in contexts in which one or more ecosystem services support or protect the production of valued final goods and services. The biological resource or ecological service is treated as an "input" into the economic activity, and like any other input, its value can be equated with the value of its marginal productivity. Although the production function approach is best illustrated in the case where the final output is marketed, as in studying the impact of habitat and water quality on commercial fisheries, it can be used equally well where the final output is not marketed—as would be the case in valuing the impact of habitat and water quality on recreational or subsistence fisheries. Most applications of the production function approach in the past have been for marketed final output. In such cases, the translation of changes in the quantities of outputs (e.g., changes in commercial harvests) into values is greatly simplified, because market prices can be used as measures of value, at least for small changes. The more challenging aspect of these studies is determining policy recommendations for managing the aquatic ecosystems supporting the key ecosystem service or services of interest and, in turn, translating the change in ecosystem services into a change in the availability or cost of producing the marketed good or service. Complicating factors include threshold effects and other nonlinearities in the underlying hydrology and ecology of aquatic ecosystems, and the need to consider trade-offs between two or more environmental benefits generated by ecological services. More recent efforts have attempted to expand the integrated ecological-economic modeling underlying production function approaches to account for some of these important effects and trade-offs and to extend the approach to value "multiple" rather than "single" services provided by aquatic ecosystems.

To summarize, in many past applications to aquatic ecosystem services, revealed-preference methods have been restricted to valuing a relatively limited set of services and primarily use values. Even within the category of use values, revealed-preference approaches have been restricted to valuing certain types of ecosystem services and values, such as commercial harvests, recreation, storm protection, habitat-fishery linkages and erosion control. In contrast, stated-preference methods have been more widely applied to all the different values listed in Figure 7-1. Furthermore, only stated-preference methods can measure certain components of value, such as existence value or other nonuse values, which may comprise a large component of the value of a change in an aquatic ecosystem. Thus, only stated-preference methods are capable of measuring the total economic value of a change (both use and nonuse value).

As noted previously, the credibility of the estimated values derived from stated-preference methods has come under greater scrutiny in academic, policy, and litigation arenas, due mainly to concerns over eliciting values from individuals' responses to surveys. In addition, although stated-preference methods have an advantage in capturing the total value of a change in the overall state of an aquatic ecosystem or in a number of interlinked ecosystem services, such methods are not concerned with how such changes arise from disturbances to the underlying regulatory functions, habitat/production functions, and structure of the ecosystem. By focusing on the values arising from single uses and services of an aquatic ecosystem, revealed-preference methods have also tended to ignore the "interconnectedness" between the functioning aquatic ecosystem and the different values that arise through ecosystem services. However, as Chapters 3-5 of this report have emphasized, this "interconnectedness" may matter more than previously thought in valuing the different services of aquatic ecosystems, and the challenge to economists and ecologists is to collaborate on developing more integrated ecological-economic modeling of the importance of ecosystem functioning, structure, and habitat/production functions for various ecosystem services of value to humankind.

Regardless of the methods used, some issues that should be considered in the design of any ecosystem valuation study. First, unless correct questions are asked at the outset, the information generated by the ecological models may not be very useful if it is not in a form suitable for the application of valuation methods (e.g., if it simply lists affected ecosystem services but does not quantify the resulting changes in those services). For their part, economists may apply valuation methods to ecosystem valuation scenarios not built on solid ecological foundations.

Second, as noted above, typically ecological and economic information suitable for estimating reasonably precise values for ecosystem services exists for only a relatively narrow range of services. Limiting the scope of analysis to this subset implies that valuation can be conducted with a relatively high degree of confidence with existing methods. However, limiting the scope of services considered can also lead to problems. For example, a valuation study that analyzes only a subset of ecosystem services may not be sufficient to answer some policy questions. In addition, focusing on impacts of a narrow set of services may fail to capture the interconnectedness of processes within an ecosystem and important feedback effects.

A third key issue is selection of the spatial scale for the valuation exercise. Spatial scale has two important dimensions: (1) the spatial boundaries used to define the relevant ecosystem and (2) the spatial delineation of the relevant group of people whose values will be included in the study. Being too narrow in defining the spatial scale of the ecosystem may mean ignoring important linkages and spillover effects on the production of ecosystem services or in the value of those services. In addition to the physical interconnectedness, there may also be interconnections on the valuation side due, for example, to possible complementarity or substitutability among services either within or across ecosystems.

The appropriate spatial scale for defining whose values to include in an ecosystem valuation study depends on the policy context and the decision-maker's objectives. For example, benefit-cost analysis of federal environmental policies will generally consider the values of all individuals within the United States, even though some individuals in other countries may also be affected by and value the ecosystem change. Likewise, regional analyses might include only the values of individuals within the region. However, narrowing the included population in this way could lead to policy choices (e.g., regarding land development practices) that pass a benefit-cost test at the regional or local level but not at a broader level. This situation is more likely when a substantial component of the value of ecosystem services consists of nonuse values (e.g., existence values) held by individuals outside the region.

A fourth key issue is selection of the appropriate temporal scale for the valuation exercise, which allows for consideration of future impacts of current policy choices. As noted previously, when impacts occur over time, a comparison and aggregation of present and future values is necessary, which is typically done through the use of discounting. In addition, even when present impacts can be predicted fairly accurately, it may be very difficult to predict the value of future impacts, either because the factors determining the link between policy and future ecosystem structure and function are not well understood (e.g., due to complex dynamics) or because the factors affecting the value of ecosystem services (such as income or the availability of substitutes) cannot be predicted with accuracy. Knowing that ecosystem conditions may change or that values may shift places a premium on the ability to learn and adapt through time and to avoid outcomes that cannot be reversed easily. The estimates of values associated with a particular policy change need to reflect the value of any opportunities for learning and adaptation provided by the policy.

Fifth, it is important to distinguish between the estimation of marginal and average values. Marginal values and average values can differ substantially. Evaluating changes typically requires focusing on marginal rather than average values. Most economic valuation techniques (in particular, revealed-preference methods) are well suited to valuing small changes (marginal values) but are more problematic for large changes for at least two reasons. First, marginal values reflect the level of scarcity of a particular good or service, and to the extent that large changes in ecosystems affect scarcity, they can be expected to change marginal values. These changes and the changes in implicit or explicit prices that can result are not captured by the valuation techniques. Second, in terms of ecological impacts, aquatic ecosystems can exhibit threshold effects and large changes can push the system over a threshold, causing regime shifts (e.g., from an oligotrophic to a eutrophic state). These effects would not be captured by the value of small changes that would not be sufficient to trigger such threshold effects.

The preceding discussion suggests that when valuing ecosystem services, extrapolation—across space (e.g., from one ecosystem to another), over time, or over scale (e.g., from small to large changes)—can introduce significant errors in the process and outcome. Nonetheless, some extrapolation may be necessary because of limitations in data, incomplete knowledge of underlying system structures and functions, or limits on resources for conducting the valuation study. In fact, it is likely that many valuation exercises will by necessity rely on benefit transfer methods, which take values estimated in one context and apply them in another context. Such methods should be used cautiously, with a full recognition and acknowledgement of the potential implications of the extrapolation that these methods require.

Because of limitations in data and knowledge (both ecological and economic), estimation of the value of ecosystem services will necessarily involve uncertainty. In addition, economic valuation inevitably involves some degree of subjectivity or professional judgment in framing the valuation problem.

Although unavoidable, uncertainty and the need to exercise professional judgment are not debilitating. Methods such as sensitivity analysis and Monte Carlo simulation allow an assessment of the *likelihood* or *probability* that the benefits of the policy will exceed its costs, or the conditions under which this would be true. However, this approach does not incorporate individual attitudes toward bearing the risks that stem from uncertainty. An approach that is more consistent with economic theory defines the benefit of a policy change (for example, the willingness to pay for the change) *given* that the impacts of that change are uncertain. Such a measure incorporates individuals' willingness to take or accept risks, but it is difficult to estimate and has rarely been used in practice. Possible decision criteria or management strategies that explicitly recognize the uncertainty inherent in many decisions regarding ecosystem services are maximin rules, adaptive management, the precautionary principle, and the safe minimum standard. **In responding to uncertainty, it is important to recognize the possibility of learning over time and the potential value of flexibility, but not to let incomplete information bias environmental policy decisions in favor of the status quo.**

GUIDELINES/CHECKLIST FOR VALUATION OF ECOSYSTEM SERVICES

The preceding synthesis of the report's major conclusions regarding ecosystem valuation suggests that a number of issues or factors enter into the appropriate design of a study of the value of a change in aquatic ecosystem services. The context of the study and the way in which the resulting values will be used play a key role in determining the type of value estimate that is needed. In addition, the type of information that is required to answer the valuation question and the amount of information that is available about key economic and ecological relationships are important considerations. This strongly suggests that the valuation exercise will be very context specific and that a single, "one-size-fits-all" or "cookbook" approach cannot be used. Instead, the resource manager or decision-maker who is conducting a study or evaluating the results of a valuation study should assess how well the study is designed in the context of the specific problem it seeks to address. The following is a checklist to aid in that assessment. It identifies questions that should be discussed openly (and in some cases debated) and satisfactorily resolved in the course of the valuation exercise.

The Policy Frame

- What is the purpose of the valuation exercise?
    - What is the policy decision to be made?
    - What decision criteria will be used and what role will the results of the valuation exercise play?
    - How will the valuation results be used?
    - What information is needed to answer the policy question?
- What is the scope of the valuation exercise?
    - What ecosystem services will be valued?
    - Is it necessary to value only one or a few ecosystem services, or is it necessary to value all services?
- What is the appropriate geographic scale of the valuation exercise?
    - Is it a local, regional, or national analysis?
    - What is the relevant population to include in the value estimates (i.e., whose values to include)?
- How is the valuation question framed?
    - Is it seeking to measure willingness to pay or willingness to accept as a measure of value? Is the question framed in terms of losses or gains?
    - What effect is framing likely to have on the valuation estimates? Is it likely to introduce systematic biases? What effect would alternative frames likely have on the value estimates?
    - What are the advantages and the limitations of the frame that is chosen?
    - Is the frame responsive to stakeholder needs and will it generate information useful to stakeholders?

The Underlying Ecology

- How well understood is the ecosystem of interest?
    - Are the important dynamics understood and reflected in the analysis?
    - Does the ecosystem exhibit important nonlinearities or threshold effects?
    - If the analysis covers multiple ecosystems (e.g., an analysis of a national wetlands policy), how similar or heterogeneous are the included ecosystems?
    - How do important sources of heterogeneity link to important variations in value?

- o Are the interlinkages between different ecological services well understood?
- o Are the complexities of the ecosystem adequately captured by the valuation method? If not, what are the implications for the valuation exercise?

- How precisely can the changes in ecological services that are likely to result from the policy be predicted?
  - o Is the level of precision sufficient given the nature and purpose of the valuation exercise?
  - o If not, how will the underlying ecosystem effects of the policy be characterized (e.g., as hypothetical changes in services)?

From Ecology to Economic Valuation

- Is the study designed so that the output from the ecological models can be used as an input to the economic models?
  - o Does the ecological model give outputs in terms of things that people value?
  - o With cost-effectiveness analysis (use of replacement cost), are the alternatives providing the same goods or services with the same reliability?
- Given the services to be valued, what existing valuation methods are available?
  - o Which seem most appropriate?
  - o To what extent is integrated ecological-economic modeling required to capture multiple services and their values, and the "interconnectedness" between the structure and functioning of aquatic ecosystem and the services of value generated?
  - o For any given method, which services are captured in the estimated values and which are not?
  - o Whose values are captured by the method?
  - o Is the measure a "true" measure or an underestimate (e.g., a lower bound) or overestimate of the true value?
    - ▪ Under what conditions can it serve as a reasonable proxy for true values?
    - ▪ Are those conditions met?
  - o Do the values reflect the relevant scarcities?
    - ▪ Are there close substitutes for the ecological services being valued (i.e., other means of providing the service)?
    - ▪ Does the valuation technique adequately reflect the uniqueness of the ecosystem service or the availability of substitutes?
    - ▪ Will the values capture important nonlinearities or possible threshold effects?
- What are the data needs?
  - o Are original values to be generated, or are estimates of value generated from previous studies being used ("benefits transfer")?
    - ▪ If benefits transfer is to be used, how transferable are the available estimates to the ecosystem services of interest?
  - o If original estimates are to be generated, what is the appropriate sample to be used in gathering data?
    - ▪ What is the likely effect of the sample choice on the valuation estimates?
    - ▪ Have the quality of the data been evaluated adequately?

- How is aggregation handled?
  - Do benefits/values extend over time?
    - Is discounting used to aggregate over time?
    - If so, what discount rate is used?
    - What are the implications for intergenerational resource allocation using alternative decision rules?
  - How are individual values aggregated across individuals?
  - How are values aggregated across services?
    - If estimates derived by different methods are combined, is there the potential for double counting? What steps have been taken to avoid double counting?

Uncertainty

- What are the primary sources of scientific uncertainty affecting the valuation estimates?
  - What are the possible scenarios or outcomes?
  - Can probabilities be estimated and with what degree of confidence?
- What methods (such as sensitivity analysis and Monte Carlo simulation) will be used to address uncertainty?
  - Can the results of the valuation exercise be used to calculate not only point estimates but also estimates of the range of value estimates?
  - Do the value estimates capture risk aversion?
- If benefits or values extend over time, are there important irreversibilities?
  - Is it likely that significant learning will occur?
  - Is the value of being able to respond to new information (flexibility) adequately reflected in the valuation estimates?

OVERARCHING RECOMMENDATIONS

The committee recognizes that there are policy contexts in which decisions regarding ecosystem protection, preservation, or restoration will not consider the trade-offs implied by these decisions. For example, decisions may be based on rights-based decision rules, either explicitly or implicitly, where the protection of certain rights is the primary policy goal. In such contexts, valuation of ecosystem services will not play an essential role. However, when policymakers are concerned about trade-offs, then the valuation of services provided by ecosystems can inform the policy debate and lead to improved decision-making. Based on the information provided in this report, the committee has identified a number of overarching recommendations regarding the valuation of ecosystem services in such contexts. These recommendations are based on and in some cases build upon the more specific recommendations presented in the body and summaries of the six previous chapters. Two types of overarching recommendations are included: (1) recommendations for conducting ecosystem valuation and (2) research needs, which imply recommendations regarding future research funding.

Overarching Recommendations for Conducting Ecosystem Valuation

- Where possible, policymakers should seek to value ecological impacts using economic valuation approaches as a means of evaluating the trade-offs involved in environmental policy choices. If the benefits and costs of an environmental policy are evaluated, it is imperative that the benefits and costs associated with changes in ecosystem services be included as well. Without this, ecosystem impacts may not be adequately acknowledged and included (i.e., they will be implicitly given a value of zero). This does not imply that economic values are the only source of value or that decisions should be based solely on a comparison of benefits and costs; other forms of value and other considerations will undoubtedly be important as well. Rather, it implies that an assessment of benefits and costs should be part of the information available to policymakers in choosing among alternatives.
- To provide meaningful input to decision-makers, it is imperative that the valuation exercise be framed properly. In particular, it should seek to value the *changes* in ecosystem services attributable to the policy change, rather than the value of an entire ecosystem.
- A valuation exercise should recognize and delineate explicitly the sources of value from the ecosystem and identify which sources are and which are not captured in the economic approach to valuation. It should acknowledge the implications of excluding sources of value that are not captured by this approach.
- For policy evaluation, it is necessary to go beyond a listing and qualitative description of the affected ecological services. Where possible, ecological impacts should be quantified. Care should be taken to ensure that the quantification reflects the complexities, nonlinearities, and dynamic nature of the ecosystem.
- Economists and ecologists should work together from the beginning to ensure that the ecological and economic models can be appropriately linked (i.e., the output from ecological modeling is in a form that can be used as an input into economic analysis). This requires that ecosystem impacts be expressed in terms of changes in the ecosystem goods and services that people value.
- The valuation exercise should seek to value those goods and services that are most important for supporting the particular policy decision. In addition, the valuation exercise should identify the subset of services for which the economic approach to valuation can be applied with relative confidence, as well as those services or sources of value that are important but for which impacts are less easily quantified and valued. For these, it is imperative to identify the sources of uncertainty relating to the understanding of the relevant ecology, the relevant economics, or the integration of the two.
- Economic valuation of ecosystem changes should be based on the comprehensive definition embodied in the total economic value (TEV; see Chapters 2 and 4) framework. Both use and nonuse values should be included.
- The scope of the valuation exercise should consider all relevant impacts and stakeholders (although in some cases considering only a subset may be sufficient). The geographic and temporal scale of the analysis should be consistent with the scale of the impacts.
- Extrapolations across space (from one ecosystem to another), time (from present impacts to future impacts), or scale (from small changes to large changes) should be scrutinized carefully to avoid extrapolation errors.

Overarching Research Needs

Although much is known about the services provided by aquatic ecosystems and methods for valuing changes in these services exist, the committee believes that there are still major gaps in knowledge that limit our ability to incorporate adequately the value of ecosystem services into policy evaluations. Drawing from the preceding major conclusions and overarching recommendations provided above, the committee has identified the following research needs. The committee believes that funding to address these needs is necessary if progress toward improving the use of ecosystem valuation in policy decisions is to be made, and it recommends that such funding be a high priority.

- Improved documentation of the potential of various aquatic ecosystems to provide goods and services and the effect of changes in ecosystem structure and functions on this provision
- Increased understanding of the effect of changes in human actions on ecosystem structure and functions
- Increased interdisciplinary training and collaborative interaction among economists and ecologists
- Development of a more explicit and detailed mapping between ecosystem services as typically conceived by ecologists and the services that people value (and hence to which economic valuation approaches or methods can be applied)
- Development of case studies that show how these links can be established and templates that can be used more generally
- Expansion of the range of ecosystem services that are valued using economic valuation techniques
- Improvements in study designs and validity tests for stated-preference methods, particularly when used to estimate nonuse values
- Development of "cutting-edge" valuation methods, such as dynamic production function approaches and general equilibrium modeling of integrated ecological-economic systems
- Improved understanding of the spatial and temporal thresholds for various ecosystems, and development of methods to assess and incorporate into valuation the uncertainties arising from the complex dynamic and nonlinear behavior of many ecosystems
- Improvements in the methods for assessing and incorporating uncertainty and irreversibility into valuation studies

Appendix A

Summary of Related NRC Reports

Report	Summary of Content Relevant to Committee's Charge
Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy (1992)	Outlines a national strategy for restoring the nation's aquatic ecosystems. The report ecosystem functions in a larger ecological landscape greatly influenced by other con hydrologic cycle, including adjacent terrestrial systems. Because existing environme fragmented, the report suggests that analysis of aquatic ecosystems should be integ larger ecological landscape, especially in the issue of restoration. It recommends th ecosystem restoration strategy be developed for the nation, which includes innovatic use of land and water markets
Assigning Economic Value to Natural Resources (1994)	Explores the major issues and controversies involved in incorporating natural resource environment into economic accounts. It also responds to the many discussions on h economic indicators, such as gross national product (GNP), reflect the state of the e accurately. The first section of the report, based largely on a three-day workshop of field, explains the possibilities and pitfalls in so-called "green" accounting. This is fo selection of nine individually authored papers on scientific aspects of related issues
Wetlands: Characteristics and Boundaries (1995)	Establishes a reference definition of wetlands, providing a standard by which regulator actions can be assessed, and recommends changes in current regulatory practices t objectivity and scientific validity. The report includes a section on functional assessn that discusses requirements and existing and future methods of wetlands functional recommends analysis of these functions with emphasis on interactions between wetl surroundings and on various classes of wetlands in a specific region
Valuing Ground Water: Economic Concepts and Approaches (1997)	Examines approaches for assessing the economic value of groundwater and the costs or depleting this resource. It also suggests a framework for policymakers and mana evaluating trade-offs when there are competing uses for groundwater. The report al number of approaches to value services of nonmarket goods—in this case, groundw unique resource and has no close substitute
Global Environmental Change: Research Pathways for the Next Decade (1999a)	Provides guidance on formulating a framework for future U.S. research on global envir The report recommends improving decisions on global change, more specifically, ho estimation of nonmarket values of environmental resources and their incorporation ir accounts. It also provides suggestions on how to bring formal analyses together with to better respond to decision-making needs

Nature's Numbers (1999b)	Recommends how to incorporate environmental and other nonmarket measures into tł and product accounts. The report explores alternative approaches to environmental including those used internationally, and addresses issues such as how to measure natural resources and how to value nonmarket activities and assets. Specific applic: minerals, forests, and clean air illustrate how the general principles can be applied
Ecological Indicators for the Nation (2000a)	Provides a framework for selecting ecological indicators that define ecological conditio along with provides recommendations on several specific indicators for gauging the i nation's ecosystems. Specifically, the report lists five indicators for ecological functic *production capacity* as a measure of the energy-capturing capacity of the terrestrial ε *net primary production*, a measure of the amount of energy and carbon that has bee ecosystem; (3) *carbon storage*, the amount sequestered or released by ecosystems; *oxygen*, an indicator of the ecological functioning of flowing-water ecosystems; and (*of lakes*, an indicator for aquatic productivity. In addition to these five indicators, soil use, and their relationship to ecosystem functioning are also discussed
Watershed Management for Potable Water Supply: Assessing the New York City Strategy (2000b)	Evaluates the New York City Watershed Memorandum of Agreement (MOA), a compr watershed management plan that allows the city to avoid filtration of its large upstate supply. Part of the report's recommendations is broadly applicable to surface water the country, target buffer zones, stormwater management, water quality monitoring, trading. The report discusses the following provisions of the MOA that are relevant t report, including: the use of setback distances to protect from nonpoint source pollut maximum daily load (TMDL) program; phosphorus offset pilot program; antidegradat water quality; land acquisition program; and comprehensive land-use planning. One recommendations is for New York City to lead efforts in quantifying the contributions management, which is difficult to quantify, to overall reduction of risk from watershed waterborne pathogens
Assessing the TMDL Approach to Water Quality Management (2001a)	Reviews the scientific basis underlying the development and implementation of the U.S Protection Agency's TMDL program for water pollution reduction. The report include decision uncertainty that discusses a broad-based approach to solve water resource to arrive at a more integrative diagnosis of the cause of degradation
Compensating for Wetland Losses Under the Clean Water Act (2001b)	Evaluates mitigation practices as a means to restore or maintain the quality of the nati the context of the Clean Water Act. The report discusses the array of approaches to associated with wetlands functional assessment in relation to the goals of "no net los

Envisioning the Agenda for Water Resources Research in the Twenty-First Century (2001c)	Discusses the future of the nation's water resources and appropriate research needed sustainable management of these resources. The report recommends developing n estimating the value of nonmarketed attributes of water resources
Riparian Areas: Functions and Strategies for Management (2002)	Examines the structures and functioning of riparian areas, including impacts of human riparian areas, the legal status, and the potential for management and restoration of report discusses the environmental services of riparian areas; that is, fundamental ec processes that riparian areas perform whether or not humans are present to take adv In terms of functions, riparian areas provide a buffering effect of pollutant removal, su biodiversity, flood peak reduction, and removal of pollutants from runoff. The report few federal statutes refer expressly to riparian values and as a consequence, genera or ensure protection of these areas. Further, it recommends that Congress enact leg recognizes the values of riparian areas and directs federal land management and re to give priority to protecting those values

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Appendix B
Household Production Function Models

This appendix discusses in more detail the modeling of household production methods of valuing aquatic ecosystem services discussed in Chapter 4.

Household production function (HPF) approaches involve some form of modeling of household behavior, based on the assumption of either a substitute or a complementary relationship between the environmental good or service and one or more marketed commodities consumed by the household. Examples of these models include allocation of time models for recreation or other activities involving household labor allocation, averting behavior models that account for the health and welfare impacts of pollution, and hedonic price models that account for the impacts of environmental quality on choice of housing.

The underlying assumption in most HPF models is that a household allocates some of its available labor time, and possibly its income, for an activity that is affected in some way by "environmental quality" (i.e., the state of the environment or the goods and services it provides). The household therefore combines its labor, environmental quality, and other goods to "produce" a good or service, but only for its own consumption and welfare (i.e., household utility). By determining how changes in environmental quality influence this household production function and thus the welfare of the household, it is possible to value these changes.

TRAVEL-COST MODELS

Assume a representative household that allocates some of its labor time l for an "environmentally" based activity from which the household derives utility. In this example, assume that this activity is recreational fishing from a mountain lake. The household could be located near the mountains, or it could be traveling from other regions or even different countries to fish in this location.

To capture the effects that this fishing activity has on the household's welfare, one assumes that the household maximizes a utility function U, representing its welfare level and consisting of

$$U = U\left(x, l^{u}, z\right), \tag{1}$$

where x represents all market-purchased consumption goods, l^u is the time the household spends on leisure, and z is the number of visits the household makes to the mountain lake for fishing. The utility function is assumed to have the normal properties of being concave with respect to its individual arguments.

The number of visits by the household is its internal "production function" for recreational fishing at the mountain lake. These visits may depend on the total time l that the household spends traveling to and fishing at the site, the various goods and services v (e.g., mode of travel, expenditures during traveling, lodging and fishing gear) that the household uses in these activities, and the overall environmental quality of the lake q that makes it particularly suitable for fishing. Thus the household's "production" of the number of fishing visits z to the mountain lake is

$$z = z(l, v; q). \tag{2}$$

Production of z is concave with respect to l and v and will shift with changes in environmental quality of the lake q.

Finally, one assumes that the household has an income based on wage earnings and uses that income to purchase all of its expenditures, including money spent on traveling to and from the lake. Given market prices p^x and p^v for commodities x and v, respectively, and representing the market wage rate earned by the household as w, the household's budget constraint is expressed as

$$p^x x + p^v v = w(L - l^u - l) + M, \tag{3}$$

with L being the total labor time available to the household and M representing any nonlabor income of the household (e.g., property rents, interest income, dividends). Equation (3) indicates that the total expenditures of the household must equal its total income.

By assuming that the household maximizes its utility from Equation (1) subject to Equations (2) and (3), one can derive the optimal demands for the time and purchased inputs, l^* and v^*, respectively, that the household spends on recreational fishing. These input demands will depend on the prices faced by the household p^x, p^v, and w, its nonlabor income level M; and the environmental quality of the lake q. By substituting l^* and v^* into Equation (2), the household's demand for the optimal number of visits z^* to the lake for recreational fishing can be expressed as

$$z^* = z(p^x, p^v, w, M; q). \tag{4}$$

Since the number of visits for recreational fishing is observable for all households that engage in this activity, the demand function in Equation (4) can be estimated empirically across households. Moreover, it is a common practice in many travel-cost models to determine whether households would vary their number of visits if any fees for recreational fishing f also changed. As a result, the aggregate recreational visit function in Equation (4) estimated across all households would represent the willingness to pay, or demand, of these households for recreational fishing visits to the lake in response to changes in the fee rate f. Changes in environmental quality of the lake would therefore cause this demand curve to "shift," and the welfare consequences, or value, of this change in environmental quality would be measured by changes in consumer surplus from this shift in the demand for fishing visits.

AVERTING BEHAVIOR MODEL

Instead of z being a desirable commodity such as recreational visits, it could alternatively be "bad," such as the incidence of waterborne disease from use of a microbially polluted aquatic system as a source of domestic water supply or for recreational activities. This implies that $\partial U / \partial z < 0$ in the utility function from Equation (1). The household may not be able to allocate its labor time to affect the incidence of the disease, but it may be able to allocate expenditures $p^v v$ that would mitigate the adverse effects of z or reduce its occurrence. For example, these could be purchases of marketed goods (e.g., bottled water, water filters, medical treatment) or payment for access to public services (e.g., improved sewage treatment or water supply). In addition, any improvements in water quality q may also mitigate the incidence of disease. As a result, Equation (2) is now modified to

$$z = z(v; q), \qquad (5)$$

where $\partial z/\partial v < 0$ and $\partial z/\partial q < 0$. By assuming that the household's allocation of its labor time is not relevant to this simplified problem, the budget constraint in Equation (3) is now

$$p^x x + p^v v = M, \qquad (6)$$

where M is total household income, including any labor income. Maximizing the utility function Equation (1) with respect to Equations (5) and (6) yields the optimal demand for any mitigating good or service purchased, v^*, as a function of prices p^x and p^v; household income M; and water quality q. By substituting latter demand for v^* into the disease incidence function of Equation (5), totally differentiating, and rearranging, one can obtain an estimable reduced form relationship between disease incidence z^* and levels of water quality q.

HEDONIC PRICE MODELS

Another possibility is that z is a desirable characteristic of certain residential property (e.g., "good" neighborhood, beautiful scenery or views, beachfront), which is in turn influenced by the services of an aquatic ecosystem (e.g., pristine environment, unpolluted water, good beaches, protected coastline). As a consequence, the market equilibrium for this residential property, and in turn its price P, will be affected by the desirable characteristic and, thus, the ecological services and environmental quality q that influences this characteristic

$$P = f(z(q)), \quad \frac{\partial f}{\partial z} > 0, \; \frac{\partial z}{\partial q} > 0. \qquad (7)$$

For a household purchasing this property, the budget constraint is likely to be

$$p^x x + P = M, \qquad (8)$$

where M is again total household income and P is the property purchase. Substituting Equation (8) and $z(q)$ into the utility function of Equation (1) for x and z, respectively; totally differentiating with respect to P and q; and rearranging yield the following condition for optimal choice of any ecological service q that affects the value of the residential property:

$$p^x \frac{\partial U / \partial z \; \partial z / \partial q}{\partial U / \partial x} = \frac{dP}{dq}. \tag{9}$$

That is, the marginal willingness to pay for an improvement in environmental quality q must equal its marginal implicit price in terms of the impact of q on property values. Estimation of the hedonic price function in Equation (7) will allow this implicit price to be calculated.

Appendix C
Production Function Models

This appendix provides technical details on the modeling of production function approaches to valuing aquatic ecosystems discussed in Chapter 4.

The general production function (PF) approach of valuing the support and protection that environmental goods and services provide economic activity consists of the following two-step procedure (Barbier, 1994):

1. The physical effects of changes in a biological resource or ecological service on an economic activity are determined.
2. The impact of these environmental changes is valued in terms of the corresponding change in marketed output of the relevant activity. In other words, the biological resource or ecological service is treated as an "input" to the economic activity, and like any other input, its value can be equated with its impact on the productivity of any marketed output.

More formally, if h is the marketed output of an economic activity, then it can be considered a function of a range of inputs:

$$h = h(E_i ... E_k, S). \tag{1}$$

For example, the ecological service of particular interest could be the role of coastal wetlands, such as marshlands or mangroves, in supporting offshore fisheries through serving as both a spawning ground and a nursery for fry. The area of coastal wetlands S may therefore have a direct influence on the marketed fish catch h, which is independent from the standard inputs of a commercial fishery $E_i ... E_k$.

There are generally two approaches currently in the literature for valuing the welfare contribution of changes in the ecological service S, which are referred to as *static* and *dynamic* approaches (Barbier, 2000). In static approaches, the welfare contribution of changes in the environmental input is determined through producer and consumer surplus measures of any corresponding changes in the one-period market equilibrium for the output h. In dynamic approaches, the ecological service is considered to affect an intertemporal, or "bioeconomic," production relationship. For example, a coastal wetland that serves as breeding and nursery habitat for fisheries could be modeled as part of the growth function of the fish stock, and any welfare impacts of a change in this habitat support function can be determined in terms of changes in the long-run equilibrium conditions of the fishery or in the harvesting path to this equilibrium.

STATIC MODELS

To illustrate a static model, the wetland habitat-fishery linkage analysis pioneered by Ellis and Fisher (1987) and Freeman (1991) is used below. Assume that in Equation (1) there is only one conventional input or that all inputs can be aggregated into one unit (e.g., fishing "effort," denoted as *E*). The commercial fishery will seek to minimize the total costs of fishing *C*:

$$C = wE, \tag{2}$$

where *w* is the unit cost of effort.

The fishery will choose the total level of effort *E* that will minimize costs in Equation (2) subject to the harvesting relationship in Equation (1). This will lead to an optimal effort level *E**, which is a function of the harvest *h* per unit cost *w* and the area of coastal wetlands that support the fishery *S* (i.e., $E^{*} = E[h, w, S]$). Substituting this relationship into Equation (2) yields the optimal cost function of the fishery:

$$C^{*} = C(h, w, S), \qquad \frac{\partial C}{\partial h} > 0, \ \frac{\partial C}{\partial S} < 0. \tag{3}$$

The change in costs as harvest changes is the standard marginal cost, or supply, curve of the fishery. It has the normal upward-sloping properties for any marketed supply; that is, the fishery faces increasing marginal costs as it supplies more harvested output to the market. However, as shown in Figure 4-1, an increase in wetland area leads to a downward shift of the supply curve. As a result, the marginal cost of supplying a given level of harvest will fall. More wetland habitat increases the abundance of fish and therefore lowers the cost of catch. Also illustrated in Figure 4-1 is that a new market equilibrium and price *P* of fish will occur, where price equals the new marginal cost (i.e., $P = \partial C/\partial h$). The welfare gains from an increase in the habitat-fishery ecological service that occurs as an increase in *S* can be measured by the increase in consumer and producer surplus in the market for fish.

Unfortunately, many fisheries are not managed optimally so that all fishermen can agree to maximize joint profits, or equivalently minimize joint profits. Most fisheries have the characteristics of *open access*. That is, any profits in the fishery will attract new entrants until all the profits disappear. Thus, in an open-access fishery, the market equilibrium for catch occurs where the total revenue of the fishery just equals cost (i.e., $Ph = C$). Combining the latter equilibrium condition with Equation (3) yields an average cost relationship:

$$P = \frac{C}{h} = c = c(h, w, S), \quad \frac{\partial c}{\partial h} > 0, \quad \frac{\partial c}{\partial S} < 0, \tag{4}$$

where *c* is the average cost of the fishery. The average costs of supplying more fish to the market are also increasing, and as shown in Figure 4-2, an increase in the wetland habitat will also lower these average costs. However, the welfare gains from an increase in this ecological service are now measured by the change in consumer surplus only. Since there are no profits in an open-access fishery, there is no producer surplus gain from the improved ecological service.

DYNAMIC MODELS

A dynamic approach adapts bioeconomic fishery models to account for the role of a coastal habitat in terms of supporting the fishery, usually by assuming that the effect of changes in habitat area is on the carrying capacity of the fish stock and thus indirectly on production. Defining X_t as the stock of fish measured in biomass units, any net change in growth of this stock over time can be represented as

$$X_{t+1} - X_t = F(X_t, S_t) - h(X_t, E_t), \quad \frac{\partial^2 F}{\partial X^2} > 0, \ \frac{\partial F}{\partial S} > 0. \tag{5}$$

Thus, net expansion in the fish stock occurs as a result of biological growth in the current period $F(X_t, S_t)$, net of any harvesting $h(X_t, E_t)$, which is a function of the stock as well as fishing effort E_t. The influence of wetland habitat area S_t as a breeding ground and nursery habitat on growth of the fish stock is assumed to be positive, $\partial F/\partial S > 0$, because an increase in mangrove area will mean more carrying capacity for the fishery and thus greater biological growth.

To simplify this analysis, it will be restricted to the open-access case. The standard assumption for an open-access fishery is that the effort in the next period will adjust in response to real profits made in the current period (Clark, 1976). Letting $p(h)$ represent landed fish price per unit harvested, w the unit cost of effort, and $\Phi > 0$ the adjustment coefficient, the fishing effort adjustment equation is

$$E_{t+1} - E_t = \phi[p(h)h(X_t, E_t) - wE_t], \quad \frac{\partial p(h)}{\partial h} < 0. \tag{6}$$

In the long run, the fishery is assumed to be in equilibrium, and both the fish stock and the effort are constant: that is, $X_{t+1} = X_t = X^A$ and $E_{t+1} = E_t = E^A$. In Equation (5), this implies that any harvesting $h(X^A, E^A)$ just offsets biological growth $F(X^A, S)$. Also, in Equation (6), all of the profits in the fishery are dissipated in the long run, that is, $p(h^A)h^A = wE^A$. The latter expression can be rearranged to solve for the steady-state fish stock X^A in terms of the equilibrium price p^A, effort E^A, and cost w (i.e., $X^A = X[p^A, E^A, w]$). Substituting for X^A in the equilibrium condition for Equation (5) yields the long-run inverse supply curve of the fishery:

$$h^A = F(X^A, S) = h(p^A, S, w), \quad \frac{\partial h}{\partial S} > 0. \tag{7}$$

For an open-access fishery, this equilibrium supply curve is backward-bending (Clark, 1976). However, since coastal wetland habitat is an argument in the growth function of the fishery, the effect of an increase in wetland area will be to shift the long-run supply curve of the fishery downward and thus raise harvest levels downward. This effect is shown in Figure 4-3, in the case of a loss of wetland area. Welfare losses can be measured by the fall in consumer surplus, which will be greater if the demand curve is more inelastic.

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Appendix D
Committee and Staff Biographical Information

Geoffrey M. Heal, *Chair*, is Paul Garrett Professor of Public Policy and Business Responsibility and professor of finance and economics at Columbia University's Graduate School of Business, and Professor of International and Public Affairs in the School of International and Public Affairs. He has also served as senior vice dean and academic director of the Columbia Business School's M.B.A Program. Previously, he was a professor of economics at the University of Sussex (U.K.). His current research focuses on economics of natural resources and the environment, economic theory and mathematical economics, and resource allocation under uncertainty. Dr. Heal is a member of the Pew Oceans Commission, a director of the Union of Concerned Scientists, and a fellow of the Econometric Society. Dr. Heal received a B.A. in physics and economics from Churchill College in Cambridge, U.K., and a Ph.D. in economics from Cambridge University.

Edward B. Barbier is the John S. Bugas Professor of Economics at the University of Wyoming. Before joining the faculty of the University of Wyoming, he was in the Environment Department, University of York, U.K. and directed the London Environmental Economics Center of the International Institute for Environment and Development and University College, London. Dr. Barbier's current research includes natural resources and economic development, economic valuation and use of wetlands, land degradation issues, trade and the environment, and biodiversity loss. He earned a B.A. in economics and political science from Yale University; an M.Sc. in economics from The London School of Economics and Political Science, U.K.; and a Ph.D. in economics from the University of London.

Kevin J. Boyle is Distinguished Maine Professor of Environmental Economics at the University of Maine. Dr. Boyle's research interests are in understanding of the public's preferences for environmental and ecological resources and responses to environmental laws and regulation. In particular, his work focuses on estimation of economic values for environmental resources that are not expressed through the market. Dr. Boyle has served as associate editor of the *Journal of Environmental Economics* and Management and the *Marine Resource Economics*. He has a B.A. in economics from the University of Maine, an M.S. in agricultural and resource economics from Oregon State University, and a Ph.D. in agricultural economics from the University of Wisconsin.

Alan P. Covich is a professor and director of the Institute of Ecology at the University of Georgia. He was previously a professor in the Department of Fishery and Wildlife Biology at Colorado State University and in the Department of Zoology at the University of Oklahoma. Dr. Covich's research focuses on ecosystem functioning in temperate and tropical streams, including assembly of food webs, predator-prey dynamics and chemical communication, and cross-site comparisons of drought impacts on drainage networks. For the past 16 years, he has conducted research in the Luquillo Experimental Forest Long Term Ecological Research (LTER) site in Puerto Rico. Dr. Covich is a past president of the North American Benthological Society and the American Institute of Biological Sciences. He has an A.B. from Washington University and an M.S. and Ph.D. in biology from Yale University.

Steven P. Gloss is the director of the U.S. Geological Survey Biological Resources Program at the Grand Canyon Monitoring and Research Center in Flagstaff, Arizona. Dr. Gloss was previously a professor of zoology and physiology at the University of Wyoming. He is a former member of the Water Science and Technology Board (WSTB), served on the National Research Council (NRC) Committee on Grand Canyon Monitoring and Research, and chaired the NRC Committee on the Missouri River Ecosystem Science. Dr. Gloss' research interests include water resources policy and management, aquatic ecology, fisheries science, and limnology. He received a B.S. in biology from Mount Union College, an M.S. in biology from South Dakota State University, and a Ph.D. in biology from the University of New Mexico.

Carlton H. Hershner, Jr., is an associate professor of marine science at the College of William and Mary and directs the Center for Coastal Resources Management at the Virginia Institute of Marine Science. His primary research interests are in tidal and nontidal wetlands ecology, landscape ecology, and resource management and policy issues. Dr. Hershner also conducts research in resource inventory procedures, habitat restoration protocols, resource management "expert system" development, and science policy interactions. He recently served as a member of the NRC Panel on Adaptive Management for Resource Stewardship. Dr. Hershner has a B.S. in biology from Bucknell University and a Ph.D. in marine science from the University of Virginia.

John P. Hoehn is a professor of environmental and natural resource economics at Michigan State University. His primary research interests include methods for valuing environmental change, economic analysis of policies and incentives for ecosystem preservation, water quality demands, and natural resource damage assessment. Dr. Hoehn received an A.B. in anthropology from the University of California, Berkeley, and an M.S. and Ph.D. in agricultural economics from the University of Kentucky.

Stephen Polasky is the Fesler-Lampert Professor of Ecological/Environmental Economics at the University of Minnesota. He has served as a senior staff economist for the President's Council of Economic Advisers and previously held faculty positions in agricultural and resource economics and economics at Oregon State University and Boston College, respectively. His research interests include biodiversity conservation and endangered species policy, integrating ecological and economic analysis, common property resources, and environmental regulation. Dr. Polasky previously served on the NRC Committee to Review the Florida Keys Carrying Capacity Study. He is currently a member of the EPA's Science Advisory Board Environmental Economics Committee. He received a B.A. from Williams College and a Ph.D. in economics from the University of Michigan.

Catherine M. Pringle is a professor at the Institute of Ecology of the University of Georgia. Her research areas are aquatic ecology, tropical ecology, conservation biology, nutrient cycling, and effects of environmental problems on the ecology of aquatic ecosystems. Her main research sites are at La Selva Biological Station in Costa Rica, the Luquillo LTER site in Puerto Rico, and the Coweeta LTER site in North Carolina. She is past president of the North American Benthological Society and chair of the Ecological Society of America's Sustainable Biosphere Initiative Advisory Committee. Dr. Pringle received her B.S. in botany from the University of Michigan and her Ph.D. in aquatic biology from the University of Michigan, Ann Arbor.

Kathleen Segerson is a professor and head of the Department of Economics at the University of Connecticut. Dr. Segerson previously held a faculty position in agricultural economics at the University of Wisconsin. Her fields of research include environmental and natural resource economics, the economic implications of environmental management techniques, and the use of economic incentives in resource policy. Dr. Segerson previously served on the NRC Committee on Causes and Management of Coastal Eutrophication and is currently a member of the EPA's Science Advisory Board Environmental Economics Committee. She received a B.A. from Dartmouth College and a Ph.D. in agricultural economics from Cornell University.

Kristin Shrader-Frechette is the O'Neill Professor of Philosophy and concurrent professor of biological sciences at the University of Notre Dame. Dr. Shader-Frechette previously held professorships at the University of Florida and the University of California, St. Barbara. Her research focuses primarily on environmental ethics and policy, quantitative risk assessment, philosophy of science, and normative ethics. She was an associate editor of *BioScience* until 2002 and is currently editor-in-chief of the Oxford University Press monograph series on Environmental Ethics and Science Policy. She is a past president of the Risk Assessment and Policy Association and current president of the International Society for Environmental Ethics. She has served on the Board on Environmental Studies and Toxicology and several NRC committees. Dr. Shader-Frechette received a B.A. in mathematics from Edgecliff College and a Ph.D. in philosophy from the University of Notre Dame. She has completed postdocs in biology, in hydrogeology, and economics.

STAFF

Mark C. Gibson is a senior program officer at the NRC's Water Science and Technology Board (WSTB) and was responsible for the completion of this report. Since joining the NRC in 1998, he has served as study director for six committees, including the Committee on Drinking Water Contaminants that released three reports, the Committee to Improve the U.S. Geological Survey National Water Quality Assessment Program, and the Committee on Indicators for Waterborne Pathogens. He is currently directing the Committee on Water Quality Improvement for the Pittsburgh Region. Mr. Gibson received his B.S. in biology from Virginia Polytechnic Institute and State University and his M.S. in environmental science and policy in biology from George Mason University.

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Ellen A. de Guzman is a research associate at the WSTB. She has worked on many NRC studies, including the Committee on Privatization of Water Services in the United States, Committee to Improve the U.S. Geological Survey National Water Quality Assessment Program, and the Committee on Drinking Water Contaminants. She co-edits the WSTB Newsletter and annual report and manages the WSTB homepage. She received her B.A. degree from the University of the Philippines.

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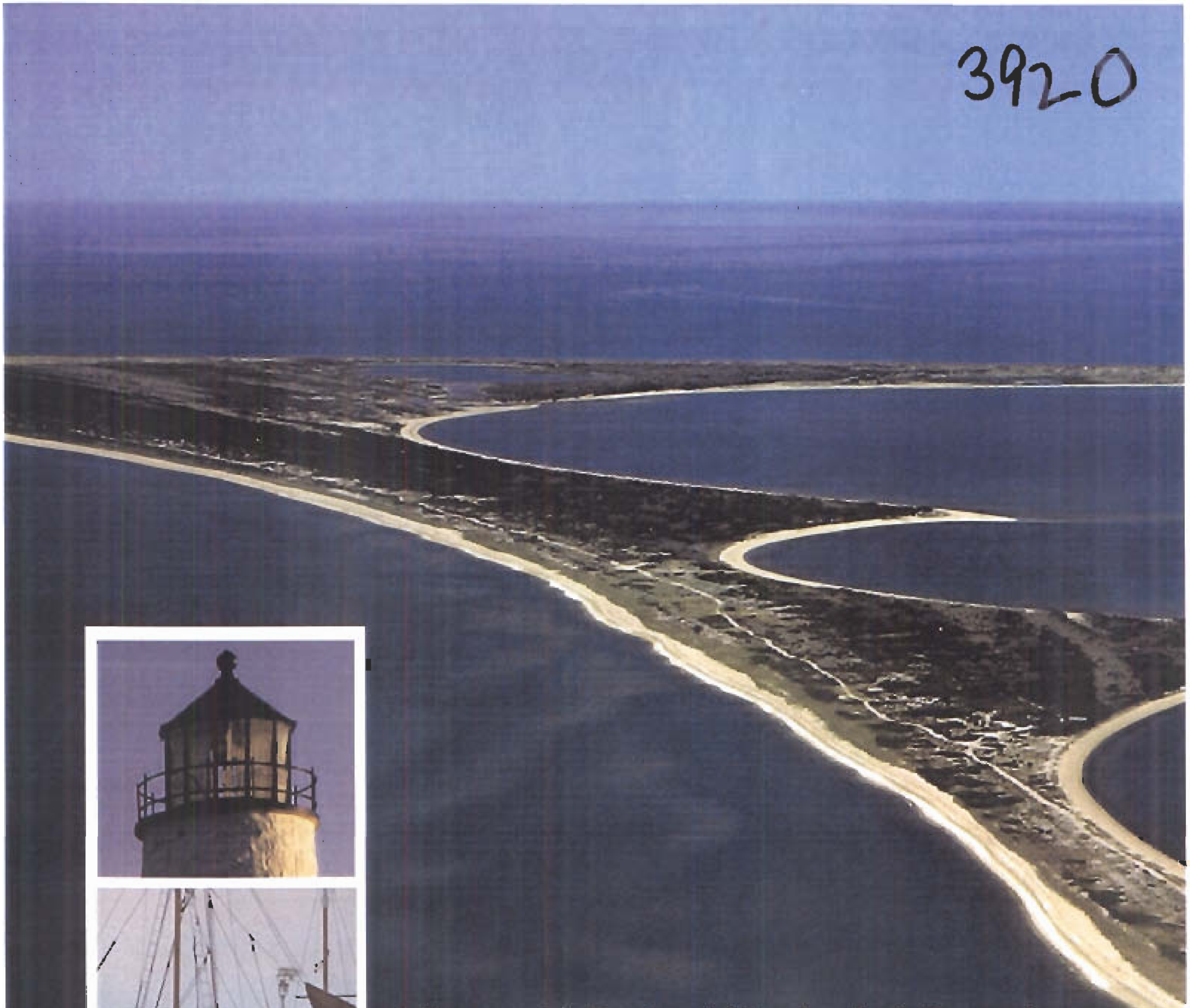

Alliance to Protect Nantucket Sound

Comments on the
U.S. Army Corps of Engineers
Draft Environmental Impact Statement
for the
Cape Wind Project

Exhibits for Volume 2

Parts 10 - 14

February 24, 2005

EXHIBITS FOR VOLUME 2 (10-14)

Exhibit No.	Description
10	Niemi, E., ECONorthwest, "Deficiencies in the Corps' Economic Analysis of the Cape Wind Project: Comments on the Draft EIS/EIR," February 2005.
11	Prepared Testimony of several speakers before the Commonwealth of Massachusetts Energy Facilities Siting Board, EFSB 02-2/D.T.E. 02-53, June 20, 2003.
12	The McGowan Group report, "A Navigational Risk Assessment Review," April 26.2004.
13	UK Department of Trade Report, "Energy White Paper – Our energy future, creating a low-carbon economy," February 2003.
14	United Kingdom, MCA, "Steps Taken to Address Navigation Safety in the Consent Regime for Establishment of Wind Farms Off the UK Coast," July 2003.

Deficiencies in the Corps' Economic Analysis of the Cape Wind Project: Comments on the Draft EIS/EIR

Prepared for

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February 2005

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On November 9, 2004, the U.S. Army Corps of Engineers, New England District (Corps) published a Draft Environmental Impact Statement /Draft Environmental Impact Report (Draft EIS/EIR) on the proposed Cape Wind energy project in Nantucket Sound, Massachusetts. The proposed project, if implemented, would result in the installation and operation of 130 offshore wind turbines to generate electricity on 24 square miles of federal lands approximately 4 miles from Yarmouth, 11 miles from Nantucket, and 5.5 miles from Martha■s Vineyard. The purpose of the Draft EIS/EIR ■is to assess the environmental impacts,■ including the economic impacts of the proposed project.

The Alliance to Protect Nantucket Sound asked ECONorthwest to determine if the Draft EIS/EIR fully and accurately describes the potential economic impacts of the proposed project in a manner consistent with the professional, analytical standards commonly applied to the underlying economic issues. This report responds to that request. Our findings will be submitted as comments on the Draft EIS/EIR to the Corps, which we expect will consider them as it prepares its final analysis of the proposed project. This report summarizes the results of our analysis to date. As we review additional information we may revise our opinions, add additional opinions, or both.

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II. SUMMARY OF FINDINGS AND COMMENTS

Before issuing a permit for the proposed Cape Wind project (Project), the Corps has an obligation to demonstrate, with reasonable certainty, that its benefits outweigh its costs. To some, this is a foregone conclusion. They see that electricity from the Project's wind-powered generators would necessarily displace electricity from generators that burn fossil fuel, resulting in reduced emissions of carbon dioxide, which scientists have associated with global climate change, as well as in healthier lives for families no longer exposed to other, harmful, pollutants from fuel-burning generators.

Closer examination reveals, however, that many of these benefits probably would not materialize. Instead of displacing electricity generated from fossil fuels, for example, the Project probably would displace electricity from other renewable sources of energy. Moreover, whatever the project's benefits, they would not come free-of-charge. The generators, themselves, will be expensive to build and costly to operate. And, as they do some good things for the environment and for communities, they will do some harmful things as well. The Project's costs are sufficiently large and diverse that one cannot conclude that its benefits outweigh its costs, or vice versa, without a thorough analysis, taking into account all relevant factors.

The Corps has acknowledged (p. 7-3) its obligation to provide such an accounting and to demonstrate that issuing the permit would be in the public interest. To satisfy this obligation, it must balance "the benefit which may reasonably accrue from the proposal against its reasonably foreseeable detriments" giving consideration to "[a]ll factors which may be relevant."

The Corps has failed to satisfy its obligation. Major deficiencies in five general areas cause the Draft EIS/EIR to give an incomplete and inaccurate picture of the Project's reasonably foreseeable benefits and costs. Table 1 summarizes these deficiencies, steps the Corps must take to correct them deficiencies, and the anticipated consequences of doing so. The available evidence suggests that, if the Corps were to account fully for all relevant factors, its analysis would show that the Project's economic costs exceed its benefits.

We emphasize that these findings are specific to this Draft EIS/EIR and the particular configuration, location, timing, and economic context of the Cape wind project. The findings should not be used to draw general inferences regarding the benefits and costs of other wind projects or of projects using renewable-energy sources other than wind. Indeed, an important lesson to be drawn from our review of the Draft EIS/EIR is that the details—configuration, location, timing, and economic context—of an electricity-generating facility should not be set aside when evaluating, from an economics perspective, whether or not the facility is in the public interest.

Table 1. Summary of Findings: Major Deficiencies in the Corps' Analysis, Recommended Corrections, and Anticipated Consequences

Element of Analysis	Deficiency in Corps' Analysis	Recommended Correction	Anticipated Consequence
Deficiencies in analytical framework and failure to consider all relevant factors			
Analytical framework	Corps ignored federal *Principles & Guidelines* for economic analysis of decisions affecting water and land resources, the agency's own economic manuals, and guidance provided by others.	Conduct analysis consistent with commonly applied professional standards. Apply *Principles & Guidelines* and other applicable guidance.	Corps will show all relevant economic information re the Project's relationship to the public interest, calculate the Project's net economic benefits (or net economic costs), and fully describe economic risks.
Deficiencies in the analysis of the project's economic benefits			
Electricity benefits	Corps assumed Project would compete in open market, displace electricity from fossil-fuel-fired generators, and reduce price consumers' pay for electricity.	Recognize the Project probably would compete in a niche market and displace electricity from other renewable resources, not from fossil-fuel-fired generators. Impacts on consumers' payments for electricity would be limited.	Calculation of benefits will fall from $25 million per year to near zero.
Human-health benefits	Corps assumed Project would displace emissions of harmful pollutants from fossil-fuel-fired generators and, hence, improve air quality and lower pollution-related sickness. Calculated monetary savings from improved health using data that are out of date or otherwise inappropriate.	Recognize the Project probably would not displace electricity from fossil-fuel-fired generators. Even if it did, cap-and-trade systems mean any reduction in emissions of SO_2 and NO_x would be offset by increases elsewhere, with no net improvement in regional air quality. Reduced emissions of particulates, if any, could improve air quality and reduce related sickness.	Calculation of human-health benefits will fall from $53 million per year to a much smaller number. Benefits would come from reductions, if any, in particulate emissions, and from possible reductions in the cost of meeting SO_2 and NO_x targets.
Greenhouse-gas benefits	Corps did not calculate these benefits, but implicitly assumed they would exist, as it assumed the Project would displace emissions of CO_2 from fossil-fuel-fired generators.	Recognize the Project probably would not displace electricity from fossil-fuel-fired generators. Further analysis required to determine impacts if it displaced other renewables.	Greenhouse-gas benefits will be much smaller than what is implicit in the Corps' analysis.
Deficiencies in the analysis of the project's direct economic costs			
Direct Project costs	Corps disregarded evidence regarding decommissioning costs, and did not estimate costs of occupying public lands and waters.	Consider the full costs of public lands and waters occupied by the Project. Consider all relevant evidence regarding decommissioning costs	Calculation of direct Project costs will increase. Decommissioning costs of $6 million may rise 2-5 times, or more. The value of public resources occupied by the Project will increase from zero.

Table 1, cont. Summary of Findings: Major Deficiencies in the Corps' Analysis, Recommended Corrections, and Anticipated Consequences

Element of Analysis	Deficiency in Corps' Analysis	Recommended Correction	Anticipated Consequence
Deficiencies in the analysis of the costs the Project would impose on others			
Costs imposed on commercial fishing industry	Corps assumes that spacing of turbines would be wide enough that they would not interfere with commercial fishing.	Consider all relevant evidence, including statements from fishermen about the risks of fishing among the structures and the fact that fishing is commonly restricted near wind turbines in Europe.	Calculation of costs will increase to reflect hazardous conditions, or the lost net output if fishing should be restricted.
Costs imposed on recreationists & tourists	Corps considered only evidence favorable to the Project and concluded there would be no adverse impact.	Consider all relevant evidence, which shows potential negative impact on recreationists & tourists. Calculate economic loss to them.	Calculation of costs will show potential annual losses are not trivial.
Costs imposed on property owners	Corps considered only evidence favorable to the Project and concluded there would be no adverse impact.	Consider all relevant evidence, which shows the Project may have a negative impact on property values. Calculate economic loss.	Calculation of costs will show potential annual losses are not trivial.
Negative impacts on the ecosystem's intrinsic value.	Corps has not considered these costs. Evidence indicates these costs may be non-trivial.	Evaluate the Project's potential negative impacts on the ecosystem's intrinsic value.	Calculation of costs will show potential annual losses are not trivial.
Jeopardy to state, local, and private investments in the ecosystem	Corps has not considered these costs. MA has long recommended a ban on industrialization of this area. Investments in the ecosystem are substantial.	Evaluate the Project's potential negative impacts on state, local and private investments.	Calculation of costs will show potential annual losses are not trivial.
Deficiencies in the analysis of the economic risks associated with the Project			
Economic risk associated with the Project	Corps has not considered the economic consequences if something should go wrong.	Evaluate financial risks borne by Project Sponsor, including risks of technological failure, major accidents, and reduction in governmental support. Evaluate economic value of ecological risks, including risks of major accidents, such as oil spills, potential bird kills, and ecological consequences of noise, vibration, and electromagnetic fields.	Analysis of risks will show potential costs are not trivial.
Economic costs associated with navigational hazards	Without considering all the relevant evidence, the Corps concluded the Project would not induce an accident or worsen the consequences of any accident induced by other factors.	Evaluate all relevant evidence, including potentially applicable hazard-management standards that might restrict vessel travel.	Calculation of costs will show the costs of potential accidents, should they occur, and the costs of restricting traffic in the vicinity.

III. DEFICIENCIES IN THE CORPS' ANALYTICAL FRAMEWORK AND FAILURE TO CONSIDER ALL RELEVANT FACTORS

Table 2 identifies major deficiencies in the Corps framework for analyzing the Project's economic effects and determining if its economic benefits outweigh its economic costs. These deficiencies originate with the Corps failure, at the inception of its analysis, to define appropriate standards applicable to the task and to develop analytical methods, evaluative criteria consistent with the standards. The absence of an appropriate analytical framework contributes to the Corps failure to consider all the relevant factors regarding the Project's economic effects.

A. LACK OF AN ANALYTICAL FRAMEWORK CONSISTENT WITH PROFESSIONAL STANDARDS

The most fundamental deficiency in the Corps economic analysis is the total absence of any analytical framework whatsoever. The bulk of the Corps economic analysis consists of two studies, prepared by contractors for the Project Sponsor, that address issues of concern to it: the amount it would receive for the electricity it generates and the Project's positive impacts on jobs, incomes, and the like (Appendices 5.16-A and 5.16-B). To these, the Corps has added a modest amount of additional work that generally has a similar focus, looking at the Project with a primary concern for the Project's economic viability for the Project Sponsor rather than for whether or not the Project is in the public interest.

For example, in section 3.4.3.3.2 Economic Analysis the Corps considers five variables that it asserts determine the economic viability of an alternative site: (1) the Sponsor's capital cost of constructing the facility; (2) the installed capacity of the proposed facility built by the Sponsor; (3) the wind regime at the site; (4) the net power production; and (5) the Sponsor's operation and maintenance costs. These variables, in effect, define Economic Analysis from the perspective of Project Sponsor's interest rather than the general public interest. This section does not contain any discussion of the Project's economic effects on the general public interest.

Indeed, the Corps never builds the foundation essential to any reliable economic analysis. Nowhere does it define what the public interest is with respect to the Project's economic effects or state the evaluative criteria appropriate for deciding if the Project is in, or not in, the public interest. Nor does it describe the professional standards for developing reliable information to which the evaluative criteria can be applied. Absent this foundation, it is impossible to develop and the Corps analysis lacks an analytical framework aimed at providing results to which the evaluative criteria can be applied and a decision justified.

Table 2. Summary of Deficiencies in the Corps' Analytical Framework and Its Failure to Consider All Relevant Factors

Analytical Component	Deficiency
Overall framework consistent with commonly accepted professional standards	Missing
Definition of the public interest regarding the Project's economic effects	Missing
Definition of a criterion for deciding if the Project's benefits outweigh its costs	Missing
Definition of conceptual basis for identifying and measuring the Project's benefits and costs consistent with the criterion	Missing
Framework for analysis of the project's externalities	Missing
Framework for analysis of the non-market goods and services affected by the Project	Missing
Framework for economic analysis of the Project's impacts on the ecosystem of Nantucket Sound	Missing
Framework for analysis of future economic and ecological conditions	Missing
Framework for analysis of the economic risks associated with the Project	Missing
Consideration of all relevant economic factors regarding the Project's economic effects	Missing
The economic benefits and costs for the Project Sponsor	Incomplete
The Project's economic externalties: the costs it will impose on others	Incomplete
The Project's effects on economic value of non-market goods and services	Missing
The economic values of the Project's effects on the ecosystem of Nantucket Sound	Missing
Foreseeable changes in the Project's benefits relative to its costs	Missing
Economic risks associated with the Project	Missing
Calculation of national benefits and costs	Missing
Calculation of benefit-to-cost ratio	Missing

The Corps failure to build this foundation stands in stark contrast with common practice elsewhere in the Corps, elsewhere in the federal government, and within the general economics profession. Most immediately, it deviates from the common practice of the Corps. Since 1983, economic analyses by the Corps of Engineers have generally been guided by a document entitled *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies.*[1] Together

[1] U.S. Water Resources Council. 1983. *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies.* March 10.

with implementation manuals developed by the Corps, the *Principles and Guidelines* defines the economic components of the public interest with respect to the decisions of federal agencies regarding the management of the nation's waters and lands:[2]

> "The federal objective of water and related land resources planning is to contribute to national economic development consistent with protecting the Nation's environment, pursuant to national environmental statutes, applicable executive orders, and other Federal planning requirements." (p. 1)

The *Principles and Guidelines* also defines the primary evaluative criterion for deciding if a federal decision regarding the management of the nation's waters and lands are in the public interest:

> "Four accounts are established to facilitate evaluation and display of effects of alternative plans. The national economic development account is required. ... The national economic development (NED) account displays changes in the economic value of the national output of goods and services." (p. v.)[3]

> "The NED account is the only required account. The NED account describes that part of the NEPA environment, as defined in 40 CFR 1508.14, that identifies beneficial and adverse effects on the economy." (p. 8)

To complete a reasonably accurate NED account, the Corps must provide a full accounting of costs and benefits stemming from the Project, including those that would accrue to parties other than the Project Sponsor. This obligation is recognized clearly in the Corps' manual governing NED analyses.

> "Many economic activities provide incidental benefits to people for whom they were not intended. Other activities indiscriminately impose incidental costs on others. These effects are called externalities. ... **Negative externalities** make someone worse off without that person being compensated for the negative effect. ... *The NED principle requires that externalities be accounted for in order to assure efficient allocation of resources.*"[4]

The *Principles and Guidelines* also requires the Corps not to limit its analysis to goods and services for which there are market prices. Where market prices

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[2] The scope of the applicability of the Principles and Guidelines is expressed in this statement: "These Guidelines establish standards and procedures for use by Federal agencies in formulating and evaluating alternatives plans for water and land resources implementation studies." (p. 1)

[3] The *Principles and Guidelines* clearly distinguishes the NED criterion from other effects, which are addressed in three other analytical accounts: impacts on jobs, incomes, and the revenues of local governments; nonmonetary measures of changes in environmental quality; and other social effects.

[4] U.S. Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources. 1991. *National Economic Development Procedures Manual: Overview Manual for Conducting National Economic Development Analysis.* IWR Report 91-R-11. October. pp. 21-23 (bold emphasis in original, italics emphasis added). A copy of this agency guidance document is available in the record at Corps AR Doc. 305 (C17684 - C17773) at C17713 – C17715.

do not reflect the full value of a resource to society, then the Corps must estimate this value using appropriate non-price data and methods.[5]

Furthermore, under the analytical standards set by the *Principles and Guidelines* the Corps has an obligation to give a full accounting of the Project's economic risks and uncertainties. As one analyst, in a report to the Corps observed, "Risk analysis is encouraged by regulation and guidance as a 'way of doing business' within the Corps ."[6] The accounting for risks and uncertainties should be broad, rather than narrow, in accordance with the guidance expressed by the agency's own manual on the analysis of risk and uncertainty: "It is the analyst's job to identify, clarify, and quantify areas of risk and uncertainty *wherever possible*, especially for those pieces of information which have a substantial influence on either the choice of an alternative and/or its size and cost."[7]

The *Principles and Guidelines* also define specific analytical procedures. Among them is the requirement for conducting an economic analysis by looking to the future. The Corps should forecast future economic conditions under two scenarios: one with a proposed action and one without it. The forecast of conditions without the proposed action is called the baseline:

> "The forecasts of with- and without-plan conditions should use the inventory of existing conditions as the baseline, and should be based on consideration of the following (including direct, indirect, and cumulative effects)." (p. 4)

The Draft EIS/EIR does not comply with the *Principles and Guidelines*. It does not analyze the Project using the NED account, nor does it look at the Project's impacts on the national economy. It does not analyze the project's externalities, nor does it analyze the Project's impacts on the value of goods and services, such as recreational opportunities, aesthetics, and birds, that do not have market prices. It does not look to the future using a with-vs.-without analytical framework. That is, it does not forecast the baseline values of future goods and services that would exist in the national economy absent the Project, compare this against a forecast of the values that would exist with the Project, and measure the difference between the two scenarios. It does not account for risks and uncertainties associated with the Project.

The Draft EIS/EIR also does not comply with analytical standards established by others. For example, it deviates widely from standards established by the Environmental Protection Agency and by a recent report of

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[5] "If market prices reflect the full economic value of a resource to society, they are to be used to determine NED costs. If market prices do not reflect these values, then an estimate of the other direct costs should be included in the NED costs." *Principles and Guidelines*, p. 10.

[6] Males, R.M. 2002. *Beyond Expected Value: Making Decisions Under Risk and Uncertainty*. Submitted to U.S. Army Corps of Engineers, Institute for Water Resources. September. p. ix.

[7] U.S. Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources. 1991. *Guidelines for Risk and Uncertainty Analysis in Water Resources Planning*. IWR Report 92-R-1. October, p. 17 (italics emphasis added). A copy of this agency guidance document is included in the record at Corps AR Doc. 305 (C17774 - C17943) at C17798).

the National Research Council.[8] These standards make it clear that, to assess the economic effects of decisions with significant consequences for an ecosystem, the Corps must consider the full set of economic consequences associated with the Projectªs impacts on the ecosystem, shown in Table 3. This analytical framework requires that the Corps consider the Projectªs impacts on direct use values, such as the value of the electricity generated, plus the indirect-use values, such as the value of recreation, plus the non-use values, such as the bequest value some place on passing Nantucket Sound to the next generation in an unindustrialized status.

Table 3. Classification and Examples of Total Economic Values for Aquatic[a] Ecosystem Services

Use Values		Nonuse Values
Direct	**Indirect**	**Existence and Bequest Values**
Commercial and recreational fishing	Nutrient retention and cycling	Cultural heritage
Aquaculture	Flood control	Resources for future generations
Transportation	Storm protection	Existence of charismatic species
Wild resources	Habitat function	Existence of wild places
Potable water	Shoreline and river bank stabilization	
Recreation		
Genetic material		
Scientific and educational opportunities		

Source: National Research Council. 2004. *Valuing Ecosystem Services: Toward Better Environmental Decision-Making.*

[a] Freshwater and marine.

B. FAILURE TO CONSIDER ALL RELEVANT FACTORS

Because the Corps failed to provide an appropriate framework for analyzing the Projectªs economic effects, the economic elements of the Draft EIS/EIR

[8] U.S. Environmental Protection Agency. 2000. *Guidelines for Preparing Economic Analyses.* September; and National Research Council, Committee on Assessing and Valuing the Services of Aquatic and Related Terrestrial Ecosystems. 2004. *Valuing Ecosystem Resources: Toward Better Environmental Decision-Making.* National Academies Press.

wander aimlessly, ignoring many relevant factors. In the end, the economic analysis never produces analytical results one can use to conclude, with reasonable certainty, that the Project's economic benefits will exceed its costs.

Nowhere in the Draft EIS/EIR does the Corps consider, let alone comply with, the analytical standards established by the Corps, itself, or by the EPA and the National Research Council's recent report. Instead, it provides a motley assortment of incomplete information, mixing together monetary values and jobs; evaluating alternative sites primarily in terms of the implications for the Project Sponsor's economic viability; and never providing a coherent assessment of the Project's economic effects on the public interest.

Nowhere does the Corps consider the public interest, defined in terms of the Project's effects on the national output of goods and services, and describe appropriate standards, evaluative criteria, and analytical methods for measuring these effects.[9]

Nowhere does the Corps consider and measure the value of the Project's negative externalities, including costs related to non-market goods and services, using all relevant information and facts. Indeed, the economic sections of the Draft EIS/EIR do not include the term, "non-market" at all, and they include the term, "externalities" only once (p. 5-275), in a reference to a European study that examined the externalities of a wind farm in Denmark. The Corps overlooked evidence contrary to the Project Sponsor's position, that there are no significant negative externalities or negative impacts on non-market goods and services.

Nowhere does the Corps analyze the economic values of the Project's effects on the ecosystem of Nantucket Sound. For example, it never estimates:

- The value of the publicly-owned seabed that the Project would occupy.
- The value of birds that would be killed by the 130 turbines.
- The value of the ecological damage that could result if the turbines were to spill oil into Nantucket Sound.
- The reduction in the intrinsic values— what economists call existence and bequest values— of the Nantucket Sound ecosystem that might result from the Project.

Nowhere does the Corps take a realistic look into the future and consider how the Project's benefits and costs might change relative to one another. In particular, it does not consider the future value of the Project's electricity, for

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[9] The Draft EIS/EIR does have a section labeled "5.16.4.4.4 Economic Benefits at the National Level" (p. 5-274). This section consists of a single paragraph that reports an assessment by the U.S. Department of Energy that is at odds with common principles of economic analysis. For example, it is standard practice when analyzing the benefits and costs of a project, such as this one, to consider the initial capital investment as a cost intended to increase the subsequent output of goods and services, which are considered benefits. The DOE, however, turns this reasoning on its head and counts the Project Sponsor's initial investment, about $500 million, as a benefit, not a cost. It also assumes that the Project would occur during "a slow economic period" implying that, absent the Project, there would be no other opportunity for investing the $500 million. This assumption contradicts standard analytical practice, as reflected (p. 5) in the *Principles and Guidelines*: "National projections used in planning are to be based on a full employment economy." It also is inconsistent with current economic conditions, as reported (p. 5-262) by the Corps: "The NSA unemployment rate in the Islands Workforce Area in June 2003 was 3.7% — well below the Massachusetts and US NSA unemployment rates of 5.7% and 6.5%."

which there probably will be substitutes, relative to the future value of other goods and services, for which there probably will be no substitutes. For example, it has not considered the growth in:

- The future value of the aesthetics associated with a non-industrialized Nantucket Sound.
- The future value of seafood.
- The existence and bequest value of the ecosystem that includes Nantucket Sound.

Nowhere does the Corps consider and quantify, consistent with professional standards, the economic costs that could materialize if things go wrong. For example, it never estimates:

- The economic consequences if the Project Sponsor should go bankrupt.
- The value of the reduction in the output of the commercial fishing industry if, contrary to the Corps' assumption, the 130 wind-turbine structures impede fishing activities.
- The economic consequences if the 130 wind-turbine generators should experience systemic technological failure, as has occurred with wind-turbine generators elsewhere, for example, at Horns Rev, in Denmark.
- The economic consequences if the Project should cause or contribute to an accident involving one or more recreational boats, commercial fishing boats, and/or larger vessels.
- The value of the economic harm that would materialize if the Project's impacts on recreation, tourism, and property values in the area should prove significantly more negative than the Corps has assumed.
- The value of the economic harm that would materialize if the risk that the Project would have negative ecological impacts, such as bird kills, than the Corps has assumed.

IV. DEFICIENCIES IN THE CORPS' ANALYSIS OF THE PROJECT'S ECONOMIC BENEFITS

Table 4 lists deficiencies in the Corps analysis of the Projects potential economic benefits. Three of these potential benefits stem from the anticipated operation of the Projects wind-turbine generators: the Corps anticipates the generators would produce electricity, displacing electricity that otherwise would have been produced by fuel-burning generators at a higher price for consumers. The Corps also anticipates that its impacts on fuel-burning generators would result in lower regional emissions of pollutants harmful to human health and of carbon dioxide, a greenhouse gas. The fourth potential benefit relates to potential increases in jobs, incomes, and taxes.

Table 4. Summary of Deficiencies in the Corps' Analysis of Potential Economic Benefits

Component of Analysis	Deficiency
Value of electricity	Analysis is based on unsubstantiated assumptions
Value of human-health impacts if the Project displaces fuel-burning generators	Analysis is based on unsubstantiated assumptions
Value of forgone carbon emissions if the Project displaces fuel-burning generators	Analysis is based on unsubstantiated assumptions
Positive impacts on jobs, earnings, taxes	Analysis fails to account for offsetting negative impacts

The Corps analysis of these benefits, however, is deficient and does not provide a reliable description of the benefits that, with reasonable certainty, would materialize if and only if the Project were implemented. Instead, it looks at goods and services that would exist if the Project were implemented and attributes these to the Project, without first determining if they also would exist if the Project were not implemented. Our review indicates it is reasonable to assume that most of these goods and services would exist, with or without the Project, and, hence, it is incorrect to classify their value as the Projects benefits. Our review also indicates the Project probably would have adverse impacts that the Corps overlooked.

We first describe the deficiencies in the Corps analysis of the potential benefits related to the Projects production of electricity and its impacts on the regional electricity system. We then describe the deficiencies in its analysis of jobs and similar, potential benefits.

A. DEFICIENCIES IN THE ANALYSIS OF ELECTRICITY-RELATED BENEFITS

To measure the Project's impacts on the electricity system, the Corps relies on a study prepared for the Project Sponsor by a consulting firm, La Capra Associates (La Capra).[10] The La Capra study reached these conclusions:

"La Capra believes that the Cape Wind Project will:

1) Reduce market clearing prices, resulting in savings to the market on the order of $25 million annually;
2) Displace emissions from approximately one percent of present NEPOOL fossil fuel generation;
3) Improve reliability of the regional electricity system by increasing the total electricity supply;
4) Help meet requirements for significant new renewable generation in New England, particularly in Massachusetts and Connecticut; and
5) Diversify the region's electricity mix in terms of fuel supply and generating technology." (p. 1)

Underlying these conclusions lie several, important assumptions that, on inspection, are seen to be unsubstantiated and unreasonable. First and foremost, the Corps assumes the Project would displace electricity that otherwise would be generated by burning fossil fuels.

"Energy produced by the Cape Wind Project will displace an equivalent amount of energy from the next available, more expensive fossil fuel fired unit(s) ..." (p. 5-267)

In other words, the Corps assumes that, without the Project, fossil-fuel-burning generators would generate electricity but, with the Project, they would not. Based on this assumption, the Corps attribute to the Project the set of economic benefits identified by La Capra: savings of $25 million per year for electricity consumers; reduced emissions; improved reliability of the electricity system; help meeting the renewable-generation requirements of Massachusetts and Connecticut; and diversification of the region's mix of electricity generators.

The Corps, however, did not go far enough in its investigation of this assumption. It did not look to see if these same benefits, more or less, would exist even if the Project were not implemented. If they would, then the Corps erred in attributing these benefits to the Project. Moreover, rather than displacing electricity from generators burning fossil fuels, the Project would displace electricity from other, renewable sources.

To reach its conclusion that the Project would displace electricity from fossil-fuel-burning generators the Corps (relying on La Capra's study) simulated the operation of the regional electricity markets and assumed the electricity generated by the Project would compete openly in these markets.[11] In reality,

[10] Cory, K.S. and D.C. Smith. 2003. "La Capra Analysis of Cape Wind Project. Memorandum to Mitchell Jacobs and Craig Olmstead, Cape Wind Associates/EMI, January 10. (Appendix 5.16-B of Draft EIS/EIR).

[11] It is not apparent, however, that the Corps (and La Capra) fully considered the Project's overall impact. A recent review of the performance of wind farms in the U.K. found that the impact has been less favorable than

however, electricity from the Project would not compete in the overall, open market, but in a niche, submarket market created by Massachusetts.

Under the state's Renewable Portfolio Standards (RPS), a fixed portion of electricity sold within Massachusetts must come from renewable sources, such as wind, biomass, or the gas from landfills.[12] This requirement creates a niche market for renewably-generated electricity. The niche market is somewhat distinct from the overall electricity market in that only renewable energy sources can be used to meet this requirement. Also, the pricing of electricity generated within this niche market is different from the pricing of electricity generated outside it, insofar producers within the niche can negotiate different terms with retail suppliers of electricity required to have a specific percentage of electricity generated from within the niche.

Since the share of renewable energy is mandated by law, the Corps' analysis should have evaluated the Project's economic benefits looking at its impacts on the niche market rather than its impacts in the larger overall market. In this context, the appropriate question is not, What electricity generator would the Project displace in the overall, open market? but What electricity generator would the Project displace in the renewable-energy market niche?

The analysis by La Capra Associate describes the niche market for renewably-generated electricity created by the region's RPS and notes the Project's probable participation in this market:

> "The renewable attributes of the Cape Wind project are needed to satisfy the requirements for renewable attributes in New England. Massachusetts and Connecticut have renewable portfolio standards ... requiring parties supplying retail load in each state to purchase a percentage of that load from new renewable suppliers. Wind is an eligible 'new' renewable technology in both states." (p. 5)

The La Capra analysis also indicates that the predicted supply of electricity from renewable energy sources (including the Project) is significantly less than that required by the RPS mandate:

> "We estimate that in order to meet the Massachusetts requirement energy production of at least 1,394 GWh per year will be needed from qualifying new renewable facilities by 2006, and about 2,386 GWh per year will be needed by 2009. These energy requirements translate to all-hours, average new renewable production of about 159 MW in 2006 and about 272 MW in 2009. At present, the amount of qualified, new renewable energy project in operation or in construction is clearly insufficient to meet this requirement." (p. 5)

In another analysis that focuses solely on describing the niche market, however, La Capra Associates provided information that contradicts these statements.[13] Information in this other study supports the conclusion that, if

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anticipated, as the unpredictable nature of wind requires that wind farms be backed-up by inefficient operation of coal-burning generators. The result is that the total cost of a dependable supply of electricity is higher than with other alternatives. Royal Academy of Engineering. 2004. *The Cost of Generating Electricity*. March.

[12] Connecticut also has established Renewable Portfolio Standards, and other states in the region are considering similar actions. To facilitate the discussion, we focus on Massachusetts.

[13] Smith, D.C., K.S. Cory, and R.C. Grace. 2000. *Massachusetts Renewable Portfolio Standard: Cost Analysis Report"*. La Capra Associates for the Massachusetts Division of Energy Resources. December 21.

it were implemented, the Project would displace electricity from renewable energy, within the niche market, rather than electricity from fossil fuels in the larger, overall electricity market. In its study of the niche market in New England for electricity generated from renewable sources of energy, La Capra found that:

> "We constructed high and low supply scenarios for existing renewables based on alternative assumptions regarding the retirement of exiting renewable plants in New England, and potential renewable imports from neighboring regions. ... Based on our analysis, the supply of existing renewables exceeds the demand throughout the horizon in the high supply [scenario] and for about ten years in the low supply [scenario]." (p. 8)
>
> "[I]t appears that sufficient new renewables will be available to retail suppliers for meeting PRS obligations, provided that suppliers promptly commit to purchases with sufficient lead-time for development and construction to occur ...." (p. 13)
>
> "[W]ith respect to existing renewables ... the projected supply of existing renewable generation in New England and its neighbors (New York, Quebec, and New Brunswick) greatly exceeds potential demand in New England and New York." (p. 15)

The La Capra study also predicted that generation from land-fill gas and biomass would be developed before generation from wind, because of lower costs and shorter development times. It predicted (p. 31) that electricity from wind would not be available until 2006, and that wind's share of total production from renewable sources in the niche market would range from 23.9 percent in 2006 to 31.2 percent in 2012. Furthermore, it predicted (p. 23) that electricity from wind initially would come from generators in New York and Quebec, rather from within the New England states, where the barriers to development would be higher.

Taken together, this information indicates that the Project's greatest impact on the electricity system probably would not be to displace electricity from a fossil-fuel-burning generator but to displace electricity derived from one or more, alternative renewable sources. It might displace electricity from another wind generator, perhaps, or from generators fueled by land-fill gas or biomass.

Here's the same conclusion, stated differently: by adopting its RPS, Massachusetts has ensured that electricity from renewable sources of energy will have a niche in the electricity system and displace electricity from fossil-fuels. If the La Capra study of the niche market is correct, there is no shortage of options for filling the niche. If the Project does not fill part of the niche some other renewable source(s) of electricity will do so. Hence, if the Project were to elbow in, it would displace some other renewable source of electricity. This displaced renewable source of electricity might have costs that are higher or lower than the Project's. It is impossible to tell from the La Capra studies or the Corps' analysis. If the Project were to displace electricity from a renewable source with lower costs, then, rather than increasing the net value of the electricity in the niche market, it would decrease the value.

If the Project were to displace another, renewable source of electricity rather than electricity derived from fossil fuels, then the Corps' estimates regarding all of the Project's electricity-related benefits are way off-target. The Project would not yield "savings to the market on the order of $25 million annually." Instead, it might yield no savings at all or it might even increase consumers' costs. If the Project were to displace another, renewable source of electricity rather than electricity derived from fossil fuels, then the Project would not yield the emissions-related benefits— for reductions in emissions harmful to human health or for reductions in emissions of greenhouse gases— reported by the Corps.

The Corps' analysis does not investigate the niche, renewable-energy market created by RPS mandates, the Project's competitive position in this niche market, or the net benefits (or net costs) that would result from the Project's economic impacts on other competitors in this niche market.[14] The Corps also does not consider the possibility that, even if the Project were to displace electricity from a fossil-fuel-burning generator, the human-health benefits might not materialize on a national level. This outcome seems likely, insofar as cap-and-trade programs for SO2 and NOx would allow any reduction in emissions resulting from the Project to be offset by increased emissions elsewhere, until total regional and national emissions are at the maximum allowed by each cap.

The Draft EIS/EIR discussed none of these issues. Instead, the Corps' analysis assumed the project would compete in the region's overall, electricity market rather than in a niche market for renewable energy. Even if this assumption were correct, evidence indicates the Corps overstated the amount of pollution that the Project would displace, insofar as it also assumed production from the Project would displace electricity from the dirtiest power plants in New England, Salem Harbor or Brayton Point, with emissions at past levels. Analysis by the Beacon Hill Institute, however, indicates that, if the project competed in the overall electricity market, its production would displace electricity from other plants with much lower emission rates.[15] The specific facility (or facilities) that would be displaced must still be determined, but the analysis by the Beacon Hill Institute indicates that, if the Project were to displace the "marginal producer in the grid" rather than Salem Harbor or Brayton Point, then adjusting the Corps' analysis to reflect this shift would lower the Project's health-related benefits from \$53 million to \$7 million per year.[16]

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[14] Other issues arise when one looks beyond the niche market. If the Corps should determine that the Project would not compete in the niche market created by Massachusetts, then among its competitors in the overall market are conservation measures, which might provide more efficient pathways for meeting electricity demand in the region and accomplishing environmental objectives. If conservation proved more efficient, then allocating federal lands and waters to the Project would not to be in the public interests of all Americans.

[15] Haughton, J. 2004. *Economic Costs Exceed Economic Benefits for the Cape Wind Project.* December 16, and Guiffre, D. 2004. *Public Health Impacts and Economic Costs from Power Plant Emissions.* December 7.

[16] Guiffre, D. 2004. *Public Health Impacts and Economic Costs from Power Plant Emissions.* December 7. p. 4.

B. DEFICIENCIES IN THE ANALYSIS OF JOBS AND RELATED BENEFITS

To measure the Project's impacts on jobs and other, related variables, the Corps relies on a study completed by Global Insight, a consulting firm working for the Project Sponsor.[17] The Global Insight study generally found that the Project would have positive impacts, including these:

- During the manufacturing/assembly and construction/installation phases of the Project, jobs would increase (597-1,013); economic output would increase ($85-$137 million); labor income would increase ($32-$52 million); revenues from the personal income tax would increase ($4.8-$7.8 million); and revenues from corporate income tax would increase ($1.3-$2.1 million).
- During the operation phase of the Project, jobs would increase (154); economic output would increase ($22 million); wholesale power costs would fall ($25 million per year); state tax revenues would increase ($460,400); and revenues for Yarmouth and Barnstable would increase ($279,700).

These numbers are misleading, however, because the underlying analysis suffers from the same discrepancies present in the Corps' analysis of electricity-related benefits. Global Insight and, hence, the Corps look at the jobs, incomes, taxes, economic output, etc., that would exist if the Project were implemented and conclude that the Project is the unique cause. They do not determine if the same levels of jobs, incomes, taxes, economic output, etc. also would exist if the Project were not implemented. In procedural terms, the Corps did not conduct a with-vs.-without analysis that isolates the unique economic consequences attributable to the project.

To correct this deficiency, the Corps must develop two forecasts, not just one, of jobs, incomes, taxes, economic output, etc. One forecast must predict what the future levels of these variables would be without the Project. The other must repeat the exercise assuming that the Project would be implemented. The impact of the Project would equal the difference between the two forecasts.

If the Corps were to conduct the analysis following this standard analytical approach, it probably would markedly reduce its estimates of the Project's impacts on jobs and the other variables. That is, it probably would conclude that the levels of jobs, etc. in the without-Project scenario closely resemble the levels in the with-Project scenario. In the Corps' current analysis, the jobs, etc. would materialize from the Project Sponsor's investment to construct the Project, its expenditures to operate it, and the savings consumers would realize from its impacts, as described by La Capra Associates, on the retail price of electricity. As we explain above, however, absent the Project, other groups would invest in, construct, and operate other plants to generate electricity from renewable energy sources. These other plants would yield levels of jobs, incomes, economic output, taxes, etc., more or less the same as those associated with the Project. The spatial distribution

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[17] Global Insight. 2003. *Impact Analysis of the Cape Wind Off-Shore Renewable Energy Project on Local, State, and Regional Economies.* Cape Wind Associates. September 26. (Appendix 5.16-A of Draft EIS/EIR).

of effects would be different, insofar as the Project's effects on jobs, etc. would occur near Nantucket Sound whereas the direct effects from other plants would be concentrated elsewhere. For the region as a whole, however, the net effect of the Project on jobs, incomes, economic output, taxes, and related variables would be near zero.

V. DEFICIENCIES IN THE CORPS' ANALYSIS OF THE PROJECT'S DIRECT ECONOMIC COSTS

Table 5 lists three deficiencies in the Corps' analysis of the costs that would or should be borne directly by the Project Sponsor. The first of these is the Corps' failure to consider the value of the lands and waters that the project would occupy. The second is the Corps' incomplete analysis of the costs of decommissioning the Project. The third is the Corps' failure to consider costs the Project Sponsor might incur if the Project experienced a serious technological failure or extraordinary accident.

Table 5. Summary of Deficiencies in the Corps' Analysis of Direct Economic Costs

Component of Analysis	Deficiency
Value of seabed, waters, and on-shore right-of-way occupied by the Project	Missing
Decommissioning costs	Analysis based on unsubstantiated assumptions
Costs (to Project Sponsor) of serious technological failure or extraordinary accidents	Missing

A. COSTS ASSOCIATED WITH LANDS AND WATERS THE PROJECT WOULD OCCUPY

The Corps' analysis in the Draft EIS/EIR does not calculate the value of a major element of the Project's costs: the publicly-owned resources that the Project would occupy. These resources include the federal seabed and waters that would be occupied by the wind-turbine generators and related facilities, as well as the federal, state, and local land that would be occupied by the transmission cable.

The Corps did not measure the values of these resources. Hence, it has not evaluated the Project's full costs. Moreover, it has not estimated the payments the Project sponsor might pay to lease these resources— federal, state, and local— and how these payments would affect the Project's financial feasibility.[18]

[18]Note that the fees the Project Sponsor might pay to lease the resources are not necessarily the same as the full value of the resources, given long history of governments leasing their resources for less than the true value. See for example, National Oceanic and Atmospheric Administration. National Ocean Service. National Marine Sanctuary Program. 2002. *Final Report: Fair Market Value Analysis For A Fiber Optic Cable Permit In National*

In measuring the value of the occupied lands and waters, the Corps should consider the full set of factors that can influence the value. These include the forgone value to of alternative uses of these resources, recognizing not just the forgone value of current and foreseeable alternatives but also the forgone option value associated with the possibility that, by leasing the resources to the Project Sponsor, each government would forgo uses that are not now foreseeable. The Corps also should consider each governmentÆs costs associated with leasing the resources to the Project Sponsor, and the value of economic risks that leasing lands and waters to the Project Sponsor would generate for the government.

Recognizing that lands, waters, and other resources have value, federal policy requires that users pay fees to consume or occupy federal resources.[19] Charging a fee helps ensure that resources will be used efficiently, that is, that they wonÆt be misused or wasted. Furthermore, the closer the fee approximates the full value of the goods and services that are forgone when a resource is allocated to one use rather than to the best, alternative use, the more likely the resources will be used in an economically efficient manner.[20] In settings where markets fully measure the tradeoffs among alternative uses of a resource, then the most efficient fee for leasing a government-owned resource would equal its market price. In reality, however, markets generally do not measure all dimensions of the tradeoffs associated with the use of government-owned resources and the fees governments charge for using their resources typically underestimate the resourcesÆ full value.

There is no uniform policy regarding fees applicable to wind farms. The U.S. Commission on Ocean Policy, however, has recommended that offshore energy projects pay fair market value to occupy the seabed.[21] The Minerals Management Service manages leasing of offshore federal lands for the extraction of oil and gas, but currently has no provisions for leasing offshore lands for the production of wind-powered electricity. Oil and gas developers typically pay three types of fees to use federal, offshore lands: a one-time lease fee established by competitive bid; an annual rental fee during the development stage; and an annual royalty fee on production. The Minerals Management Service sets a minimum bid for leases at $25 per acre for water depths of less than 800 meters. Established rental rates are $5 per acre pre year for water depths of less than 200 meters. Royalty rates for production in water depths of less than 400 meters are 16-2/3 percent of the market value

Marine Sanctuaries. August, for information on the differences that existed historically between lease payments for rights-of-way across federal and private lands.

[19] U.S. Office of Management and Budget. 1993 (and later revisions). *Circular No. A-25*. www.whitehouse.gov/omb/circulars/a025/a025.html. Accessed on January 13, 2005.

[20] Economists often use the term, opportunity cost, to refer to the costs realized by allocating resources to one use rather than to the alternative with the highest net benefits.

[21] U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century*. July 22. www.oceancommission.gov. Accessed January 4, 2005.

of production.[22] There are no current oil or gas leases on federal lands in the Atlantic.

For wind farms on its lands, the U.S. Bureau of Land Management (BLM) applies an "Interim Wind Energy Development Policy," which requires that the developers of wind-powered generators on its lands pay a minimum lease fee during development, and a production rent– calculated based on a percentage of the market rate for electricity– when the wind farm generates electricity for sale.[23] So far, the agency has applied only the minimum fee provided for by the interim policy, $2,365 per year, per megawatt (MW) of capacity.

To assist the Corps in measuring the value of the seabed and waters occupied by the wind farm and transmission cable, we offer the following:

- If the Project Sponsor paid the minimum lease fee applicable in the past to oil and gas development on federal offshore lands , $25 per acre, the payments for the 24 square miles occupied by the Project would total $384,000.[24]
- If the Project Sponsor paid the established rental rate of $5 per acre, the payments would total $76,800 per year, for each year of development.
- If the Project Sponsor paid the established royalty fee applicable in the past to oil and gas development on federal offshore lands, 16-2/3 percent of the value of production, the payments would total about $8.4 million per year.[25]
- If the Project Sponsor paid BLM's minimum lease fee of $2,365 per megawatt to occupy the federal seabed, the lease payments for the wind farm's proposed 454 megawatts would be $1,073,710 per year[26].
- Wind-turbine generators on private lands typically pay lease fees to landowners. One study found these fees range from $1,500 to $2,000

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[22] Personal Communication. Jane Johnson, Minerals Management Service, New Orleans District Office, 504-736-2811, February 1, 2005; Minerals Management Service, *Final Notice of Sale 184*, www.gomr.mms.gov/homepg/lsesale/184noticef.html Accessed February 1, 2005.

[23] U.S. Department of the Interior, Bureau of Land Management (BLM). 2002. ***Instruction Memorandum No. 2003-020, Interim Wind Energy Development Policy, Right-of-Way Management, Wind Energy***. October 16. www.blm.gov/nhp/efoia/wo/fy03/im2003-020.htm. Accessed on January 4, 2005.

[24] An oil and gas developer typically pays a lease fee for the entire tract it develops, not just for the site occupied by a drilling rig. We assume the Project Sponsor would pay a single lease fee for the entire tract, 24 square miles, rather than 130 separate lease fees, one for each of the wind-turbine generators.

[25] La Capra Associates (Appendix 5.16-B, p. 2) estimates the Project would have a capacity of 468 MW and produce 1,486 GWh of annual production. For this illustrative calculation we scaled the production down, reflecting the Corps's statement that the Project would have a capacity of 454 MW (Draft EIS/EIR, p. 1-3), and we assumed output from the Project would be priced at $0.035 per kWh.

[26] U.S. Department of the Interior, BLM. 2002. Page 5; and, Personal Communication. January 4, 2005. BLM Palm Springs, CA office, Claude Kirby, 760-251-4850. The BLM currently charges only the minimum lease fee allowed and has not yet implemented provisions allowing it to charge higher fees.

per turbine, per year.[27] If this range were to apply in this case, the Project Sponsor would pay annual lease payments for just the 130 generators (not the transmission cable or ancillary facilities) of $195,000 – $260,000.

- Developers of offshore wind-powered generators in the U.K. pay a lease fee equal to 2 percent of the total costs.[28] If this rate were applied to the Project, the present value of its lease fees would be about $16 million.

In principle, the Project Sponsor also should pay a lease fee for federal, state, and local lands occupied by its transmission cable. The Project sponsor has agreed to pay the town of Yarmouth a one-time payment of $150,000 and annual payments of $350,000 for use of its right of way.[29] We are not aware of any agreement to pay fees for the use of state or federal lands.[30]

The lease fees described above provide data the Corps can use to estimate the potential lease fees the project sponsor might pay for the right to occupy federal, state, and local lands. All else equal, additional fees would be required for the Project's occupation of federal and state waters. It is important to recognize that data on lease fees underestimate the full value of occupying public resources because they do not include the value of affected goods and services that are not, or cannot be, exchanged in the marketplace[31]. In this case, the affected non-market goods and services may include the existence and bequest values of the ocean water and seabed. See Section VI. D. for our discussion of non-market values.

B. DECOMMISSIONING COSTS

The Corps has failed to consider all factors that influence the Project's decommissioning costs, i.e., the costs of disassembling the turbines and removing all material from the Project site. The Corps assumes (Table 3-46)

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[27] Northwest Economic Associates, Inc. 2003. *Assessing the Economic Development Impacts of Wind Power.* National Wind Coordinating Committee c/o RESOLVE. February 12.

[28] Department of Trade and Industry, Strategic Energy Environmental Assessment (U.K.). "Wind Background: Cost of Wind Power Generation" http://www.offshore-sea.org.uk/site/scripts/documents_info.php?documentID=6&pageNumber=2

[29] Emery, Theo. 2004. Associated Press. hoasted.ap.org/dynamic/stories/W/WIND_FARM?SITE=WABEL&SECTION=HOME&TEMPLATE=DEFAULT. Accessed on December 28, 2004.

[30] One point of reference regarding the potential magnitude of the fees comes from the Cross Sound Cable Interconnector – a submarine cable that connects the electric transmission grids of New England and Long Island, New York. The owners paid the State of New York $750,000 for a 25-year lease for an easement across New York waters.

[31] National Oceanic and Atmospheric Administration. National Ocean Service. National Marine Sanctuary Program. 2002. *Final Report: Fair Market Value Analysis For A Fiber Optic Cable Permit In National Marine Sanctuaries.* August.

that, if decommissioning were to occur today, it would cost $53 per kW of installed capacity, or $24,873,742 for all 130 generators in the Project.

The foundation for this assumption, however, is not robust. The assumption rests on this statement (p. 3-128): "published references for decommissioning of onshore facilities generally indicate that the decommissioning cost is negligible when the salvage value of the material is considered [two citations]." Therefore, according to this reasoning, the only cost would be the cost particular to decommissioning at an offshore site. Our review of the two documents cited in this statement by the Corps, however, indicates they do not support the Corps assumption that decommissioning costs for onshore generators are negligible. Moreover, our review of other relevant literature found observations from California indicating that the decommissioning cost can exceed salvage value of the materials by $50 per kW, or perhaps more.[32] If the Project should experience similar decommissioning costs, they would be about twice the Corps' estimate, or perhaps more. At $100/kW, for example, the decommissioning costs would be $45,400,000. If these costs were incurred in year 20, the present value would be $11.7 million with a discount rate of 7 percent, or $25.1 million with a discount rate of 3 percent.

Reports from Europe indicate the decommissioning costs would be even higher. An industrial overview, aimed at stimulating development of the wind-energy industry in Europe, stated that the industry expects decommissioning of offshore projects to constitute about 3 percent of a project's total costs.[33] Some researchers, however, have estimated the decommissioning costs to be 11.8 percent of total costs.[34] At these rates, the present value of the Project's decommissioning costs would be about $24 million – $98 million. A separate study of decommissioning costs in the U.K. estimated them to be £118,000 per turbine, or £34,000 per MW.[35] At these rates, the present value of the Project's decommissioning costs would be about $29 million.

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[32] Gipe, P. 1997. "Removal and Restoration Costs in California: Who Will Pay?" http://www.wind-works.org/articles/Removal.html

[33] Garrad Hassan & Partners, Tractebel Energy Engineering, Rise National Laboratory, Kvaerner Oil & Gas, Energi & Miljoe Undersoegelser. 2001. *Offshore Wind Energy: Ready to Power a Sustainable Europe*. December. p. 6-2. http://www.offshore-wind.de/media/article000325/CA-OWEE_Complete.pdf.

[34] Henderson, A., G. Watson, M. Patel, and J. Halliday. [no date] "Floating Offshore Wind Farms – An Option?" http://www.windenergy.citg.tudelft.nl/content/research/pdfs/owemes00a_arh.pdf.

[35] Pearson, D. [no date] "Decommissioning Wind Turbines In The UK Offshore Zone." http://www.owen.eru.rl.ac.uk/documents/BWEA23/BWEA23_Pearson_Decommisioning_paper.pdf.

C. COSTS OF TECHNOLOGICAL FAILURE OR EXTRAORDINARY ACCIDENTS

The final item in Table 5 identifies the Corps' failure to include in its economic analysis any consideration of direct costs the Project Sponsor might incur, stemming from potential serious technological failures or experience extraordinary accidents.

Technological failures of wind-turbine generators have occurred elsewhere, on land and offshore. At the world's largest offshore, wind-powered generating plant, located at Horns Rev in Denmark, for example, all 80 turbines had to be repaired and upgraded within one year after their initial operation. The Corps, however, does not explicitly assess the probability of technological failures or their economic consequences. The Corps' treatment of this issue contrasts with the statements of its peer-review committee, which highlighted the importance of accounting for technological failures.[36] In its comments on the Project's long-term viability, for example, the committee stated:

> "Emphasis here should be on the long-term risks and unknowns. The worst possible environmental outcome would be a failed and derelict project, with the owners in bankruptcy court. This would lead an unattended wind farm exposed to the elements for an extended period of time, with no clear path to alternatively refurbish the project, salvage the remains, or decommission the project. This scenario has previously been played out in the late 1980's in California.
>
> "To address future unknowns, either technical or environmental, the project must have 'long-term viability'. The wind industry has seen a number of unexpected technical problems after several years of initial operation. These include rotor and gearbox failures, higher than expected O&M costs, as well as the need for unplanned environmental studies, such as to further understand avian impacts. It is critical to have a viable project generating the financial resources with access to the technical expertise necessary to address unexpected problems, and to maintain and improve the facility over time." (p. 15)

The Corps similarly failed to analyze the economic consequences of potential accidents involving the Project, even though it acknowledged the existence of precursors for extraordinary accidents. Powerful storms occur frequently; two shipping channels are nearby; recreational boats and commercial fishing boats are likely to move through the Project area; and the area experiences periods with strong tidal currents, reduced visibility, high winds, and high waves. After describing these precursors, however, the Corps did not take the next step and consider plausible accident scenarios and their economic costs.

We discuss accident-related issues in section VI.E.

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[36] Draft EIS/EIR, Appendix 3-E. "Peer Review Committee, Offshore Wind Energy, New England Technical Review of Preliminary Screening Criteria for the Cape Wind EIS Consolidated comments on Section 2.0 and 3.0 of the Draft EIS September 30,2003."

VI. Deficiencies in the Analysis of the Costs the Project Would Impose on Others

Table 6 lists deficiencies in the Corps analysis of costs the Project would impose on others, i.e. the Projects negative externalities. All of them stem from the Corps failure to account for all the relevant factors regarding the Projects potential, adverse impacts on the ecosystem of Nantucket Sound.

Table 6. Summary of Deficiencies in the Corps' Analysis of Costs the Project Would Impose on Others

Component of Analysis	Deficiency
Value of negative impacts on other uses of the ecosystem: fishing industry	Incomplete analysis based on unsubstantiated assumptions
Value of negative impacts on other uses of the ecosystem: recreation/tourism	Measures the wrong variables
Value of negative impacts on property values	Incomplete analysis based on unsubstantiated assumptions
Value of negative impacts on the non-use values of the ecosystem (including option, bequest, and existence value)	Missing
Jeopardy to state, local, private investments in the ecosystem	Missing

A. Costs Imposed on the Commercial Fishing Industry

The first item in Table 6 identifies the Corps failure to consider all relevant factors as it analyzed the Projects impacts on the commercial fishing industry. The Corps concludes that:

> "The Project is not anticipated to have significant impacts on commercial fishing ... since the [Project Sponsor] will not impose any restrictions on fishing within the Wind Park during Project operation. ... Any potential conflicts [during construction] with commercial fishing activity and gear, will be minimized by notifying registered fishermen as to the location and timeframe of Project construction activities .... [T]he physical presence of [the wind-turbine generators] should not interfere with commercial fishing activity, including maneuvering of commercial vessels." (p. 5-279, -280).

This conclusion, however, rests on several unsubstantiated assumptions. First, the Corps assumes the Project would not cause the fishing industry to alter its operations: boats would operate in the area as before, with the same maneuverability and level of risk. The Corps provides no evidence to substantiate this assumption. Moreover, it ignores contrary evidence, such as its own acknowledgement that the area experiences periods with strong tidal currents, reduced visibility, high winds, and high waves (pp. 5-278, -279). The Corps also observes that structures would pose some risk to boats and that mariners would have to be more attentive because of the risks associated with operating a boat in the vicinity of wind-turbine structures (p. 3-25). Nonetheless, the Corps dismissed this evidence and would have us believe that, even when hazardous conditions materialize, the maneuverability of and risk to fishing boats would be the same with the presence of 130 concrete structures as they would be with open waters.

Second, the Corps assumes there is zero probability that the Project would result in restrictions on commercial fishing in the area: the Project Sponsor would never see any risk from having fishing boats in the vicinity of its generators and seek to keep them at a greater distance; and the Coast Guard would never see any hazard and restrict boats from entering the area. Again, the Corps offers no evidence to substantiate its assumption and ignores contrary evidence. For the assumption to be true, either there must be zero risk of accidents from having fishing boats among the structures or, if there were risk, then the Project Sponsor and the Coast Guard must not be risk-averse and would not seek to reduce the risk. Neither of these conditions is supported by facts.

Third, the Corps assumes there would be zero economic costs from Temporary impacts on the activities of fishing boats and minimized conflicts with fishing activity and gear. Again, this assumption lacks substantiation. It is contradicted by information provided by representatives of the fishing industry. For example, in a letter to the Corps dated October 16, 2004, Capt. William Amaru stated that gear typically used in the area exceeds the proposed distance between the proposed structures, explained that the structures will impede commercial fishing operations, and create risks for boats, operators, and their crews:

> "A trawler tows a series of cables attached to doors which weight and spread the net and keep it on the bottom. The cables are towed behind the boat at a distance of between four and six hundred feet, and the net can be as much as fourteen hundred feet behind the boat. While there is much more to the operation than I can briefly describe, let it be understood that a great deal of space is necessary to safely trawl and maneuver in this fishery. The proposal to place the turbines as close together as described by Wind Associates will place in jepordy [sic] the operators and crews of trawlers. Additionally, boat traffic such as ferries, sail boats, recreational fishers and pleasure boat operators, all of whom share the resource with us, will be placed at greater risk. ... We as a profession have been asked to give up more than any other user group: The loss of this important fishery would be devastating, and unnecessary."

These points were elucidated in a letter, dated October 15, 2004, to the Corps from Wayne Kurker:

> "3) The USACE needs to understand that the gear doesn't stay right in back of the boat. Each boat tows two tow-lines that connect to two trawl doors which spread the gear 300' - 400' apart, that connects to two ground cables which connect to one net The purpose of the doors is to spread the net and keep it on the sea floor. ...

"4) Fishing is a very imperfect science, and primarily the fish are located in pods, so it is not as though each fisherman could get in between one row of turbines and simply fish that row. The fishermen need to locate the fish and concentrate their efforts where the fish are found and they need to turn at the end of each tow.

"5) Fishing is a dynamic undertaking, the boats tow, along every compass heading possible depending on the wind, tide, locations of the fish and of course locations of the other boats.

"6) When the trawler goes to turn, the gear understandably doesn't stay right behind the boat. **Therefore, a boat towing it's trawl gear needs a large turning radius (more than 1/2 mile and up to 1 mile, under unobstructed conditions)** much more than the third and half mile distances between the wind turbines. (bold emphasis in original)

"7) The USACE also cannot assume that there is only one boat working between two towers and naturally this gets much more complicated when you put many boats in the same area. It is not unusual to see a fleet of over 40 boats out there at one time.

"One example of a common difficulty is when a trawl hangs up. The boat has to haul back and the vessel is no longer under the captain's control. It is subject to tide, wind, and the trawler itself now becomes an obstruction. Other boats in the area now must make unplanned turns and maneuvers, endangering the other vessels fishing nearby."

The economic consequences of the risks that would accompany the wind-turbine structures were described in a letter, dated December 6, 2004, to the Corps from the Massachusetts Fishermen's Partnership, "an umbrella organization of 17 commercial fishing associations representing all gear and geographic sectors of the Massachusetts fishing industry:"

"Among other points, the Army Corps' DEIS characterizes the wind farm as an inconvenience to fishermen; however, according to experienced mobile gear fishermen, the spacing between the wind towers will make mobile fishing gear navigation impossible. This will have direct adverse economic impacts on the fishermen who will thus be displaced from an area that generates up to 60% of their annual income. In addition, indirect negative economic, environmental and safety impacts are likely to result from crowding fishermen who fish other areas in Nantucket Sound. The Army Corps' DEIS ignores the potential adverse impacts to fishermen operating in this productive area."

Related information was provided to the Corps based on meetings with fishermen:[37]

"Serious potential environmental impacts identified by participating representatives of the fishing industry included:

- loss of resources due to habitat disruption, pollution
- large-scale habitat conversion of shoals area due to changes in water flow and sediment transport
- increased bird mortality due to strikes and loss of forage
- loss or alteration of critical squid spawning habitat and/or
- loss of fishing access, particularly to mobile gear.

"This limited study does not purport to have determined the full scope of the potential impacts of the proposed wind farm on the portion of the fishing industry or fishing communities associated with the use of Horseshoe Shoals. Nor can the authors assert how many individual businesses will be affected, either directly or indirectly.

[37] Hall-Arber, M., D. Bergeron, and R. Ryznar. 2004. "Commercial Fishing in Nantucket Sound: Consideration pertinent to the proposed wind farm on Horseshoe Shoals."

Nevertheless, the authors do caution that a number of mobile gear fishing vessels will be displaced if the proposed Cape Wind farm is constructed, and this displacement could have a broader impact throughout the entire Nantucket Sound area."

B. COSTS THE PROJECT WOULD IMPOSE ON RECREATIONISTS AND TOURISTS

The second item in Table 6 identifies the Corps failure to consider all factors when it analyzed the economic costs associated with the Project's potential impacts on recreational and tourism uses of the ecosystem. The Corps concludes:

"As evidenced by the experiences at other wind farms, the Project will likely have a negligible effect on the use of recreational resources and a positive effect on tourism in general for Cape Cod and the Islands" (p. 5-278).

"Based on studies conducted at wind farms in the United States and in Europe, no adverse impacts on tourism and recreation are expected from the Project." (p. 5-283)

These statements reveal two fundamental deficiencies in the Corps analysis. One of these is the Corps reliance on a selective reading of the relevant literature, considering only reports that found no adverse impacts on tourism and recreation, and overlooking those to the contrary. Prominent within the Corps discussion of the Project's potential impacts on recreation and tourism is this statement (p. 5-276): "Studies conducted on wind farms performed throughout the world have shown that wind farms generally have a positive impact on tourism." To support this statement, the Corps describes a single study, commissioned by a trade association that promotes the industry, the British Wind Energy Association (BWEA), and states that this study "found many examples of wind farms that enhanced tourism, and no examples of wind farms that had a negative impact on local tourism."

The Corps failed to cite and discuss the findings of contradictory reports. In particular, the Corps failed to recognize the significance of research findings indicating that, although tourists generally are either positive or neutral to past wind farms, some tourists have strong, negative opinions. Indeed, even the study the Corps cited found that not everyone found wind turbines an enhancement to visual aesthetics. Moreover, the Corps has failed to recognize the potential for the negative opinions to be exacerbated by wind farms having features characteristic of the Project: generators larger than those in the past, situated in an area that attracts many tourists because of its undeveloped, visual amenities. For example, the Corps overlooked these reports and their findings:

- In a study conducted for the European Union, researchers surveyed tourists, local residents, and representatives of the tourism industry at sites in Spain and Portugal where offshore, wind-turbine generators have been proposed in areas with a high level of coastal-oriented tourism.[38] The researchers found that 26

[38] Iberdrola and Ecossistema. 2001. "Methodological Guidelines for the Environmental and Socioeconomic Impact Assessment of Off-shore Windfarms in Touristic Areas." Altener Programme. http://www.eia.es/windtour/docs/WINDTOUR.pdf

percent of respondents "were against or strongly against" the proposed projects, and 39 percent said the negative effects would be as large or larger than the positive effects. When identifying their first choice of concern regarding the potential negative effects, the highest scoring responses were "effects on bird life and marine fauna" (47 percent), and "loss of quality of the scenery" (22 percent). Only 1 percent of respondents agreed that an offshore wind farm could "make the scenery more interesting."

- In a summary of the literature, a study of tourists' attitudes toward wind power in Sweden observed that an earlier study (in Swedish) shows "that it is possible to combine tourism and wind power as long as wind power mills are not placed in the areas that are of importance for tourism."[39] (underline emphasis added)

- A progress report on a Danish study to examine the economic value of the visual externalities of off-shore wind farms premised the study with these observations:

  > "the turbines that are built now have a much more dominating impact on the surroundings than the turbines built 10 or 20 years ago. The larger the turbines are, the greater are the areas in which people potentially may be bothered by visual or noise externalities generated by the turbines. Combined with the already high density of wind turbines, this implies that it is becoming increasingly difficult to find areas that are both technically and socially acceptable for the placing of new land-based turbines. ...
  >
  > "Despite the intuitive appeal of taking wind power production to sea, off-shore wind farm projects have meet [sic] opposition both at the national and at the local level. The motives underlying the opposition may be attitudinal or psychological in character; e.g. it may be motivated by a – perhaps only temporary – opposition to change, a sense of having been left out of the decision process, a desire to express discontent with the underlying energy policy or a strong ecological conviction that the sea should remain untouched. The motives may however also be economic in the sense that the opposition may be caused by a rational concern for the biological and marine environment, actual or expected losses of amenity value due to visual externalities, reduced earnings in the tourist sector and/or declining catches of fish caused by reductions in the area available for fisheries."[40]

- A study of the potential impact of wind farms on tourism in Scotland, commissioned by an arm of Scotland's National Tourism Board produced these findings:

  > A survey of visitors to Scotland found that 38 percent of respondents felt that wind farms 'spoiled the scenery' and, although more than three-quarters had "overall views [that] were either positive or neutral towards wind farm development, ...21 percent of visitors held much more negative views toward wind farm development."
  >
  > Interviews of "key players" and other representatives of the tourism industry found that, although they recognized the positive attributes of wind farms, they concluded that, because of the negative visual impacts, wind farms

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[39] Lindberg, K, J.M. Denstadli, T. Vuorio, and P. Fredman. 2002. Residents in Sodra Jamtlandsfjallen: Attitudes toward windpower, national park designation, and tourism development. European Tourism Research Institute. http://www.etour.se/download/18.d09ad3f455c7702f7fff1804/WP2002000300002002110546941556sv.dat_p.pdf, accessed January 11, 2004.

[40] Dubgaard, A. 2004. *Annual Status Report 2003: Economic Valuation of the Visual Externalities of Off-Shore wind Farms*. KVL: The Royal Veterinary and Agricultural University, Denmark. http://www.hornsrev.dk/Miljoeforhold/miljoerapporter/POST-CONSTRUCTION-Annual%20Report-2003-Economic%20valuation%20of%20the%20visual%20externalities%20of%20off-shore%20wind%20farms.pdf, accessed January 14, 2005.

should be sited outside National Parks, national Reserves, and "those areas which are regarded as key tourist 'honeypot' locations."

- The Swedish Commission on Wind Power has concluded: "The best wind conditions often exist in areas of considerable natural beauty and scientific and cultural interest, e.g. along the coasts and in the mountain region. Wind power stations directly utilise only small areas. Sound emissions and shadow effects, however, entail disturbances over wider areas and greatly restrict localisation options, e.g. out of consideration for settlement and recreation. Wind power stations impact on the landscape at great distances, due to their height and also because they are tending more and more to be built in groups. Studies by the Commission have shown that many people find this the most troublesome effect on the surroundings."[41]

In sum, many studies have findings contrary to the Corps' statement that the literature supports its conclusion that "no adverse impacts on tourism and recreation are expected from the Project." The Corps either was unaware of these studies when it prepared the Draft EIS/EIR, or it knew of but disregarded them. Either way, its failure to consider the full set of relevant literature undermines its economic analysis. Until it corrects this deficiency, one cannot have confidence in its findings regarding the Project's potential impacts on recreation and tourism.

Another fundamental deficiency in its analysis of the Project's recreational and tourism impacts is the Corps' total failure to consider, let alone measure, the economic value of these impacts. As we explain below, evidence indicates the Project would reduce the value of recreational and tourism assets and activities in the area. This reduction would constitute a significant economic cost that the Corps must consider if it is to describe the Project's overall impacts on the value of nation's output of goods and services.

Central to the analysis of this aspect of the analysis is the economists' concept known as consumers' surplus. Consumer's surplus in this context is the difference between the total value a recreationist or tourist places on sightseeing, boating and other resource-related activities, and the cost s/he incurs to engage in the activities.[42] Recreationists and tourists in this area would incur an economic cost if, all else equal, they suffered a reduction, because of the Project, in the consumer's surplus they derive from the resources of Nantucket Sound.

The Corps's discussion of the project's impacts on socioeconomic (Section 5.16) makes no mention of the Project's impact on consumer's surplus in any context, including the recreational and tourism impacts. Instead, it focuses on the numbers of recreationists and tourists; asserts that the Project would not affect the number of recreationists and would increase the number of tourists, and concludes that no further analysis was needed.

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[41] "The Right Place for Wind Power." http://www.svensk-vindkraft.org/WindPowerReportSOU1999-75SummaryJune99.htm, accessed January 14, 2005.

[42] U.S. Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources. 1991. *National Economic Development Procedures Manual: Overview Manual for Conducting National Economic Development Analysis.* IWR Report 91-R-11. October.

These dots don't connect, however. The Corps has not examined the possibility that, even if it is correct and the Project would not cause recreationists to avoid visiting the area, some of them would experience a loss in consumer surplus. That is, some recreationists might find that the presence of the wind-turbine generators on Nantucket Shoals would diminish their enjoyment of the area, but they would visit nonetheless because they would rather recreate here, even with the windmills, than recreate elsewhere. For such individuals, the reduction in their enjoyment of the area would constitute a reduction in consumer's surplus and, hence, a real economic cost attributable to the Project.

To our knowledge, there exists no study that quantifies the potential loss of consumer's surplus. A recent study by the Beacon Hill Institute, however, indicates that the loss could be substantial.[43] The authors, recognizing the difficulty in determining the impact on consumer's surplus of something that does not yet exist (and for which there are no nearby analogs with which people are familiar) surveyed tourists in the area and gathered data that look at consumer's surplus from three different perspectives:

1. **Tourist spending if the Project were built.** More than ten percent of tourists responding to the survey indicated that, if the windmills were built, their tourism spending in the area would decline. The average reduction in spending, per respondent, was greater than $75 per year. When these rates are applied to the current, total number of tourists, they indicate that the total, gross reduction in spending by tourists would be about $57 $123 million.
2. **Royalty rate to allow the Project.** Tourists responding to the survey indicated, on average, that, if the windmills were built, the Project Sponsor should pay a royalty to the federal government equal to about 8 percent of the revenues earned from the wind-turbine generators. The authors of the study concluded that, at this rate, the Project Sponsor would pay a royalty of about $8 million per year.
3. **Direct willingness to pay to stop the Project.** About 5 percent of the tourists responding to the survey indicated that, on average, they would be willing to pay $87.54 to stop the Project. When these rates are applied to the current, total number of tourists, they indicate that the total, gross willingness of the area's tourists to pay to stop the Project would be about $3 $8 million.

Collectively, these numbers provide empirical support for the expectation that the Project would reduce the consumer's surplus some tourists derive from the area's recreational resources. Moreover, these numbers indicate that the costs stemming from the potential loss of consumer's surplus are substantial and may even exceed the Project's economic benefits, which, as we explain above, probably would be much smaller than the Corps' estimates. These numbers must be used cautiously, however. The study by the Beacon Hill Institute gives only insights into the range of potential loss of consumer's

[43] Haughton, Jonathan, Douglas Giuffre, and John Barrett. 2003. *Blowing in the Wind: Offshore Wind and the Cape Cod Economy*. The Beacon Hill Institute. October.

surplus, not the probability that the true loss would be any particular value. Thus, the study's findings do not, by themselves, provide a definitive, precise measurement of the potential loss of consumer's surplus. Absent further research that clarifies the study's findings, though, they stand as the only quantification of the costs the Project would impose on tourists' consumer's surplus, and the Corps should take them into account.

The Corps, of course, also should consider the likelihood that as the Project would reduce the consumer's surplus for tourists who don't want to see windmills on Nantucket Sound, it also would increase consumer's surplus for those who do. The study by the Beacon Hill Institute found (p. 21) that 13.5 percent of the respondents to their survey said they would be willing to pay, on average, $70.33 "to encourage windmills to locate in the Sound."

These numbers, however, are even more problematic to interpret than those just discussed. Under current conditions, electricity consumers would pay additional amounts on their electricity bill to subsidize the Project, and this arrangement has been widely publicized, making it impossible to know if respondents were expressing their acquiescence to making these payments or expressing a desire to pay even more, specifically to site the Project in Nantucket Sound.[44] Moreover, respondents' expressions regarding the apparent increase in consumer's surplus they would experience from the Project are cast into doubt by the statements of more than one percent of the respondents that, if the Project were built they would, on average, spend a whopping 13.1 additional days per year in the area as tourists. Undoubtedly some people would be attracted to view the wind farm and/or related public-education exhibits, especially as long as the Project remains a novelty. As wind-turbine generators become more common, however, this novelty probably would erode.

Whatever the true values of the Project's initial impacts on the consumer's surplus of recreationists and tourists, they almost certainly would evolve over time. They might decrease. Adverse perceptions of windmills elsewhere have diminished over time, although the extent to which this evidence, which comes from sites with significantly different characteristics, is applicable here remains in doubt. Or, they might increase. This would be the outcome, for example, if consumers increasingly came to see the generators as an encroachment of industrialized development on scarce, open seascapes. The Corps' economic analysis should investigate these and related factors that might influence the future magnitude of the Project's impacts on the consumers' surplus of recreationists, and show the implications if a significant increase or decrease in the impacts should materialize.

[44] We recognize that similar ambiguity may apply to some respondents' statements regarding the Project's potential negative impacts.

C. COSTS THE PROJECT WOULD IMPOSE ON PROPERTY OWNERS

The third item in Table 6 identifies the Corps’ failure to consider all factors when it analyzed the economic costs associated with the Project’s potential impacts on local property owners. The Corps concludes:

> "Based on recent studies conducted in the United Stats and Europe, property and real estate values are generally not affected, or actually increase in areas near wind farm development. Based on these studies, the Project is not expected to adversely affect property values." (p. 5-283)

These statements reflect fundamental deficiencies similar to those present in the Corps’ analysis of recreation and tourism. The Corps has relied on a selective reading of the relevant literature, considering only reports that found no adverse impacts on property values, and failing to critically evaluate the extent to which studies elsewhere accurately indicate the Project’s potential impacts on local property values.

In the previous section we report studies that show many people believe offshore wind-turbine generators can reduce the value they derive from the surrounding area. More acknowledge that the generators have an adverse effect, but say they are willing to accept this because they recognize the advantages of deriving electricity from renewable sources of energy. In a study in Spain and Portugal, for example, 39 percent of the respondents to a survey stated that the negative effects would be as large or larger than the positive effects.[45]

These and similar findings indicate there is some non-trivial probability that the Project, if implemented, would reduce the value people derive from the area surrounding Nantucket Sound.[46] If such a reduction should materialize, property values in the area could fall, through several mechanisms. If the Project should result in fewer tourists visiting the area, then the demand for tourist-oriented services would decline and, in turn, so too would the prices of tourist-oriented properties.[47] A similar outcome could materialize if the Project did not affect the number of tourists, but caused some to enjoy their visits less and to spend less while in the area. The Project’s negative impact on recreationists and tourists also could result in lower prices for residential properties, insofar as reduced demand for tourism-oriented services would lower the demand for labor and, hence, induce some workers to look elsewhere for employment. Or, the Project’s impact on residential properties could be more direct. Some people willing to pay a given amount for property

[45] Iberdrola and Ecossistema. 2001. “Methodological Guidelines for the Environmental and Socioeconomic Impact Assessment of Off-shore Windfarms in Touristic Areas.” Altener Programme. www.eia.es/windtour/docs/WINDTOUR.pdf.

[46] The reverse outcome could conceivably materialize, for example, if the Project should become a tourist destination, boost overall tourism, and increase the value people derive from the area’s natural resources. We recommend that the Corps investigate both possibilities thoroughly.

[47] Prices might fall absolutely or grow more slowly.

with a view of Nantucket Sound as it is today, for example, might be willing to pay less if the view were cluttered with industrial development.

The results from the study in Spain and Portugal are notable in part for the study's focus on offshore wind-turbine generators in coastal areas recognized as having high recreational and tourist use, similar to the area surrounding Nantucket Sound. The same cannot be said for the information on which the Corps relied. It provides an extensive summary of a study by the Renewable Energy Policy Project (REPP), which looked at data on residential property sold in the vicinity of ten wind-turbine facilities.[48] None of the ten, however, is located in an area with characteristics similar to Nantucket Sound, where tourism related to natural resources is the major segment of the economy and it is reasonable to expect that property derives a significant portion of its value from the scenic amenities of unindustrialized, marine open space. The same is true of properties near the four wind-turbine facilities in the northeastern U.S. the Corps investigated.

The Corps' evidence that comes closest to replicating conditions associated with the Project's potential impact on property values is its citation of a study of the impacts on property values of a wind-turbine facility in Denmark, but it is not the surrounding area apparently does not have the scenic amenities present in Nantucket Sound.[49] Moreover, the Corps' description of the study shows that its authors based their conclusions on shaky information: "reports that most of the people living in the neighboring area accept the wind farm and there have been no reported lighting or noise-related impacts" (p. 5-275).

A more rigorous research effort is underway to investigate the impacts of offshore wind-turbine generators in Denmark on local property values. Results of the study have not yet been released, to our knowledge, but a status report on the study explains that it is being undertaken because there are widespread concerns about the visual impacts of offshore generators as they become larger and more numerous:[50]

> "[T]he turbines that are built now have a much more dominating impact on the surroundings than the turbines built 10 or 20 years ago. The larger the turbines are, the greater are the areas in which people potentially may be bothered by visual or noise externalities generated by the turbines. Combined with the already high density of wind turbines, this implies that it is becoming increasingly difficult to find areas that are both technically and socially acceptable for the placing of new land-based turbines.
>
> "Despite the intuitive appeal of taking wind power production to sea, off-shore wind farm projects have meet opposition both at the national and at the local level. The

[48] Sterzinger, G., F. Beck, and D. Kostiuk. 2003. *The Effect of Wind Development on Local Property Values.* Renewable Energy Policy Project. May.

[49] The Corps also cites a newspaper article that quotes a local real estate agent as saying there has been no impact.

[50] Dubgaard, A. 2004. *Annual Status Report 2003: Economic Valuation of the Visual Externalities of Off-Shore Wind Farms.* KVL: The Royal Veterinary and Agricultural University, Denmark. http://www.hornsrev.dk/Miljoeforhold/miljoerapporter/POST-CONSTRUCTION-Annual%20Report-2003-Economic%20valuation%20of%20the%20visual%20externalities%20of%20off-shore%20wind%20farms.pdf.

motives underlying the opposition may be attitudinal or psychological in character; e.g. it may be motivated by a – perhaps only temporary – opposition to change, a sense of having been left out of the decision process, a desire to express discontent with the underlying energy policy or a strong ecological conviction that the sea should remain untouched. The motives may however also be economic in the sense that the opposition may be caused by a rational concern for the biological and marine environment, actual or expected losses of amenity value due to visual externalities, reduced earnings in the tourist sector and/or declining catches of fish caused by reductions in the area available for fisheries.

"The purpose of the present study is to estimate the monetary value of the visual externalities of offshore wind farms and to conduct a cost-benefit analysis of socially optimal locations of off-shore wind farms." (pp. 1-2)

Concern about the negative impacts on property values also has been expressed by the Royal Institution of Chartered Surveyors, an organization that represents appraisers and similar professions in the U.K. and elsewhere. From a survey of its members regarding their experience with the impacts on wind-turbine generators on property values, the organization reached these conclusions:[51]

"Whilst wind farm technologies offer many advantages, questions are being asked about the potential impact of this expansion on property values, particularly in the residential sphere.

"In order to examine whether there is any substance in these concerns, and to monitor the effects on land and residential property affected by wind farm developments, RICS (The Royal Institution of Chartered Surveyors) has carried out an initial study to examine the impact of wind farm development. The purpose of the study is not to endorse or criticise wind technology, but rather to gauge professional property opinion about its impact on both residential property and agricultural land values.

"RICS conducted an initial questionnaire-based survey among its members at the beginning of September 2004.

"The findings suggest three effects of wind farms on the value of residential property and agricultural land:

- there are negative influences on the value of residential properties, though a sizeable minority report no impact on prices
- the influence is much less on agricultural land values, to the point that the majority of responses suggested the impact was nil
- nowhere is it considered that wind farms positively affect residential property values, although there was evidence of some positive impact on agricultural land

More than half (60%) of those surveyors involved in residential property transactions affected by a wind farm development (i.e where a wind farm is visible from the property), reported that values were lower than for comparable properties which were unaffected (Figure 1). However, this still leaves a sizeable minority of 40% of surveyors reporting no impact from wind farm developments on values.

A recent review by one of the Corps' sister agencies, the Tennessee Valley Authority reached a similar conclusion: wind-turbine generators can have a

[51] The Royal Institution of Chartered Surveyors. 2004. *Impact of Wind Farms on the Value of Residential Property and Agricultural Land*. November. www.rics.org/NR/rdonlyres/66225A93-840F-49F2-8820-0EBCCC29E8A4/0/Windfarmsfinalreport.pdf

negative impact on property values.[52] The authors review of the literature stated that the actual impact depends on the specific setting:

> "Many people are supportive of wind power and other alternative energy sources because of such concerns as global warming and air pollution—the macro-scale. At the same time, however, they may have concerns about the impacts of proposed projects because of their potential to disturb their immediate environment—the micro-scale. This disturbance might take the form of visual changes to the landscape or noise intrusion, and could, if significant enough, have negative impacts on property values.
>
> "Other research related to property values, but not specific to windfarms, may also be useful in understanding these impacts. Studies on the relationship of views and property values show that desirable views do have a positive value on property values. For example, a study by Rodriguez and Sirmans (Rodriguez and Sirmans, 1994), based on data from Fairfax County, Virginia, found that a good view added about 8 percent to the market value of a home. Another study, looking at vacant property on Seabrook Island, off the South Carolina coast, found that views had significant impacts on the value of the property (Rinehart and Pompe, 1999). An ocean view added 147 percent to the market value of a lot (vacant lot, not a home), view of a creek or marsh, 115 percent, and a golf course view, 39 percent. Similar results have been found for the impacts of other environmental amenities, such as open space, proximity to recreational trails, and improved coastal wetlands (Bradec, 1992; Brabec and Kirby, 1992; Earnhart, 2001).
>
> "These studies are consistent with the expectation of some negative impact on property values from a windfarm that has significant negative visual impacts [and] it is possible that in specific cases, impacts would be greater than the range shown by the studies cited, but there appears to be no research to validate general claims of such large impacts."

The observations regarding the impacts of different visual amenities on property values highlights the inadequacy of the Corps attempt to transfer the results from studies elsewhere to this location. We have seen no evidence indicating that any of the existing wind farms in the U.S. is located in an area where the visual amenities, absent the wind farm, are powerful enough to raise property values by 147 percent, the observed effect of an ocean view. Many are located where the visual amenities are nonexistent, or nearly so: the study by REPP, for example, considers sites in the flat farm country of Texas and Iowa, and others in hilly, developed areas. In places where the visual amenities add little to property values, the installation of industrial structures, such as wind-turbine generators, can do little to compromise the amenities and reduce property values. The situation in Nantucket Sound is markedly different and, hence, the Corps attempt to transfer evidence from elsewhere to this setting is inaccurate and inappropriate.

In sum, the Corps has relied on only some of the literature and evidence regarding the Projects potential impacts on property values. It failed, however, to recognize that, for the most part, this literature and evidence is inapplicable to this setting. Moreover, the Corps disregarded studies and evidence indicating that, because of the particular characteristics of Nantucket Sound, the Project may have a non-trivial, negative impact on the

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[52] Tennessee Valley Authority. 2002. ***Environmental Assessment: 20-MW Windfarm and Associated Energy Storage Facility, Appendix F--The Impact of Views on Property Values.*** April. http://www.tva.gov/environment/reports/windfarm/appendix_f.pdf

value people place on the area's natural resources. If such a negative impact should materialize, property values in the area might decline. The Corps must expand its analysis to embrace a broader consideration of all the relevant literature before it can justifiably claim that it has estimated the Project's impacts on property values with reasonable certainty.

The Corps compounds its failure to adequately review the relevant literature by not describing all of the views that the Project would affect and the relative importance of these views to property values. As described by James F. Palmer in his comments on the Corps' analysis of the Project's aesthetic impacts, the Corps has not identified the entire view shed that the Project would affect, nor has it studied the properties within this view shed.[53] Without a thorough review of the relevant literature, and without studying the view shed and affected properties, the Corps has no basis in fact for its conclusions regarding the Project's impacts on property values.

D. Reductions in the Ecosystem's Non-Use Values

The fourth item in Table 6 identifies the Corps' failure to consider the Project's impacts on the ecosystem's nonuse values, i.e., values people ascribe to the ecosystem even though they do not actively use its resources. The Corps did not analyze the Project's potential impact on the ecosystem's:

- Existence value, which is the value some people place on knowing that the ecosystem exists, with significant parts undeveloped and able to function in a more or less natural manner.
- Bequest value, which is the value some people place on being able to pass to the next generation the ecosystem in its current state.
- Option value, which is the value some people place on keeping the ecosystem unimpaired, so that potential future uses are not compromised.

To assist the Corps in correcting its failure to analyze the Project's potential impact on the ecosystem's nonuse values, we offer the following information:

- A recent report by the National Research Council on managing marine resources describes heritage (bequest) and existence values and notes the intergenerational importance of considering these values:[54]

> "Some of the services provided by marine ecosystems have market prices that can be adjusted to reflect their direct economic value. For example, the market prices of fishery products are commonly monitored and recorded in order to gauge the apparent values that consumers place on fishery products as well as the input costs used to provide these products. At the same time, market prices are not available for all services and, in some cases, may underestimate the true value of natural resource services. Market prices also may not give the correct

[53] *See* comments on the Draft EIS/EIR by James F. Palmer.

[54] National Research Council. 2005. *Marine Protected Areas: Tools For Sustaining Ocean Ecosystems.* Ocean Studies Board, Commission on Geosciences, Environment, and Resources. www.nap.edu.

'signals' about values that might be associated with either marine products or marine ecosystem services in the future."(pp. 49-50)

This report also summarizes the literature on methods of estimating nonuse values.

- A recent analysis of the economics of marine-resource management describes consumptive and nonconsumptive values.[55] Nonconsumptive values include existence and bequest values.
- An analysis of the economic consequences of establishing the Stellwagen Bank National Marine Sanctuary includes a discussion of the Bank's existence values.[56]
- A recent study of the socioeconomic impacts of establishing the Channel Islands National Marine Sanctuary summarizes the literature on option, bequest and existence values and related these values to marine resources.[57] The researchers conclude that marine resources can have significant nonuse values and for this reason should not be ignored even though analysts may not be able to quantify these values precisely.

  "All the benefits and costs of marine reserves cannot be quantified, and so a formal benefit-cost analysis is not conducted. Instead, we use the benefit-cost framework and list all the potential benefits and costs, and quantify them where we can. Where we can't quantify benefits or costs, we discuss them qualitatively and in what direction we believe benefits or costs will move ...." (p. 1)

  The approach demonstrates the analytical feasibility of taking a broad analytical perspective, providing as much economic information as possible. This contrasts with the Corps' analysis, which disregards or fails to disclose relevant information regarding the project's potential economic impacts.

To our knowledge, there exists no reliable estimate of the non-use values associated with Nantucket Sound that might be degraded by the Project. Studies elsewhere, though, suggest that that these values may be substantial. The recent analysis of the socioeconomic impacts of establishing the Channel Islands National Marine Sanctuary (CINMS), for example, found that the non-use values of protecting areas within the sanctuary outweigh the potential benefits of continuing to allow consumptive uses in the areas.[58]

"Here we provide a net assessment using the National Net Benefits Approach. Under this approach, only consumer's surplus and economic rent values are

[55] Carter, D. 2003. "Protected Areas In Marine Resource Management: Another Look At The Economics and Research Issues." *Ocean & Coastal Management* 46, 439-456.

[56] Perez, M, and Ruth, M. 2002. *Effectiveness and Economic Benefits of Stellwagen Bank National Marine Sanctuary*. A report prepared for Environmental Defense. February.

[57] Leeworthy, V. and Wiley, P. 2002. *Socioeconomic Impact Analysis of Marine Reserve Alternatives for the Channel Islands National Marine Sanctuary*. A report for the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. April 29.

[58] Leeworthy, V. and Wiley, P. 2002. *Socioeconomic Impact Analysis Of Marine Reserve Alternatives For The Channel Islands National Marine Sanctuary*. A report for the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. April 29.

appropriate for consideration, as in a formal benefit-cost analysis. We are not able to quantify all the costs and benefits, especially not across all alternatives, as with the nonuse or passive economic use values. But with certain assumptions designed to bias the result in favor of the consumptive activities, we show that the nonuse or passive economic use values would likely exceed all consumptive use values." (p. 108)

In their summary of the relevant literature, the study's authors found there significant evidence supporting the conclusion that the non-use values Americans place on protecting ocean ecosystems is considerable:

> **Factors Supporting Positive Nonuse Economic Value.** We reviewed four studies based on National surveys of U.S. households that evaluated adult's perceptions and concerns about the environment. In addition, one of the studies focused specifically on ocean related issues (SeaWeb, 1996) and found strong support for marine protected areas. One more recent study (SeaWeb, 2001) directly addressed the issue of marine protected areas and fully protected marine reserves. Each of the surveys demonstrated that U.S. citizens have a high level of concern about the environment and believe the environment is threatened and requires action and overwhelming support the creation of marine reserves. One recent study based on a survey of Californians (SeaWeb, 2002) found support for ... marine reserves in the CINMS. (p. 103, bold emphasis in original)

These observations echo the findings of other studies that have examined the non-use values associated with healthy, undeveloped ecosystems. An extensive study of federal lands in the interior Columbia River Basin, for example, found that the non-use values associated with undeveloped lands was roughly half the total value of all goods and services derived from those lands.[59] Also, a national study following the *Exxon Valdez* oil spill found that households expressed a willingness to pay $31 (median value) as a one-time tax to support measures that would prevent similar oil spills in the future.[60]

A separate expression of concern regarding the non-use values that might be diminished by offshore wind generators comes from the international Convention on the conservation of Migratory Species of Wild Animals. The U.S. is not a party to the convention but it participates in its agreements. Recognizing that offshore wind turbines can have significant benefits, including a positive impact on trends in climate change, the parties to the convention noted that "wind turbines especially in marine areas represent a new technique of large scale energy production, the actual effects of which on nature and on different components of biodiversity cannot be fully assessed or predicted at present." Based on this observation, the parties called upon the member nations "to take full account of the precautionary principle in the development of wind turbine plants, and to develop wind energy parks taking account of environmental impact data as and monitoring information as it

[59] Haynes, R.W. and A.L. Horne. 1997. "Chapter 6: Economic Assessment of the Basin." In *An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins, Volume IV.* Edited by T.M. Quigley and S.J. Arbelbide. General Technical Report PNW-GTR-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. June. Pgs. 1715-1869.

[60] Carson, R.T., C. Mitchell, W.M. Hanemann, R.J. Kopp, S. Presser, and P.A. Rudd. 1997. *National Survey Report March 31, 1992, Draft.* November 6. www.rff.org/~kopp/Reports/alaska.pdf.

emerges and taking account of exchange of information provided through the spatial planning processes."[61]

E. JEOPARDY TO INVESTMENTS IN THE ECOSYSTEM

The final item in Table 6 identifies the Corps' failure to consider the Project's potential, adverse impacts on past, present, and future investments by individuals, communities, and the Commonwealth of Massachusetts in protecting the health of the ecosystem that includes Nantucket Sound. The Commonwealth of Massachusetts, local communities, and stakeholders have long recognized the ecological and economic importance of Nantucket Sound's marine resources. Protecting the Sound's biological diversity, pristine qualities and unique habitats has been a priority of resource-management agencies and interest groups for more than thirty years. Long-term planning goals for the Sound include coordinating management and protection efforts among the Commonwealth and federal agencies that have jurisdiction over the Sounds' resources.[62] If implemented, the Project would jeopardize the productivity of these investments and compromise on-going efforts to accomplish long-term, ecological and economic goals for the area.

A recent report by the Center for Coastal Studies (CCS) describes the ecological resources, protection efforts and management plans that the Project potentially threatens.[63]

- The Sound contains habitat for protected species including roseate terns, piping plovers, leatherback sea turtles, loggerhead sea turtles, Kemp's Ridley sea turtles, and grey seals. (p. i)
- Nantucket Sound includes biologically-diverse habitats that range from open sea to salt marshes. These complex and diverse ecosystems remain the focus of continued scientific research. (p. 3)
- The Commonwealth's legislature passed the Massachusetts Ocean Sanctuaries Act in 1970. The Act created five ocean sanctuaries, one of which— the Cape and Islands Ocean Sanctuary— included the sections of Nantucket Sound over which the state has jurisdiction. (p. 1) Especially relevant to the Corps' review of the Project's impacts on local protection efforts is the fact that the Act prohibits constructing permanent structures or citing energy facilities within sanctuaries,

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[61] Convention on the Conservation of Migratory Species of Wild Animals. 2002. "Resolution 7.5: Wind Turbines and Migratory Species." http://www.cms.int/bodies/COP/cop7/proceedings/pdf/en/part_I/Res_Rec/RES_7_05_Wind_Turbine.pdf

[62] Center for Coastal Studies. 2003. *Review of State and Federal Marine Protection of the Ecological Resources of Nantucket Sound.* 26 pages. January 28.

[63] Center for Coastal Studies. 2003. *Review of State and Federal Marine Protection of the Ecological Resources of Nantucket Sound.* January 28. *See* also, Provincetown Center for Coastal Studies. 2005. *Toward an Ocean Vision for the Nantucket Shelf Region.* January.

"The Massachusetts Ocean Sanctuaries Act obliges the Department of Environmental Management ... to protect the sanctuaries from any development or activity that would damage the ecology or aesthetics of the area. Specifically prohibited within Massachusetts Ocean Sanctuaries are the construction of physical structures on the seabed, the building of offshore or floating power plants, ..." (p. 6)

- The Sound was twice nominated for National Marine Sanctuary status as a means of protecting areas of the Sound not included in the Cape and Islands Ocean Sanctuary. The review committee did not ultimately follow through on the nomination, noting the challenges of managing diverse ecosystems that cross multi-jurisdictional (Commonwealth and federal) boundaries. (p. 9-11)
- The Commonwealth noted that denying sanctuary status for the federal portion of the Sound leaves vulnerable the ecosystems in this area and threatens the resource-protection efforts and expenditures in the Commonwealth-protected areas,

  "The absence of marine sanctuary protection for the federal waters in the center of the Sound would negate efforts by the Commonwealth of Massachusetts to insure the environmental protection of the marine resources of this important water body through its Ocean Sanctuaries Program. Nantucket Sound must have a coordinated management regime ... if the ecological, recreational, historic and aesthetic resources of the Sound are to be adequately protected." (p. 10)

Another indication of the extent to which local stakeholders value and support the region's ecosystems is the hundreds of millions of dollars spent by local land trusts to purchase and protect habitats on Nantucket, Cape Cod and Martha's Vineyard. These protection efforts include:

- The Nantucket Land Bank Commission spent over $115 million between January 1, 1984 and June 30, 2004 purchasing habitat on Nantucket Island.[64]
- To date, the Nantucket Conservation Foundation purchased approximately 4,800 acres of habitat on Nantucket Island.[65]
- Through 2004, the Martha's Vineyard Land Bank spent approximately $88 million on land acquisitions for conservation purposes.[66]
- Between January 1999 and December 2002, the Cape Cod Land Bank spent approximately $94 million purchasing lands with significant habitat.[67]

The Commonwealth, with support from local jurisdictions and stakeholders, has expressed its commitment to maintaining and protecting the ecological resources of Nantucket Sound by passing the Massachusetts Ocean

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[64] Personal Communication with Craig Hunter, the Office Administrator of the Nantucket Land Bank Commission, January 6, 2005.

[65] The Nantucket Conservation Foundation, Inc. *Properties Map*. www.nantucketconservation.com/info_files/properties/map.html. Accessed on January 7, 2005.

[66] Personal Communication with Cindy Krauss, the Fiscal Officer of the Martha's Vineyard Land Bank. January 10, 2005.

[67] Cape Cod Land Bank. *Acquisition Status: Data Through December 2002*. www.capecodcommission.org/landbank/acquisition.htm.

Sanctuaries Act, by twice nominating the Sound for national marine sanctuary status, and by supporting land trusts that purchase and protect important terrestrial habitat that boarders the Sound. Local sentiment supports prohibiting building permanent structures and energy projects in the Sound. The Commonwealth has expressed its concerns regarding the consequences of developments in the federal portion of the Sound on protection efforts and management plans in neighboring waters under the Commonwealth's jurisdiction. The proposed site of the Project is surrounded by state lands and waters. If state jurisdiction extended to the site, state regulations would bar the Project's development.

The Project would undermine these resource-protection planning efforts and investments. With its implementation, the Commonwealth, local jurisdictions, and stakeholders would have to work harder and increase their investments to accomplish their goals insofar as the Project would pose risks to the ecosystem birds and interfere with and restrict historical uses of the area, such as fishing. In effect, the Project Sponsor would be pushing costs onto others to cope with the risks stemming from the unknown impacts of the Project's blades on birds and its electromagnetic fields on marine life, as well as the risks associated with potential oil spills and other accidents.

The Corps' analysis provides no information on the extent to which the Project would reduce the efficacy of resource-protection planning efforts and investments in the area's ecosystem. To correct this deficiency, it must fully document these efforts and investments and describe the Project's potential impacts on them.

VII. DEFICIENCIES IN THE CORPS' ANALYSIS OF RISKS ASSOCIATED WITH THE PROJECT

Projecting the Projectʼs economic effects over the next 25 years and beyond is a difficult exercise that requires making many assumptions about many key variables. It is an exercise that inherently embodies many uncertainties. Before the Corps can demonstrate, with reasonable certainty, that the Projectʼs benefits outweigh its costs, it must do more than evaluate the Project assuming that everything will occur as planned.[68] It must also consider the economic consequences if one or more things go wrong.

The Corps has not thoroughly considered the economic risks and uncertainties associated with the Project. Particularly important are the three categories of deficiencies in its analysis, shown in Table 7.[69]

Table 7. Summary of Deficiencies in the Corps' Analysis of Risks Associated with the Project

Component of Analysis	Deficiency
Financial risk, including risk of technological failure	Missing
Economic aspects of ecological risk	Missing
Navigation risk	Incomplete analysis

The first item in Table 7 identifies the Corpsʼ failure to assess the risks associated with the Projectʼs financial feasibility. Unless the Project Sponsor has unlimited resources to dedicate on the Project, should something go wrong, then there is some probability that it would lack sufficient resources to build, operate, and decommission the Project as planned. At the extreme, the Project Sponsor would go bankrupt, operation and maintenance of the facilities would be halted, and the wind-turbine generators would be abandoned on-site.

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[68] Guidance for how to conduct an analysis of risk and uncertainty is available to the Corps from the *Principles and Guidelines*, discussed above, and from the agencyʼs manuals. *See* U.S. Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources. 1991. *National Economic Development Procedures Manual: Overview Manual for Conducting National Economic Development Analysis*. IWR Report 91-R-11. October; and U.S. Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources. 1992. *Guidelines for Risk and Uncertainty Analysis in Water Resources Planning, Volume I: Principles*. IWR Report 92-R-1. March.

[69] Technical discussions of things that can go wrong sometimes distinguish between narrow interpretations of the terms, risk and uncertainty, with risk referring to those things whose probability of occurrence is known and uncertainty referring to those whose probability is not. To facilitate the discussion, we use the term, risk, in a broader sense to refer to both.

The Corps has not analyzed the Project's financial risks. Specifically, it has not evaluated:

- The extent to which the Project's financial feasibility depends on continued federal and state tax-abatements or subsidy programs, and the financial performance of the Project if these programs ceased.[70]
- The overall financial risks associated with merchant-power projects in the New England market given the recent bankruptcy filings and downgraded credit ratings for electricity producers in this market.[71]
- The Project-specific financial risks, including risks associated with its technology and its location.

There is much that remains unknown regarding the financial risks for the Project Sponsor stemming from the possibility that the Project might experience technological failure. The Project would push technology beyond the current envelope. It would be the first offshore, utility-scale, wind-powered generating plant in the U.S. Its generators with a generating capacity of 3.6 MW per turbine, would be twice the size of the largest land-based wind turbines previous installed in a utility-scale project in the U.S.[72] Moreover, the Project Sponsor has no experience with this type of project.

There also is much that remains unknown regarding the financial risks for the Project Sponsor stemming from the Project's proposed location. The Corps has not analyzed the potential financial and operational consequences if, for example, the Project should prove to have devastating impacts on birds or other wildlife, or if public discontent with having 130 generators operating at the site should grow.

The Corps' failure to analyze technological risks is at odds with the experience and concerns of the wind-power industry. A recent survey, sponsored by the British Wind Energy Association of "key players in the wind industry and related sectors" in the U.K. produced these observations:[73]

> "Technology risk is often cited as being the major issue in the development of offshore wind. Certainly there is great temptation to move to larger turbines quickly and sponsors who wish to take risk on new technology in order to get higher returns will undoubtedly have to find more equity for their projects. ...
>
> "It is the operational aspects of offshore wind farms, which are the most uncertain. Methods of access, the times when access can be gained, and other aspects of maintenance procedures are still debated.
>
> "Safety is an issue raised in a number of interviews in the survey. The industry is still developing solutions to the problem of safe and secure maintenance at large scale.

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[70] Evidence from the U.K. indicates financial support for offshore wind generators is sensitive to the degree of governmental support for the industry, and uncertainty about future governmental incentives can erode the supply of capital for offshore projects. *See* Temperton, I. 2003. "Financing Wind Beyond 2010: Survey Results." British Wind Energy Association. September. http://www.bwea.com/pdf/RO-Review-SurveyResults.pdf.

[71] Benson. 2004. U.S. Department of Energy White Paper. June 6.

[72] Peer-review committee, p. 9-10.

[73] Temperton, I. 2003. "Financing Wind Beyond 2010: Survey Results." British Wind Energy Association. September. http://www.bwea.com/pdf/RO-Review-SurveyResults.pdf.

However, this again is an issue on which there is much innovation and is an issue for the private sector and the relevant safety authorities." (p. 17)

The economic analysis in the Draft EIS/EIR is not consistent with these observations. It does not recognize that, among those with experience with offshore development of wind-powered generators Technology risk is often cited as being the major issue in the development of offshore wind. Failing to recognize the significance of this risk, it fails to evaluate its consequences.

The second item in Table 7 identifies the Corps failure to analyze the economic aspects of the Projects potential adverse ecological impacts. It has not, for example, estimated the economic values associated with bird kills or with ecological disruption stemming from noise, vibrations, and electromagnetic fields. It also has not estimated the economic values of ecological damage that would occur if the Project were to experience an oil leak from one or more generators or to contribute to a navigational accident involving an oil leak.

The third item in Table 7 identifies the Corps failure to conduct a complete and thorough risk assessment of the Projects navigational hazards. The McGowan Group reviewed the proponents assessment of navigational risks and found the assessment lacking.[74] As described in the McGowan Groups report, deficiencies in the proponents risk assessment include:

"Cape Wind's proposed Horseshoe Shoal location is at odds with common international practice and threatens disruption of the Main Channel as a marine transportation route.

Cape Wind's proposal for a Nantucket Sound site is fatally flawed in that it appears incompatible with marine transportation activity and poses unnecessary and unacceptable risks to cruise and ferry vessel, oil transport, fishing and recreational users.

Cape Wind proposes an inferior tower structural design, which may catastrophically fail if struck by known marine threats.

The Cape Wind assessment severely underestimates the safety and pollution consequences including loss of life and injury resulting from vessel collisions with a wind tower or with their rotating blades.

The Cape Wind assessment fails to explore the negative impacts to the Nantucket Sound fishing industry by acknowledging that these projects will effectively cutoff all trawling/dragging within the entire confines of the wind farm." (p. iii-iv)

The Corps nonexistent or incomplete economic assessments of the Projects financial, ecological, and navigational risks prevents a thorough review of the Projects benefits, costs, and feasibility. Without thorough assessments, it is impossible to discern from the draft EIS/EIR if the Projects economic benefits outweigh its economic costs.

[74] The McGowan Group. 2004. *Cape Wind Offshore Wind Farm: A Navigational Risk Assessment Review.* The Alliance to Protect Nantucket Sound. April 26.

Prepared Testimony of

Richard S. LeGore, Ph.D.

On Behalf Of

Alliance to Protect Nantucket Sound

Before the

Commonwealth of Massachusetts Energy Facilities Siting Board

Cape Wind Associates, LLC and Commonwealth Electric

EFSB 02-2/D.T.E. 02-53

June 20, 2003

Q: What is your name?

A: Richard S. LeGore.

Q: What is your current position?

A: I am President of Mote Environmental Services, Inc. and a Senior Scientist of Mote Marine Laboratory. I am also the Executive Director of the Association of Marine Laboratories of the Caribbean.

Q: Please describe your expertise and professional background and experience.

A: My particular fields of competence are multidisciplinary project management in marine and freshwater ecology; environmental policy; fisheries including marine ornamentals, invertebrates and finfish; oceanography and limnology; water monitoring; aquatic toxicology; and environmental impact assessment.

Q: What is the purpose of your testimony?

A: The purpose of my testimony is to provide a review of the potential benthic impacts of the proposed Cape Wind project. This review was conducted at the request of the Alliance to Protect Nantucket Sound. The Alliance requested that Mote Environmental Services, Inc. (MESI) conduct an objective review of the adequacy of the impact analysis in the Environmental Notification Form (ENF) published on November 15, 2001 for decision-makers to competently judge whether there are net environmental benefits associated with the power that would be produced as a result of the Applicant's development proposal. It is restricted to components of the ENF dealing with impacts on benthos potentially resulting from the proposed Cape Wind wind-to-energy project. This version of the ENF is the only information from the Applicant that MESI has had an opportunity to review. My understanding is that a draft Environmental Impact Statement/ Environmental Impact Report will be produced at some point, which might allow a more refined analysis, but that the document is not yet available.

Q: What are your general conclusions regarding the ENF's description of the potential benthic impacts of the proposed development?

A: In general, this review determined that the ENF provided inadequate information concerning benthic community impacts to allow competent evaluation of the Applicant's proposed development. The document contains several general conclusions without providing supporting data or analysis. For example, on page 1-2, the document states: "The studies and investigations indicate that construction and operation of the Wind Park will not result in any significant adverse environmental effects to existing seabed conditions, aquatic resources, and avian communities on Horseshoe Shoal." This statement may or may not be true, but it is impossible to adequately evaluate it with the information provided in the ENF. As described below, critical information is omitted from the report, while other analyses normally required of such investigations were apparently not conducted. It is clear that in order to adequately evaluate the potential for environmental impacts of this proposed development on benthic resources, additional investigation and analysis is required.

Several suggestions for additional study are provided in this review. All are intended to support the general requirement that the Applicant's EIR "should evaluate the potential impacts of the WTG array and associated cables (construction, operation, and maintenance) on benthic habitat and species composition and relative abundance in the project area" as provided by the Massachusetts Certificate of the Secretary of Environmental Affairs (April 22, 2002) by recommending specific areas or approaches contributing to this analysis.

Q: What do you see as the deficiencies in the existing benthic impact analysis?

A: I have identified 12 respects in which the existing benthic impact analysis is deficient. These relate to:

- The function of an environmental review in general;
- The requirement for improved reporting of the benthic sampling plan;
- The inadequacy of the benthic impacts analysis offered by the Applicant;
- Homogeneity vs. heterogeneity of sediments in the development area;
- The absence of data concerning epibenthic macrofauna;
- The issue of taxonomic specificity;
- Trenching impacts;
- The impacts of the piles on benthos;
- Recommendation for sediment transport modeling;
- Habitat changes and their impacts;
- Electromagnetic effects of transmission cables; and
- Construction issues.

Q: What are your comment regarding the ENF with respect to the function of environmental review?

A: In my view, it is not the role of the scientist to decide the social significance of environmental impacts; this is a socio-economic decision made by society at large and by its responsible representatives. It is the scientist's role to provide, to the best of his ability, accurate and sufficient information upon which society may base its decision-making. While "significance" plays a role in scientific analysis, this term is properly restricted to use in a statistical sense. It is reserved to the public and its representatives to decide whether the environmental cost of any particular project is counter-balanced or outweighed by its social benefits.

In the area of impacts on the benthic community, the level of environmental impact analysis for the Cape Wind project is currently inadequate. This project may or may not ultimately be judged sufficiently beneficial for it to be implemented, but the information currently available is inadequate to responsibly make this decision. It is recommended that additional study be conducted before this application is decided and relevant state and federal permits are issued.

Q: What is your opinion with respect to the reporting of the benthic sampling plan for the project?

A: It should be improved. The benthic field investigations are claimed to have been "comprehensive" for determining environmental effects, but this is impossible to know with the level of detail provided in this report. A maxim of technical scientific writing is that the methods and strategies employed in any study must be provided so that reviewers may evaluate them and form their own opinions as to conclusions that may be justified by the study. In this case, the methods employed were not described. The rationale underlying the sampling plan was not described. Even the equipment utilized was not described.

The ENF indicates that "46 benthic grab samples" were collected [page 7-17], but nowhere is the kind of grab indicated. Numerous styles of benthos grabs are commonly used, and each has its own uses and limitations. Some penetrate sand well while others do not. Some sample a small area, while others sample larger areas. Some are more efficient at digging into the substrate, while others tend more to scrape upper layers of sediment. It is important to understand what was done in this study, but details are not provided.

Similarly, the ENF reports that "Ninety-five taxa were identified in the benthic grab samples collected for the Project" [page 7-18]. This statement may be sharply contrasted with the literature review conducted by Battelle, which "reports that 333 species of polychaete worms [alone] were identified in sandy sediments from Georges Bank and Nantucket Shoals in a 981 study" [same page]. This huge discrepancy is lightly dismissed by the statement that "Biomass is most likely lower in Nantucket Sound because of the unstable sandy sediments in these shallow waters." No documentation or data are provided, however, to support such a conclusion. Another potential reason for the discrepancy is that the current study may have used a coarser mesh screen to separate benthic organisms from the sediments. Many of these species are tiny, and many species may be lost from the sample if overly coarse meshes are used. This report provides no basis for considering this possibility, because the equipment and methods used in the study are not reported. This is very important, because as the ENF itself states: "These polychaetes are a favorite prey of several species of demersal fish, particularly winter flounder . . ." Thus the impacts of this project on these important fish food species cannot be evaluated using the current information.

Data resulting from the benthos surveys were not even reported. There are no species lists, no numbers of organisms captured, and no density data. In addition, data provided by the Battelle literature review are not included in the report. There are no analyses of species richness, species diversity, or any other parameters or comparisons useful for estimating project impacts on benthos. There is no indication that spatial variations in benthic community characteristics throughout the proposed project area were sought.

Data resulting from the Applicant's survey should be compared to previous studies in tabular and text discussion formats. Changes or variations in benthic community structures over time and over space should be identified, so that reasonable estimates of potential environmental impact may be made.

Finally, copies of the Battelle literature review should be provided as an attachment to the ENF, because it is not otherwise available in the openly published scientific literature. It is cited in the ENF as follows: "Battelle. 2001. Technical Report Submitted to ESS, April, 2001." This report clearly contains substantial information relevant to this environmental impact analysis that is not provided in the ENF. These important data should be made readily available.

Q: What is your opinion of the benthic impacts analysis offered by the Applicant?

A: It is inadequate. The Applicant's benthos survey was apparently conducted one time, in Spring-Summer 2001, which is probably not adequate to characterize seasonal fluctuations of the benthic communities in the development area, unless a strong case may be made from the literature that adequate information already exists. The structure of benthic communities frequently exhibits seasonal cycles, and such fluctuations are likely in the project area. As noted by the ENF [page 7-13], bottom water temperatures in Nantucket Sound range from 61-66 F in the summer to 32-35.6 F in the winter. This implies annual community structure cycles caused by factors such as growth patterns, reproductive cycles, and predation cycles by fish. This issue is not addressed by the current ENF, however, and additional sampling is recommended to account for seasonal fluctuations, which may be important both for understanding benthic community dynamics in the area, and during consideration of construction operations and schedules.

A very important consideration not addressed n the ENF is that of particle size distribution of sediments in the project area. The character of the benthic infaunal community – that part of the benthos living in the sediment as opposed to on the sediment – is frequently determined primarily by the distribution of sediment particle sizes in their environment. It is therefore usual to include samples for particle size analysis in benthos surveys, so that particle size profiles may be correlated with benthic community type. Particle size profiles then become an important tool for predicting kinds of animals occurring in particular types of sediments, and which animals are likely to become established in new areas as sediments are disturbed or redistributed. The virtual lack of such information in the ENF is a serious deficiency, which should be corrected. The sediment classification data provided in Table 7-3 of the ENF was collected for other reasons, and is far from adequate for benthic community analysis, because it utilizes far too few size categories.

It is not clear that any attempt was made to determine spatial variability in benthic community structure, and this omission should be corrected. The entire proposed project area was treated as a homogenous unit, which is apparently not accurate, based upon other statements and data provided by the ENF (see section 3.4, below). It is important to understand spatial variability in order to predict whether anticipated impacts on benthos will be restricted to specific areas or not, or whether there are particularly sensitive zones that should be treated differently within the development area.

It is not clear that any statistical analyses, such as species richness or species diversity, were conducted to support the Applicant's analysis of benthic impacts. None are reported. Indeed, the only benthos data appearing in the report is in Table 7.5, which provides data from a published report in an unconventional format whose meaning is unclear, the data are quite old (1958), and the citation for the original report is not provided.

The ENF states, "The diversity (i.e., numbers of species and numbers of individuals per species) of the Nantucket Sound benthic fauna is lower than diversity in the rest of the Southern New England Shelf" [page 7-15]. There is no indication or documentation, however, of the basis for this statement, nor is the relevance of this statement to the impact analysis discussed.

A puzzling statement appears on page 7-18 of the ENF: "gastropods [snails] were often found in relatively high densities, particularly along the proposed submarine cable routes" It is not clear whether the high densities of snails were characteristic of the specific cable routes proposed by the Applicant, or if they also would have been found in other nearshore areas if these had been sampled. If they are indeed so much more plentiful along the specific proposed cable routes, however, one must wonder whether it would be appropriate to consider other alternatives to the route that might not be so heavily populated. It would also be helpful if the report indicated what kinds of snails were found. Impact conclusions might well differ, depending on whether the snails were large commercially significant whelks or small mud snails.

In summary, the existing report contains several deficiencies that should be addressed if authorities wish to consider benthic impacts in their deliberations concerning this proposed project.

Q: Has the Applicant adequately addressed the heterogeneity of sediments in the proposed development area?

A: No. The ENF treats the entire project area as though it were a single homogenous benthic community. It states: "Although the same species are expected to be the dominant inhabitants of sandy sediments throughout Nantucket Sound . . ." [page 7-17]. The sound is not uniform, however, as stated within the ENF itself [page 7-3], "Charted seabed conditions of the shoal are noted on navigational charts as being rocky in areas shallower than 30 feet . . ." Also, on page 7-5, the ENF states that "the bottom sediments on and surrounding Horseshoe Shoal consist of fine to coarse-grained sands, with localized fractions of clay, silt, gravel and/or cobbles," indicating substantial variation in bottom types. It is further significant that the report refers to "fine to coarse-grained sands," because fine-grained sands frequently support different benthic communities than do coarse-grained sands. It is clear that treating the project area as a homogenous unit is inappropriate for analysis of impacts on the benthos.

In order to overcome this deficiency, it is recommended that mapping of the benthic habitats within the project area be required. This may be accomplished by conducting a video survey of the bottom, as described in the following section 3.5, supplemented by several bottom coarse for particle size analysis. It would be most helpful if results were plotted in GIS format for future use.

Q: What is your view of the Applicant's treatment of epibenthic macrofauna?

A: I find that data regarding such macrofauna are virtually absent from the ENF. This appears to be due, at least in part, to the definition of "benthos" provided in the ENF, which I find to be somewhat misleading. It states, "Benthic organisms (or benthos) include those organisms that live either on or beneath the seabed floor, and include worms, insects, small clams, and other macroinvertebrates" [page 7-15;]. Benthos also includes large clams, as well as other large organisms such as large snails (e.g. whelks), crabs, starfish, and lobsters.

Most benthos grabs, as used by the project study, are inappropriate for even semi-quantitative sampling of these important larger benthic animals. The current study, as well as the ENF in general, virtually ignores these important animals in its analysis. This is a deficiency that should be corrected.

It is recommended that a video survey of the project area bottom be conducted to estimate the populations, locations, and habitat associations of these animals. The larger epibenthic organisms can be observed directly, and it may be possible to estimate quahog populations by counting siphon holes. The latter technique has been used successfully in other studies.

Q: How effective is the ENF in its treatment of taxonomic specificity?

A: Taxonomic classifications used in the ENF discussion are much too general for understanding impacts; data should be presented to species level if possible, and to the lowest identifiable taxon when unable to identify animals to the species level. Characterizing the benthic fauna of Nantucket Sound as being dominated by crustaceans (including amphipods) and mollusks, with bivalves being "the most abundant and diverse of the mollusks" but with snails also being "common," is absurdly superficial for environmental impact analysis. There are few coastal environments on the planet for which these statements would not be true, and they are hardly discriminating for the current case.

Using more discriminating taxonomic classifications will allow more powerful statistical treatments of biodiversity, species richness, etc., and will be useful in clarifying how homogenous or heterogeneous the benthic communities in the project area actually are.

They may also allow somewhat discriminating consideration of which components of the benthos are of most importance as food for specific fishes, which may assist clarification of impacts on local fisheries.

Finally, a more discriminating taxonomic record will be particularly important for defining an environmental baseline against which future monitoring may be compared to assess actual impacts over time, and definition of corrective actions should they become necessary.

Q: What is your opinion regarding the treatment of trenching impacts in the ENF?

A: The conclusion that trenching impacts to benthic fauna "will be localized, temporary and short-term" are inadequately supported by data or analysis presented in the ENF.

The ENF states: "The submarine cables will be installed using the environmentally sensitive (low impact) and well accepted methodology of water powered installation known as 'jet-plowing.' Jet-plow embedment technology involves the use of pressurized water jets to fluidize the seabed sediments along a very localized path. The cable is layed (sic) out directly following the jet-plow tool, settles via gravity through the fluidized sediments to the established depth of 6 feet and then is buried as the sediments settle back in place." This description raises several unanswered questions that should be addressed before deciding the future of the proposed project.

First, the claim of low impact environmental sensitivity should be substantiated by data or studies documented in the literature. If this methodology is indeed "well accepted," surely effects of earlier applications of it have been documented, and representative documentation should be provided as input to the decision-making process. If such documentation is not available, then the suggestion by Mass Audubon to stage development becomes more attractive to acquire local experience with this equipment, and to afford an opportunity for monitoring the actual effects of the methodology.

The ENF reports that 108,000 linear feet (20.5 statue miles) of cable will be laid just for the two circuits linking the system to the landfall [page 5-2]. We were unable to find an estimate of total cable to be laid in the ENF. If we assume that the trench will be six feet wide at its surface, then we may calculate that 14.9 acres will be disturbed by jet-plowing just for these two cables. [(108,000 feet of cable x 6 feet wide)/43,560 square feet per acre]. The ENF concedes that jet-plowing will have a localized and temporary effect, but does not clarify what those effects will be.

[The Alliance informed MESI that one reviewer estimated the total length of cable required for this project to be 340 miles, but this is not possible to know from the ENF. However, if we utilize this figure for the moment, then the cable-laying will disturb at least 247 acres of bottom substrate.]

If sediments in the trench are fluidized and kept in suspension by the jet-plow, they will tend to settle after the jet-plow is gone. It is likely that sediments will settle differentially, that is, heavier or denser particles will tend to settle most quickly, and the lighter fine particles will tend to settle more slowly. If this occurs, it may well create infaunal habitat quite different from that existing prior to jet-plowing, particularly in cases where the existing habitat consists of a well-graded mixture of particle sizes. Such habitat alterations can significantly impact the rate of recovery or recruitment of new benthos populations into the disturbed sediment, and could change the ultimate character of the community.

This all assumes that the sediments remain in the trench, as implied by the ENF. However, this may not be the case. The ENF reports the "Water mass movement in Nantucket Sound is primarily dominated by strong, reversing, semidiurnal tidal currents . . . [and] the average tidal current velocity varies from about one to two knots . . . [while] peak tidal currents often exceed two knots" [page 7-12]. If this is indeed the case, it is unclear what forces will prevent the fluidized sediments from being drawn out and away from the trenches, leaving depressions or perhaps even naked trenches behind. The potential for poor retention of these sediments is a function of anticipated currents, sediment particle characteristics, trench geometry, probably duration of fluidization, and similar issues. It is recommended that the potential for loss of these sediments be examined using appropriate sediment transport models.

Even if enough sediment is retained to partially refill the trench, a depression may result for some period of time. Such depressions are sometimes capable of forming microhabitats that support an altered benthos community. Whether this might occur as a result of this project, or what its impact might be is not considered in the ENF.

There also may well be potential for differential mortality of larger macroinvertebrates. Mobile invertebrates may be able to avoid the jet-plowing area, but less motile animals such as starfish and clams will not. As these areas are disturbed and sediments resettle, it is likely that the larger and heavier invertebrates will settle first and be cast to the bottom of the trench, where they will die. The impact of this phenomenon is difficult to assess in the absence of population data for these animals, which is the current situation.

Q: Has the ENF accurately described the potential impacts of the piles on benthos?

A: This ENF called for setting 170 piles averaging 20 feet in diameter to a depth of some 80 feet into the bottom sediment using vibrators or drop hammers, but

MESI has been informed that the number of WTG piles has since been reduced to 130, which was used for all evaluations in this review. This equates to 0.94 acres that will be permanently removed from benthic production. Without species density information, it is difficult to quantify the loss of benthic organisms. It also may be anticipated that significant scouring of sediments will occur at the base of each piling. The extent of this scouring should be modeled so that the aggregate impact on benthic habitat may be assessed. The ENF acknowledges that some scouring may occur, but does not quantify it. It is also not acknowledged as a benthic habitat impact, but rather as a construction issue. Nevertheless, it is possible that scoured areas will support different kinds of benthic communities, especially in cases where scouring removes sediment until more densely packed substrates are encountered. The likelihood of this occurring is not discussed in the ENF, but it should be considered.

Q: What is your opinion of the ENF's recommendation for sediment transport modeling?

A: This project calls for at least 108,000 linear feet of cable-laying trench. The trenches will be up to 6 feet across and 7 feet deep. A total of at least 4,536,000 cubic feet of sediment will therefore be fluidized and subject to transport during construction. If the estimate of 340 miles of cable is correct, however, this figure rises to 75,398,400 cubic feet, or 2,792,533 cubic yards. In addition, scouring will occur at the base of each WTG piling and at the base of each piling supporting the Electrical Service Platform. The significance of these sediment sources has not been analyzed in the ENF, and therefore remains unknown. It is recommended that the transport of these sediments be modeled to determine where they will go and where they will accumulate, and results should be evaluated to determine is significant environmental impacts will result. While this is not related directly to benthic communities, it is notable that the project area is bounded on most sides by designated navigation channels, and it will be of interest to determine if sediments will be deposited in the channels.

Q: What are the potential habitat changes associated with the project, and the impacts of those changes?

A: This project will result in the addition of a substantial amount of new hard substrate for colonization by benthic and "fouling" organisms. If we assume each WTG piling is 20 feet in diameter, and that the average piling is set in 30 feet of water depth, then more than 245,000 square feet (5.6 acres) of new vertical hard substrate is added to the system ($2\pi r$ x 30 ft depth x 130 WTG pilings = 2 x 3.1416 x 10 x 30 x 130 = 245,045 sq. ft.).

In addition, an unknown amount of riprap may be distributed at the base of each piling, adding even more new hard habitat.

An analysis of the types of organisms that may be expected to settle on these habitats will be helpful for understanding whether they might lead to changes in the local biotic communities. For example, if species formerly uncommon in the project area settle here, it is conceivable that they will provide new food sources and consequently attract new species or increase success of species already present, elevating their numbers and altering community dynamics. If this is possible, then estimates of potential impacts, both negative and positive, should be made. If this is not expected to occur, reasons and supporting data should be provided.

Q: What are the potential electromagnetic effects of the transmission cables?

A: Research indicates that several fishes are aware of and react to electromagnetic fields, including eels, salmon, sharks, and rays. Sharks are believed to utilize electromagnetic fields for navigation and for locating prey. The sensitivity of sharks to electromagnetic fields is so great that they are reportedly capable of detecting electric fields as low as one microvolt per meter, which corresponds approximately to detecting the charge from a 1.5 volt battery with terminals on opposite sides of the Atlantic Ocean.

The effect of the buried transmission cables on populations of sharks and rays is not known, but should be assessed or included in monitoring plans. This is clearly a fisheries issue, but the potential exists for it to secondarily impact benthic communities. If the EM fields created by the transmission cables cause fluctuations in shark and ray populations, benthic communities may be affected. For example, if the fields attract mollusk-eating rays, the populations of mollusks may be affected. On the other hand, of rays are excluded from the area by the EM fields, populations of mollusks might increase.

Q: What are the construction issues raised by this project?

A: Little attention is paid in the ENF to defining how long construction activities will last, and how they may affect the benthic environment. It is not clear how many months will be required to install 130 WTG pilings, or what the impact of sound generated over this time by drop hammers will be. This issue is likely more important to considerations of impacts on fishes and mammals, but the question may be raised as to whether prolonged loud sounds, which will be carried into the water through the steel piles, may affect behavior of motile epifauna. This reviewer is not personally familiar with literature pertinent to this issue, but raises the question nevertheless.

Perhaps more intuitively relevant is the issue of anchor line sweep. While pilings are driven, work barges presumably will be anchored in place, probably with multiple-point anchor arrays. Anchor lines may consist of large ropes, cables, or chains, and frequently caused substantial damage to benthos when they scrape across the bottom as they sway back and forth throughout the time the vessel is anchored. Damage inflicted at 130 pile-driving sites over a period of many months or years may potentially be substantial, but this issue is not discussed in the ENF, which is a deficiency.

Q: What recommendations do you have for the Siting Board regarding its consideration of the environmental impacts that would be associated with the proposed transmission cable and the power that would be produced by the proposed wind farm?

A: I have two recommendations. First, it seems pertinent to echo the suggestion made by Mass Audubon that should this project be permitted, it should begin with far fewer turbines so that experience may be accrued concerning construction, operations, and understanding of environmental impacts. This is a large-scale project without precedent, and it seems intuitively clear that early observations will increase our confidence that aggregate impacts may be understood before an irretrievable commitment is made.

Second, the Cape Wind project clearly will be a significant commitment if it is permitted and implemented. Its scale is also without precedent, and several environmental issues will undoubtedly remain unresolved for some time. It is strongly recommended therefore, that an environmental monitoring program be established with several objectives:

- To reassure the public that environmental issues are in control;
- To increase our knowledge base concerning impacts and mitigation potentials in such developments; and
- To assure minimum project impacts by allowing changes in construction and operations practices if unacceptable impacts are observed during monitoring.

Benthic monitoring should incorporate several system components, including pilings and rip-rap, trench areas, scouring areas, and several random stations throughout the project area. In addition, it is recommended that a third party advisory panel be established to periodically review monitoring results and recommend mitigation measures to minimize environmental impacts during the ongoing operation of the project.

Q: Does this conclude your testimony?

A: Yes, it does.

Prepared Testimony of

Mark Weissman

On Behalf Of

Alliance to Protect Nantucket Sound

Before the

Commonwealth of Massachusetts Energy Facilities Siting Board

Cape Wind Associates, LLC and Commonwealth Electric

EFSB 02-2/D.T.E. 02-53

June 20, 2003

Q: What is your name?

A: Mark Weissman.

Q: What is the purpose of your testimony?

A: The purpose of my testimony is to provide the Siting Board with information regarding the potential impacts of the Cape Wind project, and the power it would produce, on fisheries in Nantucket Sound. To further this purpose, I will also provide background on the unique regulatory milieu in which the Sound is situated, as I believe this to be a point of some confusion in the general debate regarding the proposed wind farm and associated undersea cable.

Q: What is your background and experience with respect to Massachusetts fisheries?

I am in my tenth year as a member of the Massachusetts Marine Fisheries Commission ("MFC"). The MFC is a nine-member regulatory board that oversees Marine Fisheries rulemaking activities. The MFC was established by the Legislature in 1961, and its members are "qualified in the field of marine fisheries by training and experience." Commissioners are appointed by the governor to three-year terms, and attend monthly business meetings as well as quarterly public hearings.

I was also one of the founding directors and first chairman of the Massachusetts chapter of the Coast Conservation Association, an organization that is dedicated to preserving marine resources. I have a background as an academic, consultant, editor and writer, entrepreneur, inventor, conservationist, and fisheries manager. I have also fished Nantucket Sound for over 40 years.

Q: By way of background, under what laws does the Commonwealth of Mass. have the responsibility and obligation to manage the marine fisheries resources, habitat, and fishing activity in all of Nantucket Sound?

A: Under Section 17(10) Chapter 130 of the Massachusetts General Laws and the Magnuson-Stevens Fishery Conservation and Management Act (Section 306(97-453, 98-62). Please note that this includes the portion of the Sound that might be considered "Federal" waters. While I understand that the jurisdictional implications of the specific location of the wind farm has been a topic of some debate, for purposes of my testimony regarding fisheries there is no question that the entire Sound, including the area where the wind farm would be built, is the responsibility and obligation of the Commonwealth of Massachusetts.

Q: Is the Sound a National Marine Sanctuary administered under joint state and federal control?

A: No.

The National Marine Sanctuary system was established "to identify, manage, and conserve areas of the marine environment that are nationally significant due to conservation, recreational, ecological, historical, scientific, educational, cultural, archaeological or aesthetic qualities" (National Marine Sanctuaries Act, 16 USC Section 1431).

The Commonwealth nominated Nantucket Sound for National Marine Sanctuary status in 1980 to secure protection for the central portion of the Sound not included within the Cape and Islands Ocean Sanctuary act passed in 1970 (M.G.L. c. 132A, §§ 13-16, 18). The Massachusetts Ocean Sanctuaries Act obligates the Department of Environmental Management (DEM) to protect five ocean sanctuaries, including Nantucket Sound, from any exploitation, development, or activity that would damage the ecology or aesthetics of the area. Specific prohibitions within the Cape and Islands Ocean Sanctuary include the construction of physical structures on the seabed, the building of offshore or floating power plants, the drilling through or removal of mineral resources, gases or oils, and dumping of wastes.

Q: Why is Nantucket Sound important from the perspective of fisheries and other environmental resources?

A: The Sound is clearly a significant state, regional, and national resource, a fact that is reflected in the policies of the Commonwealth toward the Sound. A recent report prepared at the request of U.S. Representative William Delahunt (MA 10th District) by the Center for Coastal Studies found that the Sound "contains significant ecological, commercial and recreational resources that have been at the heart of several past nominations for enhanced environmental protection and conservation policies within the region." The CSS report chronicles more than three decades of state policy clearly intended to protect Nantucket Sound from harmful development – from the legislature's inclusion of the entire Sound as part of the Cape and Islands Ocean Sanctuary in 1970, to the nomination of the Sound to become a National Marine Sanctuary in the early 1980s.

Although the Sound was deemed eligible for inclusion on the Site Evaluation List for National Marine Sanctuaries published in the Federal Register in 1983, it has not yet been selected for the national sanctuary program. The current freeze in

Congress on funding for new sanctuaries makes unclear what will eventually happen to this area at the Federal level, but long-standing state policy to protect the entire Sound is perfectly clear.

Q: In what ways is Nantucket Sound a unique and valuable ecosystem that warrants Sanctuary status and protection?

A: Again I would cite the Center for Coastal Studies report, which states, "Nantucket Sound is situated at a confluence of the cold Labrador currents and the warm Gulf Stream. This creates a unique coastal habitat representing the southern range for Northern Atlantic species and the northern range for Mid-Atlantic species. The transitional ecology of the region ... is characterized by an extreme richness of biological diversity, containing habitats that range from open sea to salt marshes." The Commonwealth's Executive Office of Environmental Affairs has praised the waters of the Sound "for their value as a habitat area, species area, unique area, and a recreational and aesthetic area" (EOEA 1980 Nomination, p. 5). In regard to the Sound's perceived value as a "recreational and aesthetic area," it is important to note that Sound is one of the few oceanic wilderness areas on the east coast that is readily accessible to large numbers of people. It is in fact the fishing and boating capital of the northeast. (More than 15,000 private boats are registered in Cape and island towns bordering the Sound, and a great many more can be seen crossing the Bourne and Sagamore Bridges on trailers every weekend.)

Q: Why is Nantucket Sound designated "Essential Fish Habitat" ("EFH") for many species of fish and other marine animals?

A: The U.S. Congress defined EFH in the Magnuson-Stevens Fishery Conservation and Management Act as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (16 U.S.C. 1802(10). Congress further stated, “One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats. Habitat considerations should receive increased attention for the conservation and management of fishery resources of the United States” (16 U.S.C. 1801 (A)(9)).

The New England Fisheries Management Council, charged with implementing the Magnuson-Stevens Act, has designated Nantucket Sound as EFH for all of the species included in the table below.

Species	Eggs	Larv.	Juv.	Adults
Atlantic cod (Gadus morhua)		X		
winter flounder (Pleuronectes americanus)	X	X	X	X
yellowtail flounder (Pleuronectes ferruginea)			X	
windowpane flounder (Scopthalmus aquosus)				X
long finned squid (Loligo pealei)	n/a	n/a	X	X
short finned squid (Illex illecebrosus)	n/a	n/a	X	X
Atlantic butterfish (Peprilus triacanthus)	X	X	X	X
Atlantic mackerel (Scomber scombrus)	X	X	X	X
summer flounder (Paralicthys dentatus)	X	X	X	X
scup (Stenotomus chrysops)	n/a	n/a	X	X
black sea bass (Centropristus striata)	n/a	X	X	X

surf clam (Spisula solidissima)	n/a	n/a	X	X
king mackerel (Scomberomorus cavalla)	X	X	X	X
Spanish mackerel (Scomberomorus maculatus)	X	X	X	X
blue shark (Prionace glauca)	X			
bluefin tuna (Thunnus thynnus)	X	X		

Note that bluefish and striped bass are not included in the table because they are not under Federal management.

As an aside, the Expanded Environmental Notification Form (EENF) filed by Cape Wind notes that the Sound has not been designated a "habitat area of particular concern (HAPC)." This is true, but doesn't necessarily reflect on its importance as essential habitat. HAPCs can be designated for several reasons, which include, ironically, being stressed by development activities.

Q: Why is it important for the Siting Board to have a complete and accurate understanding of the abundance and diversity of the marine resources in Nantucket Sound?

A: My understanding is that the Siting Board will consider, among other things, whether there is a need for the power that would be produced by the Cape Wind plant on the grounds that it provides environmental benefits to the state or region. In my view, no agency could make such a determination without assessing all of the potential environmental impacts of a power project and, in this case, no such assessment can be made without understanding the nature and extent of the environmental resources that would be affected by a project.

Q: How accurate are statements in the EENF regarding the abundance and diversity of marine resources in Nantucket Sound?

A: Numerous generalizations, statistics, and tables presented in the EENF grossly understate the diversity and abundance of marine resources in the area and their commercial and recreational importance. A detailed analysis (which I believe it should be Cape Wind's responsibility to secure) is beyond the scope of this paper, but could be produced by the Division of Marine Fisheries, if requested. I will limit myself to discussing several representative misleading statements and errors.

Regarding general abundance: The EENF introduces its analysis of the finfish and benthic communities by stating, "Generally, the relative abundance and diversity of species in the fish community is highest in areas of upwelling and greater productivity. These include Georges Bank ... and the Gulf of Maine; all areas outside Nantucket Sound." The implication is that Nantucket Sound is therefore an area of low abundance and diversity. However, since the Sound is a bio-geographic boundary between major warm and cold global currents, the mixing of New England and mid-Atlantic species actually results in a high diversity index. That resource abundance is also high will be evident from commercial and recreational statistics below. (Certainly the biomass of the Sound is not as high as on George's Bank, but that is hardly the point, and George's bank does not host anywhere near as large a recreational fishery as the Sound does.)

Regarding the detailed assessment of the finfish community: The EENF states, "several demersal and pelagic fish species utilize the Horseshoe Shoal area." The EENF then goes on to provide what it calls "a detailed assessment of the finfish community," said to be based on data excerpted from trawl surveys studies conducted by the National Marine Fisheries Service (NMFS) and Massachusetts Division of Marine Fisheries (MDMF). These surveys indicate, according to the EENF, "that the fish population was dominated by six species, representing more than 95% of the total combined catch by weight." The list that follows includes these items: scup (309.1 kg – 39.8%), long-finned squid (144.8 kg – 18.6%), down through three species of flounder, and ending with black sea bass (66.9 kg – 8.6%).

The confusing impression created here is that maybe a few hundred kilograms of fish represent "the fish population." Of course, it is misleading to call the sampling data "the fish population." But this section of the EENF: "7.4.2 Studies Completed to Date: Finfish Community," cites no other abundant species or measures of abundance.

This is patently absurd on several counts. First, the numbers quoted come from a few scientific trawls made each year to collect data for fisheries management purposes, not count it in absolute numbers. By analogy with a typical public opinion poll, one might deduce trends from the data but wouldn't conclude that there were only 1,500 people living in the United States.

The second, more significant problem is this data comes from slow-moving bottom survey trawls conducted in May and September. Timing of this sampling is a key study component related to the purpose for which these surveys were designed. They are not intended to characterize year-round abundance and species diversity. Important late winter/early spring forage species such as sand lance are not going to be caught during the study periods. Mid-water fish and bottom species that are quick enough to get out of the way also never show up in the net. That is why there are little or no herring, alewives, mackerel, striped bass, bluefish, bonito, etc. in the trawl survey, although these species occur in the Sound in great numbers.

A later section of the EENF, "7.7.2: Studies Completed to Date: Commercial Fisheries," lists six commercial species caught in the Sound, including squid, mackerel, scup, channeled whelk, black sea bass, and summer flounder. There is no mention of bluefish, striped bass, or tautog, which are commercially landed in large numbers.

The analysis of recreational fisheries provides another, egregious example of misleading statistics. Five tables of NMFS raw sampling data are referenced for the purpose of characterizing the recreational fishing participation and catch in the Sound. "Table 7.12 The Total Number of Recreational Species Observed by Interviewers in Nantucket Sound from 1995 to 1999 (Battelle 2001)" has bluefish in its top category, which accounted for 97 sightings in 1999, with a mere 739 total fish for the five-year period. Striped bass are next with 473 fish. There is no attempt to explain how few observers there were and what NMFS made of the sampling. The false impression created again is that we are dealing with miniscule resource abundance here.

However, the NMFS 1998 Marine Recreational Fisheries Statistics Survey, which is based on statistical extrapolations from observer intercepts and phone interviews, tells a far different story than the EENF table. NMFS estimates that in

1998, for example, 747,000 bluefish and 7,392,000 striped bass were caught in the state. According to MDMF, a substantial portion of those numbers, if not the majority, were caught south of the Cape. NMFS says summer flounder, which do not occur north of the Cape in large numbers, accounted for 618,000 catches in 1998, which one would not suspect from the 106 fish listed in Table 7.12.

Q: Can we better quantify the abundance of this productive ecosystem?

A: Yes. There are many limitations to the available commercial and recreational catch data. Accurate surveys of species abundance on a seasonal/geographical basis do not exist and are badly needed. That said, there is a lot we do know about the abundance of marine resources in the Sound ecosystem.

Recreational fishing data. Fisheries statisticians take information from small numbers of people sampled by intercepts and phone surveys and extrapolate to arrive at the total recreational catch in its annually published statistical surveys. (NMFS always accompanies the published numbers with large standard error estimates.)

The following table gives NMFS estimated recreational catches for the Commonwealth during 2002 for several popular recreational species. Again, a very substantial percentage, if not the majority of each species listed below, was caught in and around Nantucket Sound. MDMF estimates that hundreds of thousands of Massachusetts residents and visitors fish the Sound each year, drawn by the abundance of the resource, which these statistics indicate.

2002 Recreational Catch

Bluefish	856,715

Striped bass	6,026,404
Scup	1,854,149
Black sea bass	451,743
Summer flounder	491,631
Tautog	386,901

The total recreational catch of most species, just like the commercial catch, is usually limited by fisheries managers in terms of the allowed size, numbers, and/or season for each species. So for example, for 2003, the minimum size summer flounder that can be legally taken is 16.5" with a 7 per day bag limit. Therefore, we should bear in mind that the catch statistics represent only a fraction of the total species abundance in the ecosystem.

Commercial fishing data. There are numerous, traditional, directed commercial fisheries that could be affected by this project, including those for loligo squid, summer flounder, scup, tautog, black sea bass, channeled and knobbed whelk, quahog, striped bass, bluefish, etc.

The spring squid fishery involves some 40 permitted draggers, most of which fish in Nantucket Sound, although in some years weir fishermen in the Sound produce the highest landings. At last count, there were 58 permitted fluke draggers, most of whom fish in the Sound, and more than 280 hook fishermen targeting fluke. There are 32 black sea bass potters working the Sound, 17 scup potters, and 11 of the state's 16 weirs.

Geography-specific catch data are very limited. The table below shows the MDMF landing statistics specifically attributable for Nantucket Sound for 2001.

2001 Landings for Nantucket Sound in Pounds

Striped bass	15,602
Black sea bass (pots only)	267,366
Conch (pots only)	675,780
Scup	7,741

Reported catch data for the weir fisheries fill in some of the holes in the data. Preliminary reports for the 2002 weir fishery in the Sound are shown below:

2002 Landings for Nantucket Sound Weir Fishery in Pounds

Mackerel	445,575
Squid	200,550
Scup	82,382
Menhaden	81,000
Bluefish	51,374*

*Said in the EENF to be "not commercially abundant."

The total finfish catch was constrained by fisheries quotas and/or seasonal closures, so we should bear in mind that the catch statistics represent only a fraction of the total species abundance in the ecosystem.

Q: Can we quantify the economic value of the Sound ecosystem to the Commonwealth?

A: Only in a rough sort of way, and it is substantial. The NOAA Fisheries 2001 Report (for the year 2000) listed $846 million for marine recreational fishing expenditures in Massachusetts (supporting 2,000 jobs, creating $153 million in personal income and generating $86 million in state taxes). A significant percentage would have been generated by the recreational fishing opportunities in Nantucket Sound. NOAA also estimates that non-resident anglers spent more than $126 million Massachusetts in 1998, a large part of which would certainly have included fishing trips to Nantucket Sound, a fishing mecca for the entire country.

As the EENF notes, "Commercial fishing is an important industry in Massachusetts. In 2000, NMFS reported the commercial fishing catch was valued at over $1.6 billion." The EENF adds, "that most commercial fishing activity in Massachusetts occurs outside of Nantucket Sound," as if to imply that what does occur there is not worthy of much consideration. But even a small fraction of $1.6 billion is not small change. The catch in the Sound annually returns some tens of millions of dollars to local fishermen and is important to the economy of the Cape and the Commonwealth.

Q: What role does Horseshoe Shoals play in the ecosystem?

A: The Center for Coastal Studies characterizes all of Nantucket Sound as constituting "a healthy and productive ecosystem ... that should be managed as a single ecological unit." Horseshoe Shoals is a keystone part of the ecosystem, being a preferred habitat for numerous species, not simply another, replaceable piece of bottom. There are some permanent residents, including shellfish and other members of the benthic community, and many species of finfish and invertebrates that migrate between the shoal and the surrounding inshore waters with the diurnal cycles, seasons, tides, and changing distribution of forage. Some of these more noteworthy "part-time" residents include bluefish, striped bass, scup, summer flounder, black sea bass, tautog, and squid.

Depending on the species, Horseshoe Shoals is a breeding ground, spawning ground, nursery ground, and/or a predator's supermarket. Commercial and recreational fishermen target the area because it concentrates abundance. In the language of proponents of artificial reefs, Horseshoe Shoals is a large "fish aggregating structure." It can hardly be improved, but it can be damaged.

Q: How accurately does the EENF characterize the geology of the shoals?

A: The EENF describes the "dynamic nature of the sandy sediments" in the Sound this way: "Long rows of asymmetric sand waves cross much of Nantucket Sound. These sand shoals may, in part, represent recessional moraines and, in part sand ridges formed by littoral drift during the past rise in sea level. Tidal and storm currents continuously reshape sand waves and cause them to migrate slowly across the Sound. There is substantial bed transport of sand waves during storms. Wind waves are also expected to contribute to transport, particularly in shallow water and regionally during coastal storm events (Battelle 2001)." In other words, there is no distinctive, long-lived topography, just moving sand, that presumably can be shoveled around without great consequence to the ecosystem.

The reality is quite remarkably different, and may be hard for people not familiar with these waters to imagine. Nautical charts of the Sound going back decades show the same shoals in more or less the same places and with the same configurations. Despite tides, storms, and seasons, some shoals have remarkable resiliency and presence. This is doubly remarkable in that the tidal currents run the swiftest over the shallowest parts of the shoals, but don't flatten them down, the way one good rain would flatten a sand castle on the beach. Middle Ground, where I first fished 40 years ago, is still there; so are Horseshoe Shoals, Hedge Fence, Long Shoal, and others. Some sand islands grow south of the Vineyard for years then disappear, but Wasque Shoal goes on and on and is a "fish magnet," like Horseshoe. (The best fishing places have famous names.) Another remarkable fact about these shoals is that their cross-sections are usually very similar: a gently upward sloping sandbar leading to a steep edge with a relatively big drop-off. Fish have evolved over hundreds of millions of years making a living and reproducing in these distinctive underwater structures. They make up a whole class of essential fish habitats.

Q: Does the EENF understate the potential for large-scale disruption and change to the benthic habitat?

A: Yes, I believe it does.

Not much is going to occur, according to the EENF: "Localized effects to sediment transport patterns may occur immediately around the WTG foundation base, however, it is expected that a localized sediment transport equilibrium condition will be reached shortly after construction of the Wind Park."

This is wishful thinking. Consider what happens when you place an obstruction on a sandy bottom with a strong current. For example, as everyone knows, groins are intended to save beaches from erosion but are self-defeating – usually increasing erosion in the area, and requiring frequent dredging and replacement of sand for their maintenance. A similar phenomenon occurs when a person standing in the surf feels water sucking a hole in the sand and gravel around his feet during a wave's backwash. A vertical structure causes the current to increase in local velocity to get around it, causing erosion rather than simple back and forth movement of the surface sand.

The likely effect of placing 130 large diameter, vertical structures on shallow sections of Horseshoe, which experiences very strong tidal flood and ebb currents twice a day, is a massive amount of continuous turbulence, erosion, and gullying. Cables buried only six feet in the sand, as described in the EENF, may well become exposed and suspended in the current. And in all likelihood, the typical, fish-attracting shoal structure described above will suffer disruption. No one can say with certainty to what extent these large-scale changes would turn out to be destructive, beneficial, or simply unfathomable.

Q: What are the major types of impacts that should be considered relative to the proposed project?"

I would urge the Siting Board to consider the following impacts when trying to determine whether we need power from a wind farm located on Horseshoe Shoals.

A. Construction, maintenance, and decommissioning impacts.

B. Permanent habitat alteration.

C. Changes in fisheries diversity and abundance.

D. Impacts on traditional fishing practices.

E. Navigational hazards.

F. Possible closure of the area to the public.

Q: What environmental impacts are likely to result from construction, maintenance, and eventual decommissioning?

A: Negative impacts from the Cape Wind project will first result from construction activities associated with installation of 130 WTGs and many miles of connecting submarine cables. These activities will cause, over most of a roughly 24 square mile area, mortality of benthic fauna and juvenile fish, destruction of eggs, and dispersal of juvenile and adult fish and invertebrates, thereby reducing the number of those surviving to spawn as mature fish.

Loligo squid, a critical forage fish and important commercial species, is believed to spawn on Horseshoe Shoals, as well as elsewhere in the Sound. Recent work by the Marine Biological Laboratory in Woods Hole has suggested that squid demonstrate natal fidelity, that is, they return to the same area to spawn. If the area is disrupted by construction and maintenance activities, then squid production may be permanently depressed. It is important to realize that such changes in ecosystem food webs tend to ripple out and affect the entire web of predator-prey relations.

Overall, loss of fisheries production is a given. But recovery time is unknown. Long-term effects are also unknown.

The EENF blithely states, in regards to eventual decommissioning of the WTGs, "Re-establishment of the original seabed following the lifetime of the Wind Park can be accomplished, if necessary, by dismantling the WTGs and removing the steel monopile foundation structures, lifting them onto barges, and transporting them to shore for recycling."

First, it should be remarked that no one has ever recreated a large-scale shoal, and the authors of the EENF display no understanding that it has a structure. Second, the "if necessary" implies the proponent would not, unless required, take down its turbines when they reached the end of their utility. (And if the company were no longer in business, who would pay to do it?) And finally, all of the negative effects on fisheries production caused by the disruptive activities of construction would essentially be repeated during decommissioning.

Q: How will the habitat for fish and other species be permanently altered?

A: As described above, the likely effect of placing 130 large diameter, vertical structures on shallow sections of Horseshoe, which experiences very strong ebb and flood tides twice a day, is a massive amount of continuous turbulence, erosion, and gullying. Cables buried only six feet in the sand may well become exposed and suspended in the current. And in all likelihood, the typical, fish-attracting shoal structure described above will be disrupted by at least 130 large gullies and ridges.

Whether these new bottom features will be fish aggregators, as some have suggested, or dispersers, or some combination of both is unknown. What we do know is that habitat will change, with uncertain consequences.

Q: What impacts can be expected on fisheries diversity and abundance?

A: To answer this question, I would refer to the recently released Pew Oceans Commission report, America's Living Oceans, Charting a Course for Sea Change:

> The crisis in our oceans is such that many marine populations and ecosystems may be reaching the point where even a small disturbance can

cause a big changes. We must therefore initiate large changes in ourselves, if we are to protect and restore the oceans, in our governance of them and our attitude toward them.

The short answer to what impacts can be expected on fisheries resources in the Sound is that we don't know. The longer answer is that some changes may be detrimental, some beneficial, many are currently unknown, and given the complexity of the ecosystem, may be unknowable. Some species of fish such as striped bass may well adapt to an environment with a lot of manmade structure; other species such as bluefish have evolved with different requirements and may disperse around the Sound or find more favorable environments outside the Sound. Dispersion would likely reduce overall productivity. The potential long-term impacts on the benthic community, forage fish populations, and valuable finfish species caused by the large-scale conversion of the habitat from an open shoal environment to one dominated by large structures is a crucial question that needs to be carefully studied before implementing the construction plan.

Q: What impacts would there be on traditional fishing practices?

A: Certain that "potential impacts to finfish and benthos will be minimized," the EENF also asserts that the project has been "designed to minimize potential impacts to commercial and recreational activities and navigation" and to "allow for unrestricted and safe navigational access around and within the Wind Park". Those of us who have spent any time on or near Horseshoe Shoals know that the reality would be just the opposite. Both commercial and recreational fishing will be significantly impacted, with expected loss of harvest and potential physical jeopardy to the participants.

The arrangement of the WTGs will physically alter a traditional fishing ground. During the most important commercial fishing period (late April to mid-June), more than two dozen draggers have been known to work in the vicinity of Horseshoe Shoals. Draggermen will be less inclined to fish there because of maneuverability considerations with gear towed astern in tight quarters around WTGs spaced approximately only 0.3 miles apart. Many small draggers fish single-handed, making navigation and fishing dangerous or impossible in target-rich environments. The presence of other vessels, whose presence may be visually obstructed by the towers, will pose an ever-present danger among the massive WTGs. The probability of accidental collisions with the structures or other vessels will be enhanced under conditions of foul weather and poor visibility, for which the area is noted.

Less trawling effort would be expected to bring about more fixed gear fishing; this usurpation of bottom will further narrow the operating lee-way – complicating and reducing both trawling and recreational fishing opportunities. Traditional recreational fishing practices would also have added dangers. Drift fishing, during which people typically face up tide, would become especially risky as swift currents swept boats toward turbine bases. Also, trolling fishermen would find that any of the area's numerous, productive rips that survived the power plant construction had turned into obstacle courses.

The biggest unknown may be the potentially huge economic impact on Cape Cod and the Massachusetts economy as a result of converting an oceanic wilderness that is a mecca for recreational anglers into an industrial-type setting. Like rafting down the Grand Canyon or hiking our national parks, fishing in the Sound has a special recreational value because it takes place in a magnificent natural environment. Yes, one can enjoyably catch fish in New York's East River or inner Boston Harbor, but people don't travel there by the tens of thousands and spend hundreds of millions of dollars to fish in these industrialized urban settings. The chambers of commerce of most of the Cape and islands towns have expressed the fear that "if you build it, they won't come." To the best of my knowledge, there have been no market studies to help answer the question one way or another.

Q: Will the project create navigational hazards for commercial and recreational fishing vessels and others?

A: The 130 turbines could in fact act as "boat magnets" by creating strong swirling currents around themselves during times of peak tidal flow, sweeping unwary boats into collisions with the WTGs and other boats. By giving the WTGs a wide berth, boaters will find the 0.3 mile distance between them has shrunk considerably and reduced their maneuvering room. Fishing and navigation inside the WTG field and around it in the transit lanes will be especially dangerous in foggy weather with the added problem of flashing lights and noise from the WTGs confusing to the senses. Additionally, the large numbers of small boats that use the shoals typically do not have radar and are captained by operators of varying levels of experience. (Will the WTGs all have horns and bells like buoys? What a confusing cacophony that would make!)

The closeness of the proposed monopiles to the north-, east-, and south-side thoroughfares leaves no margin for error and only enhances the chances for shipping accidents and fuel oil spills.

Q: Could the entire area be closed off to the public?

A: In the face of national security concerns, the entire power plant might be closed to the public, as was a large area adjacent to the Pilgrim Power plant following 9/11. (Concerns about vandalism by boaters and fishermen who strongly opposed the project might also lead to area closures.)

Q: What studies and analyses should be required to assess the magnitude of potential risks and impacts to this highly valuable ecosystem?

A: Before the Siting Board reaches any conclusions regarding the need for power that would be produced by the Cape Wind plant, I urge the Board to demand that the following studies and analyses be performed:

1. Due to the large size of the preferred and alternative project sites, a comprehensive seafloor mapping effort should be completed as part of the siting process. Preliminary surveys using side-scan sonar have been performed, but do not adequately describe the benthic habitat. Given the magnitude of this project, all of Nantucket Sound outside of the 3-meter depth contour (MLW) should be mapped with a combination of multi-beam and side-scan sonar, sub-bottom profiling, and sediment profile imaging. Data obtained via remote sensing should

then be ground-truthed with video transects, core sampling, and direct observation.

2. There must be a comprehensive assessment of marine fisheries resources and harvest in Nantucket Sound. Although a considerable amount of data was provided to the applicant by the MDMF prior to release of the EENF, the analyses presented were incomplete and provide no support for the applicant's premise that this project "will not result in any significant adverse effects to existing seabed conditions, aquatic resources, …").

3. There needs to be a quantitative analysis of estimated impacts to fisheries resources from construction, including the mile-by-mile construction activities with a description of associated direct and indirect impacts on the habitat, flora, and fauna. Of particular concern are areas of hard bottom where blasting may be required.

4. A comprehensive assessment of the potential for large-scale changes in patterns of water movement and sediment transport is required to evaluate possible impacts. The maintenance of existing water-flow and sediment transport patterns across these shoals is a critical component in maintaining current high levels of fisheries productivity and diversity. Such an assessment would likely involve both computer and physical modeling activities.

5. A comprehensive analysis is needed to identify opportunities to avoid and minimize impacts to aquatic resources (e.g., adherence to time-of-year restrictions).

6. There needs to be an analysis of the time needed for recovery of all impacted habitats, if indeed it is determined they will recover.

7. There need to be compensatory mitigation plans for direct and indirect mortality of fisheries resources, delayed recovery of habitat, and areas of habitat that become permanently altered, including a monitoring plan to determine the success or failure of the restoration/mitigation and a contingency plan in the event of failure.

8. There should be market research studies of Cape Cod's recreational fishing tourism to determine the potential economic loss to the regional economy due to the conversion of an oceanic wilderness area into an industrial setting.

Q: What has been the response of the Romney administration in the face of this and other proposed sites for WTGs?

A: Recognizing that good management depends on accurate data, which are currently lacking, a task force has been appointed to "zone" the Commonwealth's coastal waters before taking any further actions. The criteria that will be used to delineate such zoning are unknown.

Q: Faced with the number and magnitude of uncertainties regarding the potential impacts of this project, what would be the responsible course of action for the EFSB?

A: According to the Pew Oceans Commission report, America's principal objective in formulating marine-related policy should be to "protect, maintain, and restore marine ecosystems." I agree wholeheartedly with this view. At this point, it is simply not possible to say that the Cape Wind Project won't open up a Pandora's

Box of damaging effects to the Nantucket Sound ecosystem, much less that the power from the plant will provide net environmental benefits to the state or the region. The EFSB should delay any permitting until a complete understanding is gained of the risks of going forward.

Q: Does this conclude your testimony?

A: Yes, it does.

EXHIBIT A

Review of State and Federal Marine Protection of the Ecological Resources of Nantucket Sound, Center for Coastal Studies, January 28,2003.

Cape Wind Expanded Environmental Notification Form and Combined Cape Cod Commission Development of Regional Impact Review (EENF), Environmental Science Services, Inc., November 15, 2001.

Summary Report, America's Living Oceans, Charting a Course for Sea Change, Pew Oceans Commission, May 2003.

Marine Recreational Fisheries Statistics Survey (MRFSS) for 1998, National Marine Fisheries Service.

Marine Angler Expenditures in the Northeast Region, 1998, National Marine Fisheries Service.

NOAA Guide to Essential Fish Habitat Designations in the Northeastern United States: http://www.nero.noaa.gov/ro/doc/webintro.html.

Prepared Testimony of

Jeff Byron

On Behalf Of

Alliance to Protect Nantucket Sound

Before the

Commonwealth of Massachusetts Energy Facilities Siting Board

Cape Wind Associates, LLC and Commonwealth Electric

EFSB 02-2/D.T.E. 02-53

June 20, 2003

Q: What is your name and affiliation with the Alliance to Protect Nantucket Sound (APNS)?

A: My name is Jeff Byron. I am an independent energy consulting residing in Los Altos, California doing business as Byron Consulting Group. I was originally retained by APNS in December 2002 to conduct an independent economic comparison of five different power plant alternatives in New England. Since then, I have expanded the scope of my work to include an examination of whether the electric power that would be produced by the proposed Cape Wind facility would bring with it reliability or economic efficiency benefits.

Q: What qualifies you to perform such an analysis?

A: I have over 25 years of diverse power industry experience. My background spans the disciplines of electric power generation, energy policy and regulations, distributed energy resources, strategic analysis, project management, and economic modeling. I have developed high-reliability energy centers for Internet data centers, managed the design and construction of transmission substations and distribution systems, and commissioned on-site generation projects. I have managed a number of projects from conception through design, construction and commissioning. I have developed power plant projects for Calpine, managed the high reliability energy needs of Oracle as their energy director, have held numerous research and commercialization positions at the Electric Power Research Institute (EPRI), designed renewable energy projects at Acurex, conducted nuclear containment testing at GE, and extended the life of thermal power plants at Aptech Engineering Services. I have been an invited speaker at many investor and technology-based conferences and have been quoted in numerous magazine articles and news stories. I have also provided testimony before the California Public Utilities Commission and the Energy Subcommittee of the US Congress regarding deregulation of the California electricity market. I also have Bachelor and Master of Science engineering degrees from Stanford University.

Q: Would you briefly state the purpose of your testimony?

A: The purpose of my testimony is to provide information to the Siting Board regarding the need for the electric power that would be produced by the Cape Wind project.

Q: What is your conclusion regarding the need for the power that would be produced by the Cape Wind project?

A: My analysis shows that the Commonwealth of Massachusetts does not need the energy resources that would be provided by the proposed Cape Wind project and, thus, there is no need for the transmission line that would be required to bring power from the project to shore. The Commonwealth of Massachusetts does not need the electricity that would be produced by the project because:

1. There is no evidence that the project will improve system reliability, and in fact, there are a number of reasons why it will likely decrease the functional reliability of the electrical grid, and

2. There is no evidence that the project will increase economic efficiency of the electricity market in Massachusetts or New England, and in fact, the project could distort the market and reduce economic efficiency.

SYSTEM RELIABILITY IMPACTS OF THE PROPOSED PLANT

Q: You stated, "There is no evidence that the project will improve system reliability." What do you mean by "system reliability?"

A: I am referring to "system reliability" as it pertains to the electric power transmission system in New England and as defined by the North American Electric Reliability Council (NERC). The terms "reliability" and "system reliability" are often misconstrued, and since NERC operates as the nationwide, voluntary organization to promote bulk electric system reliability by setting standards for reliable operation, monitoring, assessing, and enforcing compliance, and coordinating reliability standards with regional reliability councils, I believe it is most appropriate to rely on NERC's definition.

NERC's planning standards presently define the reliability of the interconnected bulk electric system in terms of its ability to supply the aggregate electrical demand and energy requirements of customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements; and its ability to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

Q: How does this definition compare to the applicant's use of the term "system reliability"?

A: I do not use the term "system reliability" in the same general sense that the applicant appears to use it throughout the permit application. The applicant equates the addition of any electric generating capacity with an increase in system reliability.

The application describes the following purported "system reliability benefits" associated with the electricity produced by the wind farm:

Generation Supply Adequacy: The project and the Cape Wind power delivered over it will increase the amount of generating capacity and energy available to the Commonwealth and the New England region, thereby improving the reliability of the electric system.

Local Supply Reliability: The additional transmission capacity on the Cape will provide an additional source of energy at the Barnstable substation when power is flowing across the lines.

These purported benefits basically state that the wind farm will incrementally add capacity to the grid and any incremental capacity additions always bring incremental improvements in reliability.

I cannot agree with this overly simplistic view of system reliability. Just adding electric generating capacity or new transmission lines does not necessarily improve system reliability; in fact, it could have quite the opposite effect. I use the term system reliability as a quantifiable state that involves planning, operation, and compliance to achieve desired results. Using that definition, the impact of any particular capacity addition on system reliability depends very much on the detailed characteristics of the specific plant being added, and the conditions of the grid extant at the time the plant will be added.

Q: Please describe in more detail how "system reliability" is determined and measured.

A: NERC has established operating policies and planning standards to ensure that the electric system operates reliably. Bulk electric system reliability begins with planning. The planning standards state the fundamental requirements for planning reliable interconnected bulk electric systems. As described above, the planning standards define the reliability of the interconnected bulk electric system in terms of its ability to supply the aggregate electrical demand and energy requirements of customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements, and the ability of the system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements. In addition to planning standards, individual NERC regions develop their own regional planning criteria. These are evaluated to ensure that the regional criteria are consistent with NERC's planning standards.

There are also operating policies based on the premise that all control areas share the benefits of interconnected systems operation and recognize the need to operate in a manner that will promote reliability in interconnected operation and not burden other entities within their interconnection. NERC's doctrine for interconnected systems operation consists of standards, requirements, and guides. Together, these form the operating policies. The operating policies place the responsibility for operating reliability primarily on the control areas that operate within the three interconnections of the United States, Canada, and northern Baja California Norte/Mexico. The applicable regional organization for New England is the Northeast Power Coordinating Council (NPCC).

NPCC compliance with NERC's standards is achieved through a mandatory enforcement program that monitors and enforces conformity with operating policies and planning standards. NERC is currently developing a single set of reliability standards based upon an existing reliability and market interface principles. The process is complicated and, although it primarily addresses the operational aspects of reliability, there are a number of guiding principles. The first such principle is that interconnected bulk electric systems shall be planned and operated in a coordinated manner to perform reliably under normal and abnormal conditions. The second is that frequency and voltage of interconnected bulk electric systems shall be controlled within defined limits through the balancing of real and reactive power supply and demand.

NERC imposes these principles and standards through a combination of training and certification and auditing and thus assures that a consistently high level of reliability is maintained throughout the region.

As I mentioned earlier, these bulk power system requirements are passed onto the regional organizations and ultimately all electrical facilities must be designed, built and operated in accordance with applicable NERC, NPCC, NEPOOL and the interconnecting Transmission Owners' standards, guidelines or criteria. This provides a consistent, functional framework by which the bulk electric transmission system is built, operated, and maintained. It also provides a consistent means for assessing the benefit or deterioration of system reliability resulting from changes or additions to the transmission system.

As I will discuss later, in more detail, I do not believe the proposed transmission line interconnection design will pass NERC reliability standards.

Q: Who is responsible in New England for maintaining compliance with NERC standards and system reliability?

A: The Independent System Operator (ISO) New England, a not-for-profit, private corporation established on July 1, 1997 by approval of the Federal Energy Regulatory Commission (FERC), is responsible for managing the New England region's electric bulk power generation and transmission systems, the wholesale electricity market, and administering the region's open access transmission tariff.

Q: How does the ISO New England maintain system reliability?

A: As I have indicated in my earlier responses, this is a complicated process. In general, however, the ISO New England maintains system reliability by adherence to written and approved planning standards, operating policies, and compliance requirements as set forth by NERC and adopted by the New England Power Pool (NEPOOL).

Q: How can an electric generating plant improve system reliability?

A: An electric power plant can contribute to system reliability in a number of ways. The plant may add capacity resources or regulation services, such as voltage support, reactive power, and standby power. The ISO adheres to strict operating procedures that balance the need for capacity and regulation services. Based upon operating experience and daily information from generators, the operator determines what is needed to balance the system throughout the day. As the demand for electricity changes, system configuration is altered due to scheduled maintenance or unexpected plant or transmission line outages, the ISO calls for changes in capacity or generation services. If a generator can respond to this call with a high level of certainty, then it will contribute to the reliability of the system. If the generator is not available to respond to a call from the ISO in response to the dynamic changes of the system, it is not able to improve system reliability.

Q: Does every type of electric power generating plant contribute to system reliability?

A: There are many factors that must be considered in determining if a plant will contribute to system reliability. Aside from the market bid price and self-scheduling generation rules allowed for wind generators, the ISO must also consider generator availability, capacity, location on the system, speed at which the unit can be started or increase its power output, and the type of services the plant is best suited for. These characteristics can and do also change throughout the day, depending upon system load, weather conditions throughout the region, and maintenance that is being performed on the transmission system.

Each electric generating plant has different operating characteristics based upon the type of generator, the fuel it uses, and its vintage. For instance, a large coal-fired power plant or nuclear power plant typically operates best at full power for long periods of time. This type of plant is often best utilized providing continuous power to the system. Or, a natural gas-fired power plant, which will also have a high availability factor, may have the added capability to be brought online more quickly. This plant might best be utilized for providing peaking power or standby services. Among other things, the system operator will also consider transmission congestion and, thus, how the location of the power plant will affect system reliability.

From the perspective of the ISO, a major consideration is the availability of the unit to provide the resources when it is needed. This is a major drawback for a power plant that has an intermittent source of fuel and variable output. If the system operator cannot rely upon a generating unit to be available at a certain capacity level, when it is needed, that plant does not contribute to system reliability.

Q: What impact would a wind generation plant have on system reliability?

A: Wind generation is just such an intermittent power source, with a fuel supply that is both random and variable. From the perspective of the system operator, such a power source simply does not make the electrical grid more reliable merely because it occasionally produces energy. The system operator cannot count on this generation source to fulfill its capacity and regulation services requirements. In fact, when the system is operating at or near its capacity and is utilizing intermittent resources, the system is actually less reliable than it would be otherwise. This is because the system operator will have fewer options at peak load to balance the system. If the capacity from wind-generated power changes or ceases unexpectedly, which it does regularly, it will create an imbalance. This variability and randomness places additional demands on the system operator that are not offset by the wind farm merely producing electricity occasionally.

Q: What specific impacts do wind generated electricity have on the role of the ISO New England for maintaining system reliability?

A: Wind-generated electricity is, due to the nature of wind, intermittent, random and variable. Electric power produced by a wind farm is intermittent, meaning that its availability cannot be relied upon for sustained periods of time, such as a power plant with a firm fuel supply. Wind-generated electricity is random, meaning that its availability is relatively unpredictable. It is variable, meaning that when it is available, the output of the wind farm is constantly changing and rarely operating at its full capability.

These concepts can be illustrated by using the example of a similarly sized gas-fired power with the same characteristics. If we were to assume that this power plant had a capacity factor of 33 percent, this hypothetical plant would be available 10 days out of the month. Those 10 days, however, would not necessarily consist of continuous periods of operation, that is, it would be

intermittent. The system operator would not know in advance which periods of time the plant would be available, that is, the availability of the plant would be **random**. Finally, when the plant was available, there would be no way to predict or control the level of its output and this output would fluctuate unpredictably, that is it would be **variable.**

If such a gas-fired plant was proposed, and a dedicated transmission line was needed to interconnect it to the grid, it is very doubtful that anyone would argue that the plant would improve system reliability. Thus, these characteristics of a wind-powered plant render it of little value to the ISO for purposes of improving, or even maintaining, system reliability.

Another result of the intermittent, random, and variable nature of wind-generated electricity is that it rarely matches the demand for electricity by consumers. Most other electric power generators can be switched on when needed and the system operator is able to dispatch generation to match supply with demand as the demand for electricity changes. Wind-generated power may often not be available when it is needed and if the wind is generating power, the output can fluctuate between zero and one-hundred percent of its rated capacity depending upon the varying speed of the wind. The system operator must perform a balancing act with wind-generated electricity.

Thus, the intermittent, random, and variable nature of wind-generated power does not increase the reliability of the system, but instead presents the system operator with a number of problems it must manage to maintain a reliable system.

Q: What are some of the reliability issues from wind-generated electricity that must be managed by the system operator?

A: First, I should say that the system operator already has a difficult job maintaining the reliability of the grid, forecasting and meeting changing demand, providing voltage support, managing spinning reserve, and all while minimizing total production costs. The complexity of this process merits more explanation.

The electric power grid is a dynamic system requiring continuous load balancing. Operator control is critical. The ISO New England must follow certain prescribed principles to determine the minute-to-minute generator output levels, dispatch levels for external transactions, and on/off/output status of dispatchable loads. Collectively, this is referred to as "desired dispatch points." Desired dispatch points are determined with the following objectives in mind, in order of priority:

1. Maintaining at all times the minimum level of system reliability consistent with national, regional, and NEPOOL standards;
2. Minimizing system energy production costs while maintaining sufficient 10-minute spinning reserve and automatic generation control, again consistent with national, regional, and NEPOOL standards;
3. Minimizing the costs of providing automatic generation control in conjunction with energy demand; and

4. Minimizing the costs of providing 10-minute spinning reserve in conjunction with energy demand and automatic generation control.

There are other procedures that must be followed, as more completely described in NEPOOL's Market Rules & Procedures, but this should provide a sense of the complexity and difficulty of the task of maintaining system reliability.

Now, with wind-generated electricity, an intermittent and variable generation source is introduced and the operational challenges for the ISO become more complicated. These additional complexities include:

1. Wind-generated electricity cannot be predicted with any reasonable degree of certainty day ahead, hour ahead, or from minute to minute;
2. The ISO New England must procure an increased amount of regulation services from other generation sources;
3. Wind-generated electricity is often produced in large quantities when it is not needed and can contributed to over-generation (over-generation occurs when system capacity exceeds current demand);
4. Wind-generated electricity can cause additional transmission line overloads during some periods of heavy power flow;
5. Wind-generated electricity is a "must take" electricity generation source and is non-dispatchable by ISO New England; and
6. Wind-generated electricity can cause voltage collapse at wind farm areas, which may result in units automatically shutting down and restarting repeatedly.

Large quantities of wind-generated electricity present many operational challenges for the system operator. Although these issues are typically manageable, they do not contribute to the reliability of the system. On the contrary, large quantities of wind-generated electricity make balancing the system more difficult and create a less reliable system.

Q: How do the NEPOOL and ISO New England operating rules and procedures treat wind power?

A: NEPOOL rules classify wind units as "dispatchable limited energy generators." These rules begin by assuming a much lower capability rating for wind generators. For new wind-generators this is 25% of the nameplate capability, or in the case of the proposed project a little over 100 megawatts. ISO New England will allow the wind-generator to submit a daily energy limit that defines the megawatt-hours available to be dispatched for that day and is far less than allowed for other generation sources.

These "dispatchable limited energy generators" do not participate in the ISO New England markets in the same manner, as do other generators. Wind generators are allowed to generate more electricity than they bid into the system. This is called "self-scheduling" and is permitted only for renewable energy sources. If the electricity is needed, ISO New England will dispatch the resource in real time in accordance with the bid price. If it is not needed, it may be used as reserve capacity. If the wind-generator generates less electricity than is scheduled, the generator is not penalized, as another type of generator would be. These rules allow the intermittent and variable energy generated by a wind plant to be integrated into the system in a manner that accommodates some of the limitations of wind-generated electricity. However, the fact that NEPOOL and ISO New England rules allow wind-generated electricity to be sold in the New England market does not change the fact that wind generated power does not contribute to overall system reliability because the operator cannot rely on wind plants to be available when they might be needed. If fact, because wind power is also variable capacity, it may decrease reliability when system capacity is at or near its operating limits.

Q: Is that to say that wind-generated electricity can never contribute to system capacity?

A: Wind-generated electric power can contribute to system capacity, but only when the wind is blowing above a certain minimum threshold. Because of the factors discussed above, however, the capacity that a wind plant might add in those circumstances would not bring with it any improvements in system reliability.

Q: How often could the ISO New England operators expect that a wind farm such as that proposed by Cape Wind would be contributing capacity to the system?

A: There is no precise data available for how often and to what extent the proposed project will generate electricity, but there is a great deal of operating data from other wind farms that provide an indication of how often this might be for the proposed project. Figure 1 from the California ISO depicts the output from the various wind farms in California for May 2002.

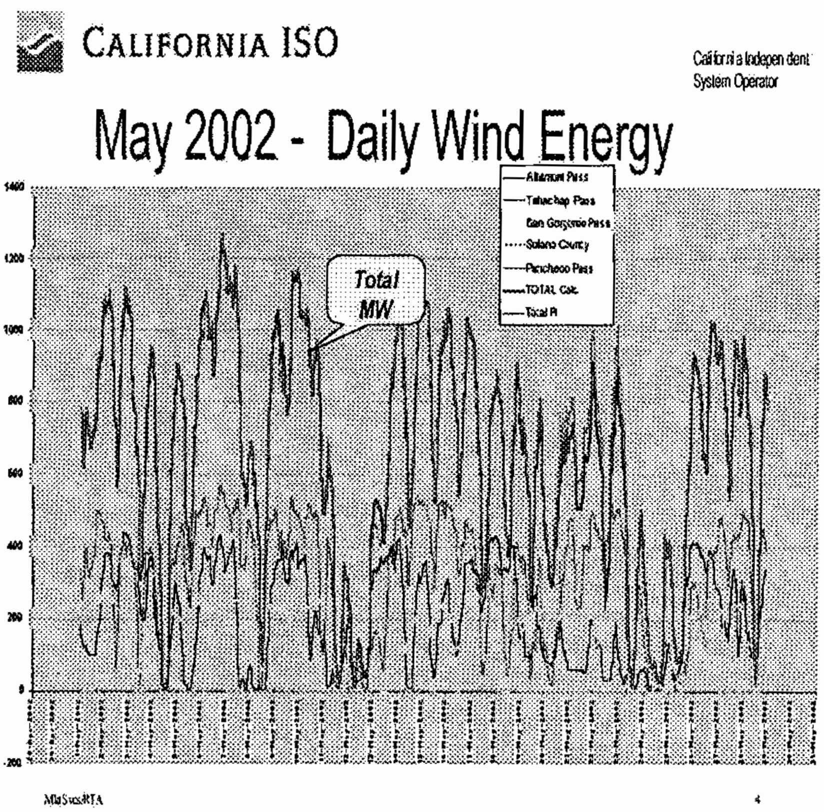

Figure 1: California ISO Typical Daily Wind Power Output

From this figure we can see that full capacity is rarely realized and that there are many instances that capacity is at or near zero output. For California, the highest output is often during early morning hours when demand for electricity is lowest. Besides demonstrating the intermittent nature of wind power, Figure 1 also shows how variable the output can be over the course of a few hours.

There is no similar data available for the proposed Cape Wind project; however, I was able to find publicly available wind data for Nantucket Sound from a University of Massachusetts file server. This hourly wind data from 1994 indicates the intermittent, random, and variable nature of wind for the region. Figure 2 is a monthly summary of mean wind velocity and Figure 3 depicts the hourly variability of wind velocity over the course of a month.

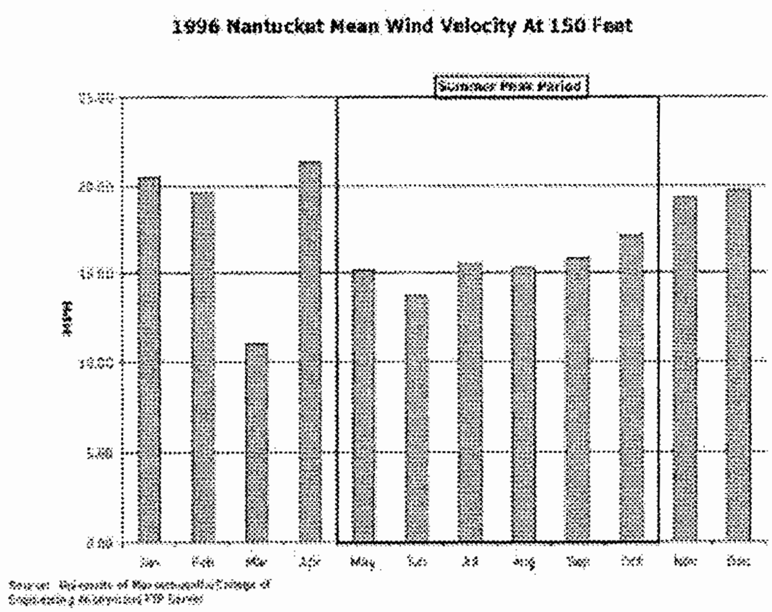

Figure 2: Nantucket Bay Monthly Wind Velocity

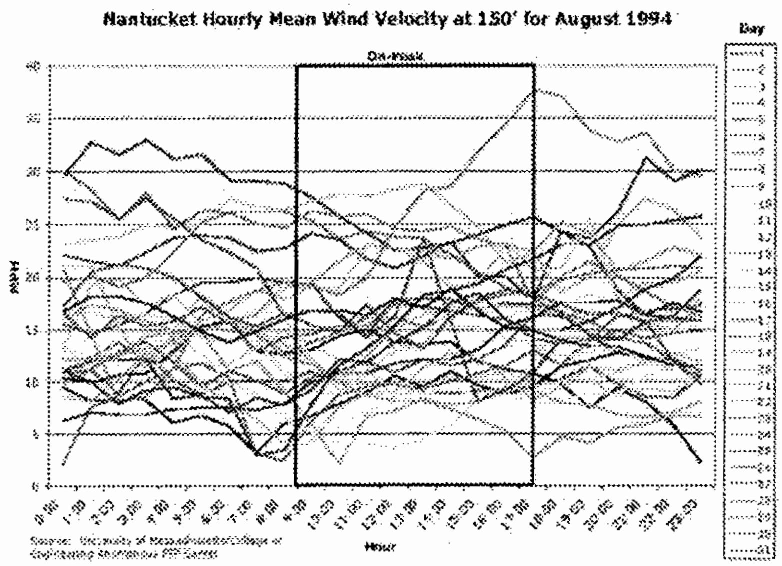

Figure 3: Nantucket Bay Hourly Mean Wind Velocity

The data not only indicate a significant variability, but the higher wind velocities occur primarily during off-peak hours and months. That is to say, the wind, and therefore electric power output, is lower during summer months and lower between the hours of 9:00 AM and 6:00 PM, when it is needed most. Although there may be more sustained wind for an offshore wind farm, one would expect this intermittence and variability to be representative of the output from the proposed project. This intermittence and variability will prevent the proposed project from being a source of power that the ISO can rely upon in times of need, even though the plant will contribute capacity to the system at certain times during the month.

Q: What does the system operator do when the wind-generator is not producing sufficient power to meet its requirements?

A: The system operator must procure increased regulation services in the form of additional generators that are on automatic generation control or supplemental energy production by adjusting output from certain generation units. This is done at a higher cost because ISO New England must procure a larger amount of regulation services when dealing with the uncertainty of wind generation. The higher costs associated with this reduced level of reliability is eventually borne by consumers.

Q: What happens when the wind-generator is producing more electricity than is needed by the system?

A: This situation can lead to a couple of challenges for the system operator. The first level of over-generation may require the system operator to shed other generation from the system because ISO New England is required to take the wind-generated electricity. This is not desirable for the operator but is the unintended consequences of law that require the operator to curtail more reliable generation sources in favor of wind generated electricity. If, however, there is a significant imbalance that ISO New England cannot manage by shedding other generators, then the ISO will require the wind-generator to curtail production. This is not common, but happens two or three times per year in California and could be expected to happen periodically in Massachusetts as well.

There are a couple other over-generation issues that ISO New England must deal with that contribute to the unreliability of wind-generated electricity. Under certain circumstances, wind generated power could cause transmission line overloads during heavy power flow and require ISO New England to shed load or generation to protect the system. There is also a circumstance where the surge impedance load of a transmission line requires additional reactive power or "VARS." This can cause voltage collapse, automatically tripping the protection relays separating the wind-generation equipment from the grid. After the trip, the relays sense adequate voltage and re-close, putting the wind generator back on line. This automated process can occur repeated requiring operator intervention. The problem can be addressed, but is another way that wind generation introduces a measure of unreliability to the system.

Q: How does ISO New England schedule "dispatchable limited energy generation" in its day-ahead and hour-ahead market?

A: Just as for all other generators, ISO New England relies on information provided by the wind generator. However, knowing that there is much higher uncertainty in projecting wind-generation output, the ISO limits what the wind-generator is permitted to schedule. As mentioned earlier, this is 25% of the installed capacity rating or it is determined from actual performance data from the first year or operational experience. However, for this project the wind generator has assumed a much higher average capacity factor of 36% over the course of the year. ISO New England is obliged to take the excess electricity under a "self-scheduling" arrangement permitted for renewable energy sources and also cannot penalize the wind-generator if he is unable to meet his scheduled commitment. The effect of these rules benefit dispatchable limited energy generation but excess power cannot be counted upon for system reliability and deficit power can contribute to a less reliable system.

Q: What other factors are relevant to the question of whether the proposed wind farm will bring system reliability benefits to Cape Cod, Massachusetts, and New England?

A: The reliability of the equipment itself and the transmission cable interconnecting the wind farm to the grid will also be relevant.

Q: What do you know about the reliability of the design and equipment that has been proposed for the wind farm?

A: It is my understanding that the equipment selected for this project is the GE Wind Energy 3.6 megawatt wind turbine that was under development by Enron prior to the acquisition of Enron Wind by GE.

This is a newly developed machine and the manufacturer claims improvements in economy of scale, lower costs, variable speed control, advanced electronics, and improved reactive power to enhance grid stability. This is a significantly larger machine than is currently in widespread operation, with 100-meter diameter rotors resulting in the largest output of any other wind turbine. To my knowledge, the only installation of this machine thus far is a prototype placed on-shore on farmland in Spain in September of 2002, which is still undergoing testing. I also understand that there is an offshore installation proposed in Ireland, however, I note from a recent press release for the project that GE Wind Energy will operate the facility as a demonstration site and the customer will hold an option to purchase the project only after the successful trial period. This indicates to me that this equipment is still clearly in a period of demonstration and testing. The literature about this new machine indicates that the technology builds upon the experience gained from smaller turbines and that it has been expressly designed for offshore applications due to its size. I also understand that GE Wind assigns a design life for this machine of 20 years and that there is an effort underway to obtain certification of this.

However, as with any newly designed equipment, particularly with such a substantial increase in size and loading, there is a higher level of uncertainty about the performance, durability, maintenance, and repair of a new product. This uncertainty is never fully addressed until there has been extensive testing, many years of successful operation and performance experience.

In short, this is a brand new machine and, as a result, very little is known about the reliability of this machine. The unit has yet to be tested in offshore, salt-water conditions to substantiate its reliability in conditions similar to the ones it will encounter if installed in Nantucket Sound. I do not believe that this machine has been deployed in any commercial operations and the proposed project would be the first large-scale application of its kind.

Previous wind generator designs have not met manufacturer's expectations for life span and this new and significantly larger design would not be expected to do better. Typically, a new design tends to introduce additional operational problems. Based upon my experience at EPRI, an organization that assesses new technologies and opportunities to commercialize them, I would expect a number of years of field-testing of any new prime mover in order for it to be considered a commercially reliable product.

Before a large-scale installation takes place, the reliability of the generator and the integrated electrical equipment should be demonstrated in order for the Siting Board to determine that the technology is sufficiently reliable to support the developer's claims and not reduce system reliability.

Q: In what way will the proposed transmission cable have an impact on the reliability of the proposed wind farm?

A: Most power plants are obviously built on land with consideration to the "linears" such as fuel, electrical, and water. An offshore wind project presents a uniquely long, single-ended transmission line to get the power into the system. In this case, the transmission line is approximately 17 miles long with most of it being submerged. Normally, a power plant is built adjacent to a double-ended substation for reliability. A single-ended tap is not uncommon but is also not preferred. It is preferred that the tap be as short as possible. In this case the tap is very long and subject to a number of significant potential failure mechanisms. Even though the design is for two separate 115,000-volt circuits, some failure mechanisms could cripple the plant for a long period of time, and most of the remaining failure mechanisms would half the rated output of the wind generator for the duration of repair. This is a regrettable but unavoidable limitation on the reliability of the design.

The general transmission system design requirements for the interconnection of new generators to the NEPOOL system states a preference for interconnection at a new or existing substation with a ring bus or breaker-and-a-half connection scheme for redundancy. The requirements document states that this is preferred over a tapped transmission line connection. The requirements document recognizes that a tapped transmission line increases the exposure to loss of the line due to additional line length of the interconnection and increased exposure to failure or disoperation of the generator's facilities. This exposure represents additional risk of failure or disoperation of the transmission system, which may impact customer service. Transmission line maintenance on a tapped line also requires an outage of the entire circuit and the generator. Due to the decreased opportunities to perform maintenance, less maintenance is likely to be performed and system reliability also decreases. Additionally, since the generation is unavailable to the system whenever the transmission line is forced out of service, tapped generating stations can lead to the sequential loss of significant amounts of generating capability.

A long tap reduces overall system reliability in a number of ways, but more significantly, the proposed design is not consistent with the NERC reliability standards.

This could be corrected with the addition of a double-ended substation adjacent to the wind farm as part of the electrical service structure. However, this would likely more than double the interconnection costs and was not considered further by the applicant.

Q: Is the reduced reliability associated with a tap an inherent characteristic of a wind power generator?

A: It is a limitation of any power supply that is a long distance from an interconnection point to a transmission line. This is the case for offshore wind power. This is not the case for most any power plant on land, including, in most instances, onshore wind plants.

Q: How can the impact on reliability of the long tap be quantitatively assessed?

A: A System Impact Study (SIS) would determine power flow, needed upgrades to the existing transmission system, project cost, test conditions, transmission stability analysis, post-transient stability, short circuit study, and should assess the reliability of the interconnection due to various postulated failures. I can speak generally about the impact of the long tap on system reliability, however, without having a completed SIS, it would be impossible to determine what specific effect the proposed interconnection would have on system reliability.

Q: Based upon the issues you have raised regarding how wind-generated electricity reduces system reliability, unanswered questions about the proposed wind generators, and uncertainty about the added risk of a long interconnection for the proposed wind farm, what would you consider prudent action regarding the application?

A: Without the results from a completed SIS, there are many unanswered questions and concerns about some of the unsubstantiated claims made by the applicant. I can say that the applicant has proposed a plant that has certain inherent characteristics that make it more difficult for the system operator to maintain system reliability. Certainly if a plant with a reliable fuel source, such as a natural gas, displayed these characteristics, the argument that it increased system reliability would be rejected out of hand. At best, I would conclude that the applicant has not presented enough information that would allow one to determine that there is anything about this proposed plant that would actually increase system reliability. On the contrary, based upon what we know, the proposed project likely reduces system reliability.

I believe that it would be prudent to have the applicant quantify the impact of the design and operation of the proposed project on system reliability and unless he can demonstrate that it improves system reliability the Siting Board should not permit the application of resources for a transmission interconnection. The Siting Board may also wish to require the applicant to evaluate alternative interconnections for wind-generation or other renewable energy sources that would not degrade system reliability, such as biomass or onshore wind.

<u>ECONOMIC EFFICIENCY IMPACTS OF THE PROPOSED PLANT</u>

Q: How do you define economic efficiency with respect to an electric generating plant?

A: The best measure of economic efficiency is long run marginal cost. In a head-to-head comparison of two different electrical generating plants, the one with the lower long run marginal cost would be considered the more economically efficient of the two.

Q: Using this definition, is it your opinion that the proposed wind farm would bring economic efficiency benefits to the electricity market in Massachusetts or New England?

A: This question is complicated by some of the factors I have already discussed in the context of reliability. The fact that the wind farm would be an intermittent, random, and variable source of power means that it cannot bid into the day ahead markets in the same manner as other power plants, keeping in mind its marginal operating costs and its need to cover other long-term costs as well, such as debt service. As the applicant has pointed out on several occasions, a wind farm must bid a zero price into the day ahead markets, so it will be sure to be in the bid stack when the plant actually produces electricity. Thus, the proposed plant would be taking whatever price was being offered, or what is sometimes called being a "price taker."

The applicant maintains that a zero-bid resource, of necessity, brings economic efficiency benefits by displacing the plant that would otherwise be on the margin and, thus, lowering the market-clearing price for power in the hour the plant operates.

Q: Do you agree with this view of the impact on economic efficiency of a zero-bid plant?

A: I do not. The argument that a zero-bid resource by definition increases economic efficiency is unsupportable. In the case of a wind farm, this argument is another way of saying that short-term operating cost, rather than long run marginal cost, is an accurate measure of economic efficiency, a position I cannot agree with.

The position that a plant with very low operating costs is the most economically efficient ignores the fact that to be economically viable, a plant must take in sufficient revenue to cover all of its costs. The fact that a wind plant does not pay for its fuel says nothing about whether the plant will cover these other costs as a truly "economically efficient" plant must.

Q: In a deregulated generation market, why should we care whether a generating plant could cover its costs?

A: In the case of a plant that bids zero into the market, we should care because that plant will displace some or all of the output of the plant that would otherwise be on the margin. The applicant presents this as a good thing, but it is only good if the "price taker" plant is, in fact, more economically efficient than the plant it displaces. If the zero-bid plant is not more economically efficient than the plant it displaces, the presence of the zero-bid plant results in a distortion to the market. The distortion might be temporary, as the zero-bid plant would likely discontinue operations if it cannot cover its costs in the long run but, in the meantime, the effect the plant would have had on the market could hardly be called an increase in economic efficiency.

Q: How would you recommend that the Siting Board proceed in attempting to reach a decision regarding whether the proposed plant brings economic efficiency benefits to the state or region?

A: I preface my answer by saying that I am not an expert on the Siting Board's procedures. My understanding is that the issue of whether the plant would bring economic efficiency benefits to the state or region would not be present were this power plant within the Siting Board's jurisdiction and if the plant did not require a dedicated transmission line in order to interconnect to the grid. Because the plant does require a dedicated transmission line in order to interconnect to the grid, the Siting Board will inquire into the economic efficiency impacts of the proposed plant. That being the case, and having reviewed the application and ensuing interrogatories, it does not appear that it is currently possible to review the economic efficiency of the project in a comprehensive manner that would allow the Siting Board to reach the conclusion that the plant, in fact, will bring economic efficiency benefits to the state or regional energy market.

The evidence that has been made available on this point is sorely lacking. The applicant has admitted that he has not conducted an economic analysis of the project. He also states that he has no bilateral agreements for the sale of electricity for the project. The applicant has objected to producing information that would allow the Siting Board and others to reach a knowledgeable conclusion regarding whether the plant would increase the economic efficiency of the state or regional electricity markets. One would need to know certain minimum facts about the long term costs of the wind project to know whether it would, in fact, be more economically efficient than the plants it might displace as a result of its zero bid into the wholesale market. Without such information, one cannot reach a definitive conclusion, although it is possible, and appropriate, to use available information to reach some preliminary conclusions on this point.

Q: If it is possible that the plant is not economically efficient, as you use that term, what could be the justification for building such a plant?

A: The essence of the justification appears to be direct subsidies that are available to certain renewable projects. The applicant must be relying to a great extent on subsidies to cover its costs and, without those subsidies; I doubt that any such power plant would ever have been proposed.

Q: To what subsidies are you referring?

A: There are two primary subsidies that will have the most impact on the project: the Federal production tax credit ("PTC"), which would provide about 1.8 cents per kWh, and the sale of renewable credits required by the Massachusetts Renewable Portfolio Standard ("RPS"). The renewable or green credit is capped at 5 cents per kWh, but could also have no value depending upon the demand for them. According to the research sponsored by the Division of Energy Resources and cited by the applicant, this subsidy would provide about 2.5 cents per kWh to the project.

Q: What influence do these subsidies have on the issue of the proposed plant's impact on economic efficiency?

A: To answer this question, it is important to keep in mind the relevant market being discussed. When I speak of economic efficiency, I am referring to the market that is, as I understand it, the one that is relevant to the Energy Facilities Siting Board's jurisdiction. For a generating plant, I would consider this to be the bulk electricity markets as operated by ISO New England. Direct subsidies such as the PTC and the RPS tend to distort the bulk electricity markets, as they allow matters that are external to those markets to influence the resource choices within it.

Q: What do you make of the argument that the proposed plant would increase economic efficiency by having a positive impact on the market for green credits?

A: I find that to be a questionable argument for several reasons. First, the fact that green credits have a non-zero value is a strong indication that these plants are not economically efficient from the perspective of the bulk electricity market. If renewable plants were as economically efficient as other plants, the value of green credits would eventually approach zero as renewable plants displaced other types of generation based on their relative direct economic merits alone and the output from the renewable plants greatly exceeded the percentage required to meet the RPS. The applicant's argument, which is that an "economic efficiency benefit" of the proposed wind farm is that it may tend to lower the level of subsidy received by all renewable producers, ignores the negative impact of that subsidy on the market that matters here; the bulk electricity market. I do not consider that argument to be persuasive with respect to the question of whether the electricity markets would be more or less economically efficiency with the addition of the proposed plant.

Just as importantly, however, this argument obscures what I consider to be the fundamental policy justification for measures such as the PTC and RPS. By passing such measures, the Federal and State legislatures are saying, in effect, that they would like more renewable power despite the fact that it will tend to decrease the economic efficiency of our electricity markets. In other words, due to the perceived non-economic benefits of renewable resources, society is willing to pay more for electricity by introducing distortions into the electricity markets that will cause these resources to be chosen in circumstances in which they otherwise would not be. That is a policy choice that is the legislature's to make, and one may agree or disagree with it, but in no way should the resulting market distortions be re-cast as "economic efficiency benefits."

I believe it is critical for the Siting Board to keep this in mind when deciding this case, which I understand is the first of its kind to come before the Siting Board. Others may determine that there are good reasons to build a plant like this, but a positive impact on the economic efficiency of the electricity market, is not one of them. No plant that will depend on direct subsidies to cover, what I believe will be long run costs that are higher than other producers of electricity, can be said to increase economic efficiency.

Q: Have you performed any analysis that leads you to conclude that the proposed plant does, in fact, have higher costs than other producers of electricity?

A: Yes I have. Based upon the economic analysis I have performed, I do not believe that the proposed project will compete with other electric generators in the region and it would be uneconomical to operate despite the revenue streams made available to it through State and Federal subsidies that I have discussed above. If such subsidies were not available, of course, I believe the proposed project would not exist.

Q: What were the results of your economic modeling of the proposed wind project?

A: I performed a comparison of the proposed wind park with alternative power plants, from the perspective of what I consider to be the most meaningful measure of economic efficiency as discussed above, namely long run marginal cost. I should note at this juncture that I would have preferred to use data directly from the applicant that would be specific to the proposed project, but my understanding is that the applicant has not made such data available. Nonetheless, I believe my assumptions are reasonably in line with those that would apply to the proposed project and, where possible, I have used information produced by third parties but referred to in the applicant's discovery responses.

From my analysis I found that the proposed wind project does not economically compete with lower cost alternative power plants, and if it is built, will likely not generate sufficient revenue to cover its costs, much less provide a return on investment.

The results of the analyses were the price needed to sell electricity for each model in order to provide an equivalent return on investment. The plant with the lowest modeled price was the combined-cycle natural gas-fired plant at $42.20/MWh and the most expensive was the proposed offshore wind project at $85.00/MWh, a difference of over 100%.

Q: What were the alternative power plants and what assumptions did you make?

A: The first model was a modern combined-cycle natural gas-fired power plant, the second a circulating fluidized bed coal-fired plant, and the third was a petroleum coke-fired plant. In addition to these fossil-fuel plants, I modeled a small hydroelectric power plant and, of course, I modeled the offshore wind project proposed by the applicant.

I assumed reasonable sizes for these plants based upon their various capabilities. I also assumed realistic construction schedules, project lives, consistent fuel prices, realistic debt levels, amortization, discount rate, escalation, taxes, and depreciation. I used published information about the performance characteristics of the various plant types and I assumed the same rate of return that an investor would expect for all models. For the offshore wind model I used the limited data that was provided by the applicant in his application to the Siting Board and Expanded Environmental Notification Form to the State Office of Environmental Affairs. Where information was not included about the project, I sought publicly available sources. I conducted a fair comparison of each model as though I was an investor making a financial decision.

Q: What is the impact on your results of the alternative interconnection approaches included in the application to the Siting Board?

A: The interconnection costs for the proposed offshore wind project are very significant. The preferred approach by the applicant's estimate is more than $79,000,000. The second alternate approach is more than $292,000,000. The higher cost alternative results in a modeled price of $107.00/MWh for the offshore wind project; over 25% higher that the preferred approach. The interconnection costs for the proposed offshore wind project are a significant aspect of total project cost.

Q: Did you consider the financial benefits to the plant owner of a wind production tax credit in your analysis?

A: Although the PTC and other subsidies distort the relevant electricity markets rather than making them more efficient, I have included the effect of these subsidies on the relative "economic efficiency" of the proposed plant versus other technologies. Assuming that Congress continues to approve this tax credit for the life of the project, with an escalation linked to the consumer price index, the modeled price for the offshore wind project is calculated to be $66.00/MWh. This result is based upon the assumption that the PTC would be applied over the life of the project. However, current law only allows the project to benefit from the PTC for the first ten years. When this conservatism is removed from the analysis, the modeled price for the offshore wind project is $73.00/MWh. This is significantly higher than the cheapest alternative and is, in fact, higher than all the other alternatives.

Q: How significant is the capacity factor assumed in the financial modeling for the wind project?

A: As for any generator, the amount of electricity sold into the market is a direct measure of revenue. In the Expanded Environmental Notification Form, the applicant assumed that the project would generate electricity and revenue, on average, 40.5% of the time. In subsequent documentation to the Facility Interconnection application, the applicant stated that the project would generate, on average, 36% of the time. Although this difference may appear small, it actually represents a 12.5% difference in annual revenue for the project.

In my analysis, I included the increased revenue for the wind model associated with the larger capacity factor of 40.5%. However, the lower capacity factor of 36%, which the applicant state in his response to interrogatories is the correct value, would have a significant negative impact on the financial results.

Q: What conclusions do you draw about the economic efficiency of the proposed wind project from your analysis?

A: Many claims about the cost of renewable energy projects often do not include all of the real costs involved in construction, such as insurance, development, permitting, engineering, construction management, start up, finance, debt service, initial working capital, net interest during construction, and interconnection. When all of these costs are included, the result is a fair and clear comparison of costs, which is what I have done for all of the modeled projects. I conclude that offshore wind projects are a very expensive way to generate electricity compared to all other reasonable alternatives due to the higher capital costs. These capital costs are so high that they are greater that the applicant's perceived economic advantages of a zero fuel cost and Federal and State subsidies. Thus, I conclude that the proposed project is not economically efficient when compared to alternatives.

Q: Based on this analysis do you believe the proposed project would make wholesale electric markets more efficient?

A: I do not believe that this project will make the wholesale electric market in New England more efficient. As discussed above, the applicant has stated his intent to bid this intermittent resource into the wholesale power market at zero value, thus ensuring that the generator will be able to sell into the market as a "price-taker." My analysis shows, however, that the zero-bid wind plant will likely displace other generation that is less costly to produce from the perspective of long run marginal cost, which I consider to be the most useful measure of economic efficiency. This approach will not make for an efficient wholesale market and cannot be sustained very long. The proposed project must eventually cover its capital and operational costs or it will go out of business. In the meantime, this approach will create havoc with lower cost electricity producers who may be forced out of the market during this time. Cape Wind has not presented any evidence that the proposed project is sustainable as a price-taker, surviving only on a steady diet of renewable energy and production tax credits. Even if it were sustainable on that basis, the result might be profits for Cape Wind, but it would not be economic efficiency for the Massachusetts and New England electricity markets.

Q: Did you consider any other renewable power plants and if so, what were the results of your analysis?

A: I also considered the costs of a similarly sized onshore wind project. I determined that the costs of an onshore wind modeled power project were approximately half that of the offshore wind project. Even with a significantly lower capacity factor, onshore wind resulted in modeled prices for electricity that was competitive with the lowest cost alternative.

In recent months I have read a number of news stories of Cape towns considering the construction of small clusters of onshore windmills, including a recent announcement of a project by the Town of Barnstable. In addition, I found that nearly 300 MW of new onshore wind projects have completed applications to NEPOOL for interconnection since May 2003, all of which appears to support the notion that the cost of onshore wind is more competitive.

Q: What conclusions do you draw from this analysis and why is this significant to consideration of this application?

A: Offshore wind, even when the wind production tax credit is included, is a highly capital intensive source of energy. In order to sustain debt service for the proposed project, the long-term marginal costs to operate profitably will be about $92.00/MWh. This is nearly double the cost of other energy alternatives, and much higher than onshore wind projects. If the project is justifiable, it must be on grounds other than economic efficiency.

Further, it is my understanding that the Siting Board considers alternatives to the proposed location of an energy facility within its jurisdiction. In this case, that could mean considering different locations for the proposed transmission line. I would suggest that the Siting Board consider alternative onshore locations for the transmission line, which could accommodate a single- or multiple-site wind development on the Cape or elsewhere in Massachusetts or New England. Such a development would likely provide all of the non-economic benefits claimed by the applicant at a much lower cost. The resulting project might still not be justified purely on economic efficiency grounds, but it would at least be more economically efficient than the proposed offshore development.

Q: Does this conclude your testimony?

A: Yes, it does.

Prepared Testimony of

Erich K. Bender

On Behalf Of

Alliance to Protect Nantucket Sound

Before the

Commonwealth of Massachusetts Energy Facilities Siting Board

Cape Wind Associates, LLC and Commonwealth Electric

EFSB 02-2/D.T.E. 02-53

June 20, 2003

Q: What is your name and your affiliation with the Alliance to Protect Nantucket Sound ("APNS")?

A: My name is Erich K. Bender. I am an acoustical engineer, and have been requested by APNS to analyze the acoustical impacts of the proposed wind farm that Cape Wind Associates, LLC plans to construct in Nantucket Sound.

Q: What qualifies you to conduct such an analysis?

A: I have over 25 years of professional experience in the acoustical field. I have managed BBN Technologies' Acoustic Technology Division, led military oriented acoustics activities at BBN Technologies, developed BBN Technologies' business in noise assessment and control, and led a wide range of technology development programs involving acoustics at BBN Technologies. Additionally, I am a Fellow of the Acoustical Society of America and have published over thirty technical papers in acoustics and related fields. I hold BS, MS, and ScD degrees from the Massachusetts Institute of Technology.

Q: Please briefly state the purpose of your testimony.

A: The purpose of my testimony is to provide guidance to the Siting Board regarding the environmental impacts of the power that would be produced by the Cape Wind project. My understanding is that the Siting Board considers noise emissions along with other types of emissions in reviewing the environmental impacts associated with power produced by a particular plant. In this case, I believe those noise impacts will be sufficiently significant that they should be brought to the Siting Board's attention.

Q: What noise sources are associated with the proposed wind farm?

A: Wind turbines generate noise from various sources. The primary source is the fluctuating aerodynamic pressures on each set of rotor blades. Fluctuating pressures result from turbulent boundary layer flow over the blades, the ingestion of unsteady atmospheric turbulence, and steady but unsymmetrical inflow fields due to the atmospheric boundary layer and possible upstream structures. The latter effect is pronounced for so-called "downstream turbines" in which the rotor is downstream of the pylon supporting the hub and rotor. This effect is not present for "upwind turbines" in which the rotor is upwind of the pylon. Other noise sources include gear trains and electromagnetic generators located within the hub. All of these components radiate sound directly and transmit vibrations to other structural members, which radiate into the air and water.

Q: How, and to what extent, will noise be propagated to neighboring shore communities?

A: Propagation of sound to communities along Cape Cod is controlled by a number of factors, including the number and geographical distribution of turbines as well as atmospheric conditions as determined primarily by wind and temperature gradients. Gradients refract sound waves such that amplification is experienced in the downwind direction and attenuation in the upwind direction as compared with propagation in the absence of gradients. Similarly, amplification is provided when the air near the surface is cool (e.g. at night) and attenuation when it is warm. This means that wind turbine sound levels will be higher on the Cape at night and when winds have a southerly component, and lower during the day and when winds have a northerly component.

Q: Will noise generated by the proposed wind farm have an affect on buildings?

A: Yes. Low-frequency sound, which is clearly evident in wind-turbine data, will cause building walls and windows to vibrate and this vibration may be perceptible. Additionally, window vibration causes windows to rattle, which may be heard as audible sound.

Q: What are the predicted sound levels of noise generated by the proposed wind farm?

A: Within 1,000 meters of the edge of the proposed wind farm, A-weighted noise levels will be in the vicinity of 55 dB(A) to 60 dB(A). Along the shoreline of Cape Cod, including residential areas of the shoreline, noise levels are expected to range between 45 dB(A) and 55 dB(A).

Q: What are the impacts of noise levels on water ranging from 55 dB(A) to 60 dB(A)?

A: People in motorboats traveling at low speeds and people in sailboats will hear the noise generated by the proposed wind farm. These noise levels are intrusive, and will detract from the peaceful ambience of Nantucket Sound.

Q: What are the impacts of noise levels on shore ranging from 45 dB(A) to 55 dB(A)?

A: Noise levels ranging from 45 dB(A) to 55 dB(A) will be clearly audible in relatively quiet indoor or outdoor environments ashore. Accordingly, people on Cape Cod will hear the proposed wind farm in operation, especially when the wind has a southerly component, and many people will find the noise intrusive and annoying. People will perceive both noise and building vibration from wind turbines at these noise levels. Further, some people register complaints under these conditions.

Q: Will wildlife be able to hear noise produced by the proposed wind farm?

A: Yes, birds and sea mammals will be able to hear noise produced by the proposed wind farm. It is likely that seals will be able to hear noise produced by the proposed wind farm anywhere in Nantucket Sound.

Q: Does this conclude your testimony?

A: Yes, it does.

Prepared Testimony of

Michael L. Morrison

On Behalf Of

Alliance to Protect Nantucket Sound

Before the

Commonwealth of Massachusetts Energy Facilities Siting Board

Cape Wind Associates, LLC and Commonwealth Electric

EFSB 02-2/D.T.E. 02-53

June 20, 2003

Q: What is your name?

A: Michael Morrison.

Q: What is your background and experience?

A: I hold a Ph.D. in Wildlife Ecology, and have twenty years of experience in this field at major academic institutions. I have served for over eight years as the primary biological consultant to the National Renewable Energy Laboratory's Bird-Wind Energy Program and consulted with multiple government regulatory agencies concerning environmental impacts of wind energy developments. A copy of my current CV is attached as Exhibit A. A copy of my relevant wind experience is attached as Exhibit B.

Q: What is the purpose of your testimony?

A: The purpose of my testimony is to provide information to the Siting Board regarding the potential environmental effects of the power that would be produced by the Cape Wind Energy Project (CWEP). My understanding is that the Siting Board considers whether this power would have environmental benefits such that there would be a need for that specific power. If that is the case, it is my view that it would be appropriate for the Siting Board to consider both the potential positive and negative impacts of the power from the plant before determining whether there are net environmental benefits from the power that would be produced by the plant. One potential negative environmental impact from producing power by wind is its impact on birds and bird habitat. My testimony is limited to these potential effects.

Q: What work did you perform in reaching the opinions expressed in your testimony?

A: To evaluate the potential impacts of the proposed (CWEP) on birds, I reviewed existing data and proposed surveys in and around the project area; reviewed bird-wind data, including that existing on offshore developments; and used my extensive experience in avian ecology and bird-wind studies. Literature cited is listed at the end of this document.

Q: Could you please summarize your conclusions?

A: Based on my review I conclude that:

- Many onshore wind farms have been evaluated with regard to bird-wind interactions. Although most developments kill few birds, substantial kills have been noted in some locations. The extremely high incidence of bird kills at the Altamont Pass Wind Resource Area, California, has had a devastating impact on wind development in North America; such a situation should not be risked for offshore projects;
- Numerous authorities (e.g., National Wind Coordinating Committee [NWCC], National Renewable Energy Laboratory [NREL]) recommend that areas of high bird use, areas harboring rare and endangered species, and other special wildlife areas be avoided when locating wind developments;
- Virtually no data are available on the impact of offshore wind developments on birds, and no data are available on windfarms of the size of CWEP; thus, no reliable predictions can be made on potential impacts without further data collection and analysis;
- In Europe, many governments are conducting extensive environmental analyses to identify areas that are favorable for development and where, because of environmental

sensitivities, areas that should not be developed; thus, an overall strategic plan is being instituted and such a strategy should be followed in North America;

- Recommendations on offshore wind facilities by many European governments include constructing relatively small farms, avoiding areas of high numbers of birds or areas with sensitive bird species, and intensive monitoring before and after (if the project is approved) construction;
- Standard guidelines recommend that multiple years of intensive, rigorous data be collected before beginning construction of commercial windfarms;
- Insufficient data on bird abundance, bird movement, and bird behavior exist in the project area to conduct a rigorous risk assessment of the potential impacts of CWEP on birds;
- Virtually no data are available on the impacts of the relatively tall turbines (blade tip height), such as those proposed for CWEP, on birds; and no such data exist for offshore placement of such turbines;
- Proposed surveys for CWEP will not provide the data necessary to evaluate risk in a rigorous manner; the proposed studies are insufficient both in terms of intensity and duration;
- In general, all wind farms (onland and offshore) should avoid areas of substantial bird passage and use, including areas that harbor one or more species of special concern (e.g., rare, legally threatened or endangered); and

- I conclude that 2 years of intensive surveys would be adequate to evaluate risk; data collected for CWEP to date are preliminary in nature and should not be considered part of the recommended 2 full-years of data.

Q: What are your conclusions regarding the research both proposed and completed by the developer for CWEP?

A: In summary regarding CWEP, the research designs are flawed, the results presented to date are biased in favor of the project, relevant information has been overlooked, and additional data need to be gathered before informed decisions can be made. At this time, any conclusion that power produced by the CWEP would have net environmental benefits associated with it would be made on insufficient information to evaluate the environmental risks of the project.

Q: How is the remainder of your testimony organized?

A: Below I first summarize the status of bird-wind studies and risk assessments as they apply to CWEP. Next I review the data available from the project area, relying heavily on a thorough review made by the Alliance to Protect of CWEP and for which I provided extensive commentary. Then I provide recommended sampling procedures to evaluate both direct (e.g., fatality) and indirect (e.g., habitat loss) impacts of windfarms on birds.

Q: Could you provide some background on the history of modern wind development and its environmental impacts?

A: Wind power has been used commercially to produce energy since the early 1980s, when the world's first large-scale wind development, or wind resource area (WRA), was built in California. There are over 22 states with wind resource areas, with many more in the planning process (see review by Sterner 2002). Wind energy offers a relatively environmentally benign source of electricity and many more wind projects are being proposed throughout the United States and Europe. There are, however, a number of issues that have been raised concerning the feasibility of placing commercial wind developments in certain geographic locations and landscape settings. Developments near scenic areas, residential and commercial developments, and other locations frequented by people raise issues about noise and visual pollution. Additionally, birds and bats are known to collide with the rotating blades of a wind turbine, and substantial numbers of fatalities are known from a few locations. Finding solutions to the wind turbine/bird fatality issue would help assure government, wind industry, and the public that permitting wind development is being conducted in an environmentally responsible manner.

Q: What are some of the potential environmental issues related to wind power?

A: Wind power developments have been shown to cause environmental impacts, including loss or degradation of wildlife habitat and fatalities from collisions with rotating blades. It has been projected that 15,000 turbines operating in the United States by the end of 2001 would cause between 10,000 to 40,000 bird fatalities a year, with most of these occurring in California (Erickson et al. 2001). In some cases, there may be threats to local populations, and most birds including raptors and migratory species are given legal protection. In light of the cumulative effects of all human-caused avian mortalities (e.g., striking cars and buildings, pollution), any efforts to reduce mortalities become important. Additionally, wind developments can cause visual and noise pollution and land use issues when located close to areas of human use (e.g., houses, parks, roads). In the late 1980s, avian fatalities, particularly those of raptors at the Altamont Pass WRA in central California, became evident. Much of the material I summarize was gathered and synthesized independently by Erickson et al. (2001) and Sterner (2002).

Q: Could you please summarize the available evidence regarding bird fatalities?

A: Researchers have conducted a large number of avian fatality surveys at WRAs in the United States and Europe. Fatality studies in the United States indicated that the incidence of raptor collisions in California, particularly at the Altamont Pass WRA, is considerably higher than in other WRAs (Erickson et al. 2001, Hunt 2002). Passerines composed the highest percentage of fatalities in the non-California studies. Reports from these studies indicate that the levels of fatalities are not considered significant enough to threaten local or regional population levels. A major difference between the Altamont Pass WRA (California) and other WRAs is that many other areas lack the dense populations of raptors and diverse topography of the Altamont Pass WRA. The high number of fatalities at the Altamont Pass WRA has served to create awareness of potential siting problems and in some cases, more regard has been given to the level of avian use prior to construction. Thus, intensive, multi-year pre-siting studies are recommended before approving any commercial wind development. Multiple years are required because numbers of birds, and their behavior (e.g., flight times and locations), can change substantially between years.

Studies on avian interactions have been conducted at over 100 sites in Europe, but most of these studies focus on solitary or small groups of turbines. Although the fatality rates in Europe are often higher than those that occur in California and the rest of the United States, many European scientists have not considered this impact a significant threat to bird populations in most of Europe because the number of deaths is small relative to the total number of birds using or passing through the area.

Very few studies have been performed to determine the overall effects of wind turbine impacts on the population viability of an individual species. This type of evaluation is exceedingly difficult and relatively costly; studies that are based on field-level tracking of population parameters require intensive sampling over a number of years for each species of concern. Most evaluations of wind-turbine-related avian fatalities have concluded that the impacted birds are fairly common and not threatened at the population level.

However, because some raptor species are relatively less abundant and produce fewer young, compared with many other groups of birds, human-caused fatalities could have a more noticeable effect on populations. *Additionally, it is the number of fatalities relative to the population size, and not the absolute numbers killed, that are of concern. Thus, even a few fatalities of a locally or regionally rare species could have negative impacts on the population structure and size.* Thus, in my view, proposed wind developments that are located within or adjacent to substantial concentrations of rare species should not be permitted.

Q: Could you please discuss the impact of wind developments on animal habitat and movements?

A: Yes. First, I should define what I mean by habitat. The term habitat refers to the specific configuration of environmental features (e.g., water depth, rock outcrops) that an animal uses at any point in time. Habitat per se is a species-specific concept. That is, every animal species uses a different combination of environmental features. Therefore, no specific area is "good" or "bad" habitat unless it is assessed in relative to a specific species. Thus, what is "good" for one species might be "poor" for another species (Morrison et al. 1998).

This definition and discussion of habitat has relevance for all resource-use issues. For wind developments—both on land and offshore, issues of habitat concern (1) outright loss of a species' habitat because of development, (2) indirect impacts because of disturbance (i.e., the animal will no longer reside near the development), and (3) disruption in animal passage through or over the development because of the addition of towers and turbines.

On land, wind developments often stretch for many miles along ridge tops. As such, the turbines themselves along with the associated infrastructure, especially roads, can impact animal movements. Little quantitative work has been done, however, on the impacts of wind developments on animal movements. It is unlikely, however, that onshore wind developments will cause wholesale disruption in migratory movements of terrestrial vertebrates. This is because wind developments are seldom if ever introduced into pristine environments. As such, migrating or dispersing animals encounter a host of potential obstructions, including highways, powerline corridors, housing, farm fields and pastures, and people. Analysis of the impacts of a wind development on movements of animals, therefore, would usually focus on the additional impacts that the wind development would have on animal movements. Offshore, the existing information is scarce but indicates that turbines may, indeed, disrupt animal movements. In contrast to land-based developments, offshore developments are often placed in relatively pristine environments. Additionally, animals (birds, marine mammals, fish) have not regularly encountered large, permanent obstructions in their environment. As reviewed below, offshore developments in Europe are small relative to that proposed for CWEP. As such, there are no data that can be used to make reliable predictions on the impact that proposed offshore developments will have on birds and other animals.

Q: Could you please describe the various theories that have been formed in an attempt to explain bird fatalities from wind developments?

A: Various design features, such as perch availability, rotor diameter, rotor-swept area, rotor height, rotational and tip speeds, and fixed versus variable turbine speed have been evaluated to determine if they contribute to bird collision risk. Although earlier workers suggested that lattice towers might encourage birds to perch and thus come into close proximity of rotating blades, recent studies have failed to confirm a correlation between tower type and fatality rates (Thelander, unpubl. data).

Although no conclusive evidence has been found, several studies have found indications that increased rotor diameter or rotor-swept area is associated with fatalities. The issue of rotor-swept area and blade diameter effects on avian collision risk with turbines is important because wind developers are in the process of repowering or replacing existing, less efficient turbines with a smaller number of new, larger, and more efficient turbines.

Several studies have indicated that overall bird fatalities are higher at taller turbines. This was attributed to higher-flying, non-raptor nocturnal migrants that often constitute the greatest percentage of fatalities. Behavior differences among raptors indicate that there may be some trade-offs in benefits. For example, one species may benefit from blade tips being further from ground level, whereas others may be exposed to greater risk from blades that reach a greater overall height. Rotor velocity and a corresponding increased tip speed are correlated with fatalities. Faster turbine rotor speeds kill more raptors than would be expected by chance. Unfortunately, little qualitative or quantitative data are available on the impacts of the relatively tall, newer generation turbines (and towers) on bird behavior and fatalities.

Q: Could you please describe the work that has been done with respect to offshore wind developments and their potential impacts on avian populations?

A: As recently summarized by the National Wind Coordinating Committee (NWCC web site, www.nwcc.com, 25 September 2002 meeting), wind power developers are beginning to look offshore for greater wind resources and some lower development costs. As this is a new application for wind power in the United States, the NWCC noted that background information is needed about environmental, technical, economic, and political issues associated with offshore developments. Some of this information can be gathered from Europe as they have been working on offshore wind energy development for the past decade. However, each situation varies and thus local factors need to be taken into account. Only recently (2002) has the NWCC initiated meetings designed to learn about the issues associated with offshore developments.

The September 2002 NWCC meeting noted that a current database on locations of feeding and migratory sites does not exist and should be developed. Additionally, speakers noted that a study is needed to analyze the cumulative affects of offshore wind developments, environmental impacts as well as economic development impacts. As acknowledged by Kerlinger and Hatch (2001) when discussing offshore wind developments in their evaluation of the proposed CWEP on birds, "The few offshore, nearshore, or shoreline studies have been located at small wind plants in the United Kingdom, Denmark, and the Netherlands. The turbines involved have primarily been modern turbines of moderate electrical output (300-500 kilowatts each), each placed on a tubular tower. In addition, these turbines have been relatively few in number, ranging from about 9 to 25 turbines." Thus, not only do few data exist on offshore facilities, there are no data available on facilities using the large turbines and number of turbines proposed for CWEP. As noted by Kerlinger and Hatch (2001) in reference to offshore studies, "there are no simple conclusions about whether wind turbines disturb or displace birds ... The diversity of findings suggests that a key question has yet to be investigated." Thus, Kerlinger and Hatch concur that little is known on the potential impacts of offshore wind developments, such as CWEP, on birds.

Q: How have other countries addressed the environmental impacts associated with power produced by wind turbine developments?

A: The United Kingdom limits offshore wind farms to 30 turbines (even if 2 MW turbines are used, that is only 60 MW) to reduce environmental and visual impacts, and to ease the cost of decommissioning and dismantling when problems arise. One of the benefits of limiting the size of farms is that if problems are identified the farm can be shut down without a great disruption to the grid and loss of value, as the turbines can be used at another site. Thus, various governments in Europe have chosen to limit the size of individual wind farms because of a variety of environmental and other siting concerns. In The Netherlands, Winkelman (1992) used search approach radar, passive image intensifiers in combination with infrared spotlights, and a thermal image intensifier to study the passage of birds through an onshore windfarm. Winkelman (1995) also summarized the status of bird-wind interactions in Europe. Overall, the kill rate was considered low. She noted, however, that 2-3% of birds passing a windfarm at rotor height were killed. She concluded that disturbance and habitat loss effects associated with wind developments were probably much more important than direct bird kills due to collisions. In Spain, however, relatively high levels of kills were sometimes evident. Research in Europe has indicated that individual and single rows of turbines in areas with small bird populations provide the best landscape for wind farms (Air Quality Research 1992).

Winkelman (1995) showed that turbines in The Netherlands adjacent to the Wadden Sea showed a higher rate of bird kills relative to turbines in upland areas. These higher kills appeared to be related to the large number of birds in and around the sea relative to the upland locations. Unfortunately, virtually no information is available on fatalities at offshore wind farms in Europe (e.g., Tulp et al. 1999).

Still et al. (1994) evaluated a small (9 turbines) wind farm erected along a pier at Blyth Harbour, UK. From a total of 108 species recorded in the harbor area, collisions with the turbines occurred in 4 species: eider duck, herring gull, greater black-backed gull, and black-headed gull. A total of 19 kills were recorded over 15 months of study, and the occurrence of collisions appeared to be related to poor weather and visibility. No attempt was made to evaluate the influence of scavenging or observer bias on the number of birds found dead.

The organization "BirdWatch Ireland" developed a position statement regarding windfarms based on a review of bird-wind interactions in Europe (Galvin 2001). They noted that an overall, strategic approach should be adopted by government to identify locations that are unlikely to result in substantial bird fatalities and disturbance. In particular, they recommend that Important Bird Areas, Special Protection Areas, and other formally designated sites and other sensitive bird sites be avoided. They also noted that a paucity of information exists at offshore windfarms, and recommended that a precautionary approach be taken. Even in Europe, therefore, much uncertainty exists over the impacts of offshore developments on birds. For example, the government in the UK is working on a strategic environmental assessment that will guide the siting of offshore wind developments. This effort will identify areas where there would be a presumption in favor of development and where, because of environmental sensitivities, a presumption against development.

Some offshore windfarms in Europe have been met with public resistance. For example, a court in Belgium recently upheld a complaint that a proposed 100 MW offshore project would spoil the sea-view, and that the government had not handled the permit appropriately (Martin 2003).

Thus, the bird-wind data on offshore windfarms in Europe is scarce. It is clear, however, that there is concern about the potential impacts that offshore facilities could have on birds as witnessed by the precautionary tone taken by many individuals. Recommendations include constructing relatively small farms, avoiding areas of high numbers of birds or areas with sensitive bird species, and intensive monitoring before and after (if the project is approved) construction.

Q: Would you please describe the kind of research and monitoring that should be used with respect to a proposed wind power development?

A: Yes. This process should begin with initial site selection and permitting. The National Wind Coordinating Committee (NWCC), a collaborative of representatives from the environmental community, wind energy industry, state legislatures, state utility commissions, consumer advocacy offices, green power marketers, and federal and state governments, was established in 1994 to support the development of wind power. The Siting Subcommittee of the NWCC was formed to address wind generation siting and permitting issues. This subcommittee prepared a collaborative document, entitled *Permitting of Wind Energy Facilities: a handbook* to provide guidance in evaluating wind projects for all stakeholders. Some aspects of wind facility permitting closely resemble permitting considerations for any other large energy facility or other development project. Others are unique to wind generation facilities. Unlike most energy facilities, wind generation facilities tend to be located in rural or remote areas, and are land-intrusive rather than land-intensive. Thus they may extend over a very large area and have a broad area influence, but physically occupy only a small area for the turbine towers and associated structures and infrastructure (e.g., roads, transmission lines).

This NWCC handbook outlines the many factors that must be considered when permitting a wind generation facility, including (but not limited to) land use, noise, birds and other biological resources, visual resources, soil erosion and water quality, cultural resources, and socioeconomic considerations. Permitting processes that result in timely decisions, focus on the critical issues early, involve the public, and avoid unnecessary court challenges will enable wind generation to compete with other energy technologies and provide a diverse supply of energy.

The next step is to design appropriate sampling protocols. Sampling protocols and methods of quantifying fatalities in the field must be rigorous and scientifically valid. Failure to establish rigorous protocols and methods results in data sets that are subject to criticism and are not ideal for determining how to reduce wildlife fatalities in wind developments.

The NWCC Avian Subcommittee was formed to address avian interactions with wind developments, and it identifies research needs and serves as an advisory group. To address differences in methodologies, lack of adequate control or baseline data in existing studies, and the resulting lack of inter-study comparability, the Avian Subcommittee developed a guidebook titled *Studying Wind Energy/Bird Interactions: A Guidance Document* (Anderson et al. 1999). The document provides a comprehensive guide to standardized methods and metrics to determine impacts to birds at existing and future wind farm sites. A stated purpose of the guide is to promote efficient, cost-effective study designs that will produce comparable data and reduce the overall need for some future studies.

The *Guidance Document* identifies three levels of surveys of increasing intensity that should be applied to a proposed or developing wind development. “Site evaluation” or “reconnaissance” surveys are relatively non-rigorous and use primarily published literature and non-published report, expert opinions, and other sources of information to make a first determination if a proposed site will be likely to result in environmental problems. Such reconnaissance surveys are cursory in nature but should help eliminate problematic sites from further consideration. If the reconnaissance survey indicates that the site should be suitable for development, then a “level 1” protocol is indicated in which more intensive and quantitative on-site surveys occur, usually for a minimum of 1-year prior to a decision is made to proceed with development. Such level 1 surveys include on-site sampling of wildlife movements and other activities (e.g., foraging, nesting), quantification of the presence and abundance of sensitive species, and so forth. If a decision is made to proceed with development after level 1 surveys have been evaluated, then the data set also serves as the "before" data to be compared with changes in environmental conditions following ("after") development. In rare cases the results of a level 1 study indicates that more intensive study is necessary, such as when the presence of a legally protected species (e.g., threatened or endangered species) is located. In such cases, however, it is usually unwise to proceed with development.

To aid bird-risk evaluations, there is a need to define the "level of take" that is acceptable from avian species' interactions with wind turbines—that is, the level of fatalities that can occur without reducing that species' population. The level of assigned risk will vary among species. If threatened or endangered species are affected, incidental take permits can be issued under the federal Endangered Species Act, but "no take" may be the targeted goal. There is no accommodation for take under the Migratory Bird Treaty Act, which applies to a large number of birds, including raptors and passerines that have been killed by collisions wind turbines. To date, the U.S. Fish and Wildlife Service has been somewhat tolerant of existing conditions at WRAs. However, future wind plant approvals—particularly in California where existing avian fatality issues have not been resolved—may be in jeopardy due to enforcement of this act.

Q: Please describe the research protocol that has been used to evaluate the potential avian impacts of the CWEP.

A: The research protocol that Cape Wind and its environmental consultant, Environmental Science Services (ESS), devised will not provide the data needed to make a reasoned decision on CWEP. The agencies tasked with responsibility over avian resources, and experts in the field, have criticized the assumptions on which Cape Wind and ESS have based their research protocol. I agree with these criticisms. As noted by the Alliance, the Army Corps of Engineers (COE) has allowed the project applicant to determine the breadth and depth of the studies to be conducted for the EIS. As stated by the Alliance, "This abdication of primary responsibility as lead agency over the content of the EIS violates NEPA and other federal laws. More importantly, by allowing a private developer with a keen interest in finding avian impacts to be minimal to determine the scope of the studies, the COE potentially jeopardizes a fragile ecosystem and the health of globally significant avian populations." The views of the public agencies vested with environmental protection duties to further the public interest significantly differ from Cape Wind's proposed study. Based on the extensive comments by the USFWS criticizing the process, as discussed herein, the COE and Cape Wind are not using the best scientific and commercial data available, and indeed appear to be making little effort to satisfy the requests made by the USFWS. Again, I concur in these criticisms, and do not believe that the protocols used by Cape Wind are adequate for a project such as the proposed CWEP.

Q: What do you see as the deficiencies in the development of the Cape Wind's bird protocol?

A: In my experience, the NEPA scoping process is designed to ensure that environmental study protocols are such that they produce data adequate for a proper assessment of the potential impacts of an action. In this case, however, the scoping process has been deeply flawed for a number of reasons, including the project proponent's excessive involvement in the process. The bird research protocols adopted by Cape Wind reject suggestions from state and federal agency experts in the study of bird behavior and ignore recommendations from public citizens and groups with particular expertise on the birds of Nantucket Sound. The result is a superficial and unreasonably short study that will in no way enable the COE or any other agency to determine the impact of this project on significant populations of birds. Instead of developing its own protocol, the COE simply adopted the applicant's ENF, which Cape Wind designed.

The hypothesis from which the scoping process has proceeded is that avian risks are small and bird use is low for the Horseshoe Shoal area. This conclusion is largely the result of the research and analysis conducted by Dr. Paul Kerlinger of Curry and Kerlinger, LLC (Kerlinger and Hatch 2001). Using Kerlinger and Hatch (2001), the ENF identified the following avian studies as necessary:

(1) aerial studies of Horseshoe Shoal in July-September to determine whether certain protected species were present and in what numbers;

(2) late autumn-winter study of sea ducks, loons, diving birds, and alcids to determine presence and number;

(3) an evaluation of impacts of offshore wind energy projects based on work now being conducted in Europe and methods and techniques for monitoring.

Cape Wind had already completed many of the proposed studies when it submitted the ENF. Additionally, Kerlinger and Hatch (2001) did not follow, or even reference, the protocols and recommendations made by the National Wind Coordinating Committee (NWCC, December 1999) in "Studying Wind Energy/Bird Interactions: A Guidance Document." (http://www.nationalwind.org/pubs/avian99/Avian_booklet.pdf). Although the NWCC document does not include specific recommendations for offshore developments, the recommendations it provides regarding the general types and intensities of studies are applicable to any development, and these were not followed by Kerlinger and Hatch..

Q: Please describe what you see as the deficiencies in the Cape Wind protocols.

A: Flaws in the ENF are apparent. The MDFW objected to a number of conclusions claimed in the ENF because "the installation of turbine towers at this location in Nantucket Sound could have potentially devastating impacts on globally significant populations of migratory birds moving in and out of Massachusetts, as well as between Cape Cod and the Islands." The MDFW viewed Cape Wind's conclusion that avian risk was minimal as based on "inadequate or no data at all." The state agency had "discovered no systematically collected data on birds in the vicinity of Horseshoe Shoal." In addition, the ENF's proposed tern study "ignores substantial periods of the year [and] also the possibility of substantial variability in the temporal and spatial utilization of the Horseshoe Shoal environment." The MDFW also stated, "*Horseshoe*

Shoal is virtually at the very center of the core Piping Plover breeding range on the Atlantic Seaboard" (emphasis in original.) Consequently, "[a]lthough it would be difficult to document, we feel with virtual certainty that some plovers must fly through the Project Area at times and *any* impact to this population due to collisions would not be acceptable." The MDFW concluded, "several years of work may be required using combinations or aerial or boat surveys, sound recordings and radar surveys." As noted above, I concur that multiple years of rigorous research are required, and I concur with MDFW's other criticisms of the ENF.

I also concur with the criticisms of the USFWS, which followed with its own similar set of criticisms by letter of 31 December 2001 to Secretary Robert Durand of the Massachusetts Executive Office of Environmental Affairs. In that letter, USFWS stated that the bird analysis should include "all seasons of the year, all usable airspace, all climatic conditions and all daily temporal periods in order to capture all life cycle activities of the avian species using the project area." In addition, USFWS explained that this project requires "a vigorous analysis of daily and seasonal temporal patterns of bird activity, weather conditions, lighting conditions, and whether any features or operational characteristics of the wind turbines individually or in aggregate create or induce hazards to migratory birds." I urge all other agencies and regulators to pay heed to the conclusions of the USFWS as stated above, especially given that many federal laws concerning the disturbance or killing of birds are involved.

The MAS noted that millions of birds traverse the Sound each year and that the ENF's conclusion is not supported by sufficient data on interactions between birds and large-scale offshore wind farms, or actual bird usage of this section of Nantucket Sound. To remedy these deficiencies, MAS recommended that at least one type of bird survey be conducted on a frequency of at least one day per week throughout the year, with specific methodology aimed at gathering information during breeding, migrating, and wintering seasons, as well as during varying times of day, meteorological, and tidal conditions. I concur that this level of intensity should be required, especially given the current uncertainty over how birds offshore will respond to the turbines.

Q: How has Cape Wind reacted to these points?

A: Cape Wind has largely ignored these suggestions. Compared to the detailed information required by the parties with bird expertise, as of 8 March 2002 there were to be only five winter aerial surveys. The over flights would be conducted in good weather only, with two flown at dusk or dawn. The other three were scheduled for daytime hours. ESS also indicated that only a total of 16 hours of observations would be conducted in the month of April, and in May, it would conduct radar studies from two hours before dawn to two hours after sunset with three ten-minute observation periods conducted randomly per hour. During that same period, Cape Wind would simply rely upon non-continuous bird observations during the daylight hours, plus two additional over flights. No nighttime studies (only late-evening) were scheduled, and no continuous radar was planned. This level of work does not approach that necessary to quantify bird abundance, behavior, and movements.

ESS slightly expanded the protocol by letter dated 15 April 2002 to the COE. In that letter, ESS indicated that it intended to conduct an additional four transects in the winter of 2002-03 and to expand the April studies by increasing the 16 hour study proposed in March by only four hours. In addition, ESS proposed to conduct one overflight study in July, three in August, and one in September. ESS also proposed radar studies for September 2002 relying on the same protocol used in the spring (two hours before dawn to two hours after sunset with three ten-minute observation periods conducted randomly per hour).

The USFWS, however, deemed ESS's proposed additions to be "not sufficient to adequately characterize the spatial and temporal uses of avian and other resources at the alternative sites in Nantucket Sound and hence, to make siting decisions on a macro or micro scale," a conclusion with which I agree. The USFWS recommended that the COE and Cape Wind adopt a three-year study plan, stating, "we believe the NEPA process for this highly visible and controversial project not only demands but requires this information to adequately evaluate the effects of the proposal on avian and related resources at alternative sites in Nantucket Sound." The USFWS also indicated that section 7 compliance under the ESA would be necessary, and it recommended: (1) on-site inspection for presence and number of listed species; (2) opinions of experts on the species; (3) literature review; (4) analysis of the effects on the habitat and species, including the cumulative impacts; and (5) an analysis of alternatives. The USFWS reiterated the need for a three-year study in a May 16 letter to the COE. The USFWS also indicated that remote sensing techniques (radar and acoustic) should be operated continuously 365 days per year using a combination of land-based and sound-based facilities Additional opinions highlighting the inadequacy of the current data set and proposed study plans were summarized in the Alliance letter to COE. . I concur that such additional measures are absolutely necessary when considering a proposed power development such as the CWEP.

Q: What do you conclude about the adequacy of the work conducted to date by Cape Wind?

A: I conclude that the work conducted to date is inadequate to quantify the distribution and abundance of birds using the proposed project area, and that updated plans to conduct some additional work remain far from adequate. No allowance was made to evaluate sample sizes (e.g., are the data adequate to rigorously evaluate seasonal abundance and movements?), so it will be impossible to know if the data collected represent an unbiased analysis of avian ecology in the project area.

In a COE document dated November 2002, the avian studies appeared to be slightly modified. The document indicated that 22 surveys had been conducted as of November (each of which covered approximately 260 linear miles of transect covering an area of 65 square miles), and 16 more were planned through June 2003. Two boat surveys were completed by November as well, using the same transects as the aerial survey. Seven non-systematic boat surveys were conducted, with "several" more non-systematic surveys planned for 2003. Importantly, there are no plans to extend the two months of radar surveys previously planned by the applicant. As discussed below, the approach reflected in this protocol remains seriously deficient, and fails to meet the recommendations of all outside bird experts who have considered this project.

Q: What do you see as the deficiencies of the current bird protocol

A: There are several related to the insufficient impact analysis on the endangered roseate tern and the threatened piping plover.

The proponent's surveys for roseate tern are inadequate for documenting potential impacts on this species. The primary gap in knowledge concerns nocturnal movements through the project area. More than 40% of the North American population of roseate terns are likely to pass through Nantucket Sound in spring and fall migration. It is unknown if diurnally moving terns have the visual capacity to avoid turbine collisions in conditions of good visibility. Additionally, tern movements across the Sound at night may be subject to significant collision risk. Cape Wind's current research efforts are solely geared toward studying diurnal movements and behavior of terns. It is imperative that research on the nocturnal flight behavior of terns be carried out before a permit application is processed. Many tern species are known to migrate both nocturnal and diurnally. The only study techniques capable of documenting nocturnal movements of species are radar, acoustic, and telemetric. Caspian and royal terns are highly vocal in their nocturnal migrations, and the acoustic technique is likely to be effective in monitoring tern traffic in the Sound. Telemetry has also been used to study movements of birds. Because of the proclivity of terns to move substantially at night, and because of potentially increased collision hazard at night, it is important for the COE and Cape Wind to consider one or both of these techniques to document the nocturnal activity of roseate tern in Nantucket Sound during their migration and post-breeding periods. Similarly, the same techniques could be used to characterize piping plover nocturnal movements.

These studies are extraordinarily important, not only for the proposed project, but for future wind farms along the Atlantic Coast that may impact these species. As noted by the USFWS, any take of these species is significant. Because it is very difficult to quantify mortality at offshore wind farms, assessing risk by documenting avian traffic patterns is essential.

Q: What are your opinions regarding the Preliminary Phase I Avian Risk Assessment by Kerlinger and Hatch (2001)?

A: As noted above, the preliminary risk assessment in Cape Wind's ENF was based on a literature survey by Kerlinger and Hatch (2001). This equates to the "reconnaissance level study" of the NWCC *Guidance Document* and should only be used to assess potential wind energy sites, and not be used to draw conclusions on the suitability of a specific site. This preliminary avian risk assessment does not bring pertinent avian literature to view for the stakeholders in this proposed project.

In a similar manner, Kerlinger and Hatch tries to build a case that tall man-made structures under 500-ft. high are not a concern. They stated that "no mass mortality events of night migrating or other birds have been found at communication towers less than about 500 feet in height." This claim is misleading because there have been no long-term studies at communication towers under 500-ft and only a few short-term studies. While some of the short-term studies concluded that there is little mortality, other studies in fact indicate that significant mortality may occur. Thus, of the studies that have been completed, no consensus has been achieved, probably because of site-specific variability in avian behavior. Further, communication towers do not have rotating blades, which are the major cause of bird fatalities in wind developments. Combined tower and blade (at their apex of rotation) height is an issue, especially during inclement weather when birds tend to fly relatively low.

Kerlinger and Hatch (2001) suggested that there are now more than 20 wind farm mortality studies in North America, and the documented avian mortality is indeed small at most developments. However, it is important to recognize that most of these studies were carried out in western North America, and therefore addressed different species, different habitats, different migration routes, and different behaviors. Additionally, the absolute number of kills carries little meaning unless it is compared to the overall population size of the species in question. That is, it is the number of kills *relative* to population size that is of importance in evaluating risk. As such, even a few kills of a rare species, such as those at risk from the Cape Wind project, can have a significant population impact.

There is also very little evidence that any tall man-made structures in the west kill significant numbers of night migrating birds. In contrast, collision-related avian mortality is a well-documented phenomenon in the eastern United States. Using western studies as the basis for extrapolating mortality rates for eastern wind energy projects, particularly those sited offshore, is therefore scientifically unsound. In fact, it may be legitimate to exclude western studies in the comparative consideration when evaluating how a wind farm in eastern North America might impact night migrating birds, given the significant differences in avian habitat and behavior. Moreover, significant avian mortality at wind farms is not unheard of in the western United

States. As reviewed elsewhere in the document, Altamont Pass, located in central California, has caused significant mortality. Thus, the potential for significant numbers of kills does exist, and uncertainty is substantial when venturing into new ecological locations.

Kerlinger and Hatch (2001) stated, based on their literature review, that the frequency of low-level movements at night by any of the bird groups is unknown for the project area. Additionally, they note the lack of quantitative data on bird abundance and movements throughout much of the project area. This paucity of data calls into question their conclusion that the potential impact with regard to bird kills is minimal. Apparently, this conclusion is based on the lack of substantial kills at many other onshore wind facilities in the western United States. As summarized above, this conclusion is inappropriate and premature without supportive data. Offshore wind farms in Europe are known to cause birds to change their pattern of behavior. In addition, studies are ongoing in Europe to try and better understand the influence of offshore wind farms on animals, including birds. Thus, there is too much uncertainty regarding the influence of offshore wind farms on birds and other animals to warrant review of the Cape Wind proposal.

Q: What is your opinion regarding the assessment of lighting associated with the proposed project on nocturnal bird activity?

A: That assessment has been inadequate. Lighting may be a significant contributing factor to bird mortality at the proposed wind farm. Because there is no precedent for such a lighted array of structures anywhere in US coastal waters, and because it is well-recognized that lights in foggy or low cloud ceiling conditions may disorient night migrating songbirds and some pelagic birds, research into the lighting issue is paramount. In addition, the lighting systems on towers cannot be fully evaluated until studies underway by the USFWS coordinated Communications Tower Working Group (CTWG) are concluded. These studies are in the process of determining the role of flash rate and color of lights in leading night migrating songbirds to congregate around tall structures with aviation obstruction lighting. Over the next two to three years, these studies will reveal what the safest obstruction lighting regime is for these species. It is imperative to evaluate these results before this project review proceeds. More research is necessary on the impact of lighting on a wide range of water birds

Q: What would you recommend as an outline for conducting an adequate assessment of the potential impacts of a wind development such as the CWEP on birds?

A: The following protocol outlines the basic steps that should be taken when evaluating the potential and realized impacts of a wind development on birds. These recommendations can be used as a starting point for development of specific sampling designs for the Cape Wind project.

1. Direct Effects

a. *Fatalities*

Because fatalities cannot be assessed prior to project development, initial risk assessment must be based on time and site-specific behavioral analyses. This is done by closely observing birds that use each proposed site (*including all alternative sites*) in "zones of risk." These zones correspond to the approximate rotor-swept area that will be occupied by the proposed turbines. Simple sampling methods are available for such analyses that can easily be adapted to offshore locations. All behavioral sampling must be stratified by time of day and night, season, weather conditions, and other factors considered relevant for the specific location.

b. *Specific Fatalities Studies*

- Behavioral sampling is usually conducted weekly or bi-weekly at each proposed location. The geographic extent of the project determines how many sampling stations are needed.
- Stratify sampling as indicated above.
- Results should provide quantitative prediction of potential risk to birds (*e.g.*, frequency of passes through rotor plane).
- Results should be linked with estimated population abundance so an estimate of the relative proportion of potential fatalities can be calculated (*i.e.*, risk relative to population size).

c. *Habitat loss and degradation*

It is critical to recognize that "habitat" is a species-specific concept. Thus, there is not an "offshore habitat" per se. Habitat is defined as an arbitrary (user-defined) area around an animal. Additionally, it must be recognized that each species exploits a specific niche. Relevant niche factors include the species and size of prey consumed, air and water temperatures, and so forth. Thus, any development that impacts a niche dimension can also negatively impact a species (*e.g.*, a change in the distribution of prey of certain size classes). These issues must be evaluated for all potentially influenced species. Additionally, it is the *availability* of habitat and niche factors that is of critical importance and not the absolute abundance of a factor. For example, if prey remains equally abundant both pre- and post-construction, but a bird species will no longer use a site, then those prey become unavailable.

d. *Specific Studies/Habitat Loss*:

- Quantify distribution and abundance of habitat by species.
- Quantify availability of habitat and key niche factors by species.
- Must include preferred as well as alternative sites in analyses.

2. Indirect Effects

a. *Behavioral changes*

Birds could alter their use of a site based on positive or negative reactions to development. Positive effects include attraction because of changes in perching or foraging opportunities; negative effects include abandonment of the site because of visual obstructions (turbines), human activities (water or air traffic), and related factors. This area of analysis links closely with the overall activity pattern of animals and the relationship with habitat availability. That is, if birds abandon an area they must have an alternative area of at least equal value to occupy. Otherwise, the development will have a substantial albeit indirect impact on the species in question.

b. *Specific Studies*

- Analysis of bird movements in, around, and through each alternative development location.
- Stratify samples as outlined above.

- Determine where birds are coming from (*e.g.*, onshore roosting or nesting locations) to quantify off-development site impacts.

3. Sampling Intensities

As noted above, sampling should take place weekly or bi-weekly (depending on species) throughout the year so that thorough assessment of the distribution, abundance, and activity of birds can be quantified. Sampling should include both diurnal and nocturnal sampling, with a higher sampling intensity during migration. Radar is available that can determine both the distance and height of passing objects and is extremely useful for quantifying potential passage through a wind farm. Acoustic monitoring devices should be used to assist with species-specific identification. Because multiple species are involved during migration, sampling should be conducted on a 24-hour basis during spring and fall migration. Data on bird migration gathered from the study region should be used to determine the exact periods of migration.

Q; What are your conclusions regarding the avian protocol for the proposed project?

A: As explained herein, there are considerable shortcomings with the avian protocol, as currently established by the COE. I believe these shortcomings are sufficiently severe as to undermine the validity of the environmental impact review and, thus, the validity of actions by any of the agencies that will be relying on that review in reaching conclusions about the project. I recommend that the COE revisit the current scope of the avian protocol and require Cape Wind to follow the recommendations of the federal and state agencies and initiate multiple years of year-round, intensive research.

Based on the NWCC *Guidance Document* (Anderson et al. 1999) and standards established in field ecology, I recommend that 2 full years of data collection be gathered and evaluated prior to making permitting decisions. In ecology, two years is considered a necessary minimum because the distribution, abundance, and activities of animals cannot be determined from a single year or from spotty data collected over multiple years. Also, there are numerous species present in the CWEP area for which nothing is known regarding their activities, so intensive work is indicated. The data collected to date and that planned for CWEP should be considered preliminary sampling and cannot be used as a full year of data. It is understandable that preliminary data would be needed so investigators can become familiar with the study area, logistics, sampling problems, and other study issues. However, such data are not of the quantity and quality needed for drawing conclusions. Two years has been recommended for onshore developments, although I acknowledge that onshore impacts and bird behavior are much better known than that for offshore developments. The experience in Europe on siting offshore developments shows that governments are sufficiently concerned about both the biological and visual impacts of the projects to limit the size of each project, develop an overall strategic plan for siting of windfarms, and recognition that areas of special concern for birds (e.g., areas with particularly high abundances, areas harboring rare or endangered species) should be avoided. Thus, it would be extremely unwise for the United States to base evaluation of the potential risk to birds on insufficient data. A repeat of the experience from Altamont Pass in California at an early offshore project would have devastating effects on the future of offshore wind development. Finally, without adequate study such as those recommended herein, I believe the Siting Board could not reasonable conclude that there are net environmental benefits from this project. Such a conclusion would be premature and scientifically unsupportable.

Q: Does this conclude your testimony?

A: Yes it does.

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