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Lost Ecosystem Goods and Services as a Measure of Marine Oil Pollution Damages

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RESOURCES
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Abstract

The paper addresses the definition and measurement of liability for marine oil pollution accidents. The economic value of lost or injured ecosystem goods and services is argued to be the most legally, economically, and ecologically defensible measure of damages. This is easier said than done, however. Calculating lost ecological wealth with any precision is an enormous scientific and economic undertaking. The paper proposes practical ways to improve our future ability to calculate such losses.

Key Words: environmental liability, ecosystem services, marine pollution

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James Boyd*

1. Introduction

Marine vessel, terminal, and harbour operations can generate a range of legal damages arising from liability for response and cleanup costs, damages to private property, and damages to public natural resources, the focus here. Public resources that can be affected include water quality, beach and other coastal recreational resources, coral reefs, commercial and recreational fisheries, sea grass beds, and habitats for bird and other animal populations. They are in the public domain, neither owned nor traded, but nonetheless clearly economically and socially valuable.

Liability for lost public goods and services is an established legal principle. In U.S. waters, for example, owners and operators are liable for natural resource damages (NRDs). NRD liability serves an important deterrence and compensation function by forcing owner-operators to pay the costs of damages to valuable public resources. The goal of U.S. NRD liability law is to “make the environment and public whole” following a pollution event.[1] In economic terms, this means calculating monetary damages equivalent to the social benefit lost as a result of a release, grounding, or other marine event.

At this writing, the full scope of damages arising from the April 20 explosion of the BP *Deepwater Horizon* oil rig in the Gulf of Mexico—and the subsequent massive oil spill—are not yet known, but predicted to exceed those from 1989’s Exxon *Valdez* incident.

At a conceptual level, NRDs require us to measure lost ecological wealth. Doing so requires knowing two things: how natural systems produce valuable biophysical goods and services and what the value of those goods and service is.

Within ecology and economics, *assessment of ecosystem goods and services* is a growing area of inquiry. Broadly put, ecosystem services refers to the dependence of economic wealth and human wellbeing on natural systems. While the promise of a cohesive framework for

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[1] 15 CFR 990.53.

assessing all types of damages is not yet realized, many scholars are working toward this goal through more rigorous conceptualization and communication of the links between changes in natural systems and effects on human welfare.[2]

Such a framework would be a powerful tool for calculating natural resource damages (and marine damages specifically). Lost ecosystem goods and services are the right metric to internalize social costs and make the public whole following a marine pollution or damage incident.[3] Given this equivalence between damages and lost goods and services, the calculation of marine damages can and will hinge on the degree to which ecosystem goods and services can be understood and valued.

NRD assessment is seen as controversial because there is widespread confusion over how to account for ecosystem goods and services that are lost or gained. Complex natural systems stymie the search for clear causal relationships between a spill and many of the damages they cause. This leads to legitimate disagreement over the magnitude of legal liability. Much more needs to be done by ecologists and economists in order to calculate damages with accuracy. But just because a damage is difficult to precisely quantify does not mean that it isn't real and economically significant. The discipline of treating natural systems as sources of wealth provides a guide to the kinds of information and analysis necessary to establish ecologically and economically defensible damages.

2. Liability for Damages to Natural Resources in the Public Trust

Natural resource damages are physical damages to land, fish, wildlife, biota, air, water, and groundwater.[4] They typically relate to adverse changes in the health of a habitat or species population and in the underlying ecological processes on which they rely.[5] The analytical challenge is to convert these physical damages into the economic consequences of that damage.

[2] See Daily 1997; Johnston et al. 2002, 2007; Ricketts et al. 2004; Polasky et al. 2005, Wainger et al. 2001 Boyd 2006, Carpenter et al. 2006, Boyd and Banzhaf 2007, Barbier et al. 2008.

[3] It is worth emphasizing that economics and the goods and services mindset place no limits on what people think is important or valuable. The desire for beauty, awe, naturalness, and the protection of species other than our own may be hard to measure, but they are all benefits known to economics and accepted as important social realities that should factor in economic damage assessment.

[4] OPA 33 USC § 2701(20); CERCLA 42 USC § 9601(16).

[5] 15 CFR 990.52. "Potential categories of injury include, but are not limited to, adverse changes in: survival, growth, and reproduction; health, physiology, and biological condition; behavior; community composition; ecological processes and functions; physical and chemical habitat quality or structure; and public services."

To do so requires understanding of the larger biophysical system of which the damaged resource is a part.

Liability for events that damage resources is established in the United States under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Oil Pollution Act (OPA), and the National Marine Sanctuaries Act (NMSA).[6] Earlier, the Deepwater Port Act of 1974 and the Clean Water Act amendments of 1977 introduced NRD liability to U.S. federal law.[7] The statutes create a compensable monetary liability for damage, which in turn requires calculation of the monetary value of the damage. The principle behind natural resource damages is well-established in U.S. law.[8]

By their nature, NRDs acknowledge that natural resources produce a collective social benefit. This means that the value of NRD-related ecological benefits is the value arising from public goods, not goods traded and priced by markets. Instead, government trustees must somehow calculate the lost social value in the absence of the data that we take for granted in the case of market-oriented damages, such as lost profits, revenues, or wages.[9]

Restoration, assessment, and settlement of NRD damage claims are undertaken by federal, state, and tribal trustees. Only governmental trustees can seek natural resource damages, though private plaintiffs—if they can show a concrete harm to a legally protected, collective interest in a resource—can compel action on the part of these trustees. Injury to a natural resource alone is an insufficient to establish liability.

For example, under the U.S. Oil Pollution Act, the National Oceanic and Atmospheric Administration (NOAA) is the federal trustee for claims arising from marine injuries, while the

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[6] Respectively, 42 USC 9607(f)(1); 33 USC 2702(b)(2)(A); 16 USC 1432, 1443.

[7] For the CWA, see 33 USC 1251 et seq. Section 311 of the CWA regulates the discharge of oil and other hazardous substances into navigable waters, allows the government to remove the substance, and holds the responsible parties liable for that removal. The removal cost is defined to include "costs for restoration or replacement of natural resources damaged or destroyed." 33 USC 1321. The Deepwater Port Act of 1974, which preceded the CWA, established liability for damages to natural resources to be recovered by a federal trustee and used for restoration. 33 USC § 1501–1524, 1982.

[8] The public trust doctrine is the common law foundation upon which liability for NRDs is based. Well before the passage of the relevant federal statutes, natural resource damages were collected under common law.

[9] There is no direct private right of action to recover NRDs under federal law. See Gregg Spyridon and Sam LeBanc, "The Overriding Public Interest in Privately Owned Natural Resources: Fashioning a Cause of Action," 6 *Tulane Environmental Law Journal* 287 (1993), citing *Artesian Water Co.* v. *New Castle County*, 659 F. Supp. 1269, 1288 (D.Del. 1987), aff'd, 851 F.2d 643 (3rd Cir. 1988).

US Department of Interior is responsible for claims arising under CERCLA. Rules guide the agencies' respective NRD assessment procedures and act as a blueprint for the determination of appropriate restoration actions and damages. [10]

In practice, the calculation of natural resource damages has proved difficult and controversial. When economic value is lost in a market setting, damages can be based on production, inputs, inventories, sales, and price data. Pertinent economic data already collected by both private firms and governments is available as a basis for the damage calculation. NRDs, by definition, are damages to public goods for which market data are not available.

A further, and more serious, complication is the need to understand how physical damages to a given resource damage other parts of the biophysical system. For example, groundings that damage sea grass beds also damage the species that rely on sea grass for habitat. Similarly, oil spills don't just create oily beaches, they can disrupt a broader range of ecological processes that ultimately can affect wetlands, commercial fisheries, recreation, and species abundance for years to come as news reports about the ruptured BP oil well in the Gulf of Mexico attest.

Let's focus on one of the earliest likely consequences from an oil spill: public resource damages to coastal wetlands that provide necessary habitat to marine species that are commercially, recreationally, or ethically valuable. What is the relationship between wetland damages and the population dynamics (breeding, foraging, and migration) of these species? Wetlands may also buffer inland groundwater supplies from the intrusion of salt water and thus help provide potable water to coastal communities. They can also protect against storm surges and flooding. If damaged, they may no longer provide this buffering and communities may be exposed to flood damages.

As this example suggests, the damage assessment problem is two-fold: First, what are the broader biophysical consequences arising from the incident (e.g., the spill, grounding, or other accident)? Second, what is the economic loss associated with that range of biophysical consequences? These two issues push ecology and economics to their analytical limits. The physical questions demand a sophisticated understanding of a complex and interconnected natural system where changes are difficult to observe and can arise over large scales (both geographic and temporal). The economic questions require the application of non-market

[10] 15 CFR 990 (the NOAA regulations); 43 CFR 11 (the DOI regulations).

valuation tools because the goods and services damaged are public, neither owned nor traded in markets. Not only that, but the two forms of analysis must somehow be integrated, so that biophysical damage measures can be translated into economic costs.

3. Current Damage Assessment Practices

In practice, government trustees understandably have found it difficult to measure lost ecosystem goods and services. As an alternative, agencies have focused on a more practical route to damages: namely reliance on resource *replacement cost* as the measure of damages. In the 1989 case, *Ohio* v. *Department of Interior* the court strongly favored the use of restoration costs as a basis for damages even if restoration is more expensive than available monetary estimates of lost value.[11] In 1996, NOAA followed the 1994 DOI rules with rules of its own, to be applied to assessments authorized under OPA.[12] For example, if an oil spill damages sea grass the objective is to replace the sea grass. What does it cost to replace the sea grass? That "procurement cost" becomes the measure of damages. Superficially, this strategy avoids the need to measure lost social wealth, since the point is to simply "replace the wealth" via restoration. And clearly it is much easier to solicit restoration bids and use those monetary costs as a concrete focus in damage negotiations (as opposed to conducting a broad ecological and economic assessment of lost goods and services).

There are drawbacks to the replacement cost approach to damage assessment, however. The most obvious is that replacement costs have nothing to do with the actual social damage that has occurred (the benefits of goods and services foregone). In some cases, replacement costs may vastly exceed the social damages they are meant to repair. This is particularly true if the replacement activity is taken seriously, monitored over time, and guarantees a successful restoration outcome. In other cases, replacement costs may vastly under-represent the social damages caused by the proximate injury.

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[11] The NRDA rules' current focus on the replacement cost of resources, rather than their estimated market value, is a direct outgrowth of these cases. H.R. Conf. Rep. No. 653, 101st Cong., 2d Sess. 108 (1990). Also, see discussion in Russell Randle, "The Oil Pollution Act of 1990: Its Provisions, Intent, and Effects," 21 *ELR News and Analysis* 10119 (1991).

[12] The rules are codified at 15 CFR 990 (the NOAA rules for OPA damages) and 43 CFR 11 (the DOI rules for CERCLA damages).

A damaged sea grass bed or coral reef may be restorable at an estimable cost. But it is possible that the bulk of social costs arise from damages to *other* resources dependent on the sea grass or coral reef. If these resources are not replaced—as they are generally not[13]—replacement costs may fall significantly short of the real social damage. In either case, replacement cost as the damage measure fails to achieve the main legal and economic principle in play: the desire to have polluters internalize the full costs of their behavior. Economically, basing penalties on the lost social benefits is the correct and most precise way to make the public whole.

A related drawback is that restoration-costs-as-damages (by design) over-simplify the government trustee's analytical problem. By removing the need to analyze ecological and economic effects more comprehensively, the government is able to under-invest in the analytical capability required to measure real damages. For environmentalists and economists concerned about real measures of natural wealth lost and gained, reliance on replacement cost has been barrier to scientific progress.

The deterrent and compensatory functions of maritime accident law thus demand continued development of methods to measure real social damages that take into account biophysical causation and subsequent economic impacts. This is the goal of ecosystem services assessment generally. To the extent ecosystem services assessment becomes more practical, there may be important implications for the marine commercial and governmental sectors. The OPA does not limit damages to those that can be directly measured in markets or that are based on observable resource uses. As long as the agencies' own damage assessment rules are adhered to, there is a "rebuttable presumption" of the analyses' correctness and legal validity.[14] This presumption provides agencies with considerable latitude in their choice of damage assessment methods. At least in the United States, where natural resource damages based on lost economic wealth are well-established in theory, there is a firm legal rationale for using lost ecosystem services benefits as the measure of damages, particularly as assessment methods improve.

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[13] See Carol A. Jones and Katherine A. Pease, "Restoration-Based Measures in Natural Resources Liability Statutes," *Contemporary Economic Policy*, XV (October 1997); also see Monica P Medina, "Just Do It," *The Environmental Forum* (July/August 2001).

[14] CERCLA § 107(f)(2)(C); OPA § 1006(e)(2).

4. Ecosystem Services Assessment

Ecosystem services are the benefits of nature to households, communities, and economies. The term is interpreted in a variety of ways, but conveys an important idea: ecosystems are a tangible source of economic wealth. This is intuitively obvious and consistent with the entire concept of resources in the public trust. What is less obvious is how that wealth is to be measured.

Because environmental goods and services are often public goods not traded in markets, economists lack information on the prices paid for those goods and services—we don't explicitly pay a price for the glorious view. Of course, just because something doesn't have a price, doesn't mean it is not valuable. The challenge, then, is to get people to reveal the values they place on goods and services that are un-priced.

Broadly, there are two ways to value un-priced goods and services. First, we can get people to state their preferences by asking them questions designed to elicit value. Second, we can look to people's behavior and infer natural resource benefits from that behavior. Houses near beautiful scenery sell for more than houses without scenery, for example. When people spend time and money traveling to enjoy natural resources, they signal the value of those resources, what are called revealed preferences. The definition of environmental *commodities* is central to both methods.

One of the nice things about markets is that they not only tell us the prices people pay for things, but also about the units (the quantities) people place value on. A grocery store is full of cans, boxes, loaves, and bunches; the number of these units bought yields a set of quantity measures to which prices can be attached. But public, nonmarket environmental goods and services don't come in convenient quantity units. Put another way, what are the *physical* damages that give rise and can be attached to economic losses?

In conventional markets, we take the difference between physical quantities and the price or value of those commodities for granted. At the store, we are presented with rows and rows of quantity units (the goods and services we buy) and we pay their price at checkout. For public, non-market goods, however, the distinction between quantities and their value is not obvious.

Ecosystem services analysis explicitly demands a linkage between ecological outcomes and economic consequences. It is important to get the units right—or at least be able to clarify why we use the units we do. The challenge lies in disentangling complex natural systems into more discrete commodity units so that natural scientists and economists can use the same terms to describe ecological changes in the same way.

Ecological Endpoints

Natural systems are composed of features, things, and qualities that interact with other physical features, things, and qualities and are thereby changed via physical processes. These natural processes convert inputs—some natural, some man-made—into outputs (endpoints) such as air and water quality and species populations. Ecologists and economists refer to these processes as biophysical production functions (U.S. EPA, 2009; Daily and Matson, 2008; Boyd, 2007). Ecological endpoints are defined as features and qualities of the natural environment that matter *directly* to people. While many, many things in nature matter to people—and therefore should be counted—endpoints create a distinction between environmental features that are "directly" and "indirectly" valuable.

The notion of direct versus indirect goods and services is conventional in the economics of traditional markets. Intermediate goods, for example, are those used to produce final goods. Final goods are what we count in GDP and their value embodies the value of intermediate goods used to produce them. This in no way implies that intermediate goods are less valuable than final goods. But it does mean that we needn't count everything in nature, only those final ecosystem goods and services that embody the value of the whole system.

Three distinct economic principles are central to the definition of ecological commodities and the way in which ecological changes can be integrated with economic assessment (for more detail, see Boyd, 2007, Boyd and Banzhaf, 2007; Boyd, 2006, Banzhaf and Boyd, 2005). First, clearly and consistently distinguish outcomes—in this case ecosystem goods and services—from the value or weight placed on those outcomes. In economic terminology, this means we must clearly distinguish quantity measures from price or value measures.

Second, choose quantity measures—the ecological endpoints—whose value can be credibly revealed through choices or human preferences. In practice, this means choosing endpoints that have direct, concrete meaning to people.

Third, treat the quantity units as units in an economic accounting system. This implies that all the units that contribute to welfare should be counted, but only be counted once. In practice, it requires a distinction between final and intermediate goods and services.

The distinction between final and intermediate goods and services arises in any economic accounting system. Final goods are not necessarily more important or valuable than intermediate goods. Rather, the distinction arises because of the fundamental accounting identity: count everything, but only count it once. We must distinguish between final and intermediate if we are to avoid double-counting. Nature is a system composed of complex interrelationships. Even in purely biophysical terms, the ecological “output” of one process will almost always be an “input” to another ecological process. This means that most ecological features and qualities can be thought of in dual terms: as input and output. How can we deal with the double counting problem in order to improve the quality—and validity—of the accounting system?

Nature presents us with an uncountable number of such inputs. Does that mean we must count all nature’s features and qualities in order to comprehensively depict its contributions to wellbeing? The answer is no. Much as GDP does not count all the units exploited and traded in the market economy, an ecological quantity index need not count all the elements of nature. In both cases, a utilitarian approach to accounting allows us—requires us, actually—to focus on final units of consumption or enjoyment.

Ecosystem end products can be defined economically as the results of complex processes involving multiple inputs, but where the end product is what is perceived, consumed, and appreciated by people. From a valuation standpoint (the damage calculation) end products have a wonderful economic property: the social value of end products includes the value of all the inputs and processes needed to create them.

Consider the issue of double-counting in conventional economic accounts, like GDP. Take cars for example. If we counted both cars and the steel used to make them and then weighted carts and steel by their market prices, we will have double counted the value of the steel. The reason is that the steel’s value in car production is embodied in the value of the cars. If a good or service’s value adds to the value of a good or service subsequently sold in the market, it is an intermediate good. The labor, leather, steel, and human capital required to make the car are intermediate goods. The final good is the car itself.

What do final goods mean in an ecological context? Consider cleaner water. What is the value of the intermediate goods, natural processes (nutrient cycling) and inputs (vegetative cover) that lead to cleaner water? This question can only be answered by placing a value on the clean water itself—the ecological endpoint and final good. If you ask people to place a value on nutrient cycling, they are likely to respond by asking “what is nutrient cycling?” Once that is explained, they will conclude that, “the value of nutrient cycling is the clean water it makes available to me.” Only the clean water has direct value to people. The value of nutrient cycling, in contrast, must be derived from the value of the clean water provided.

Another example is a particular fish population in a marine environment. The fish population is an ecological endpoint if people harvest the fish commercially or for recreation or simply value their existence if threatened. Of course, fish populations depend in turn on many things (inputs to the production of fish), including water temperature, currents, nutrient upwelling, and habitat quality and quantity, along with the life-cycle characteristics of the species and its food chain. From an economic accounting perspective, these inputs are valuable, but their value as inputs is captured—embodied—in the value of the fish population, the ecological endpoint.[15]

To illustrate the importance of measuring endpoints, consider the following common measures of oil spill contamination and recovery: molecular biomarkers, benthic indices, contaminant levels in water, sand and soil, and mortality statistics for certain species. These measures are all scientifically desirable and are practical to apply. However, if the goal is to link damages to economic losses, they are less than ideal. Imagine an economist or lawyer translating biomarker changes into an economic loss. The problem is that these biophysical measures are not economically meaningful endpoints. If physical damages are measured in these terms, there remains a huge gap between them and physical measures that are economically meaningful—such as species population effects, healthy swimmable beaches, and safe food consumption.

In the scientific response to the 2002 Prestige tanker spill in Spain population changes were detected, including reductions in inter-tidal animals and fishery production. These quantifiable physical damages are more amenable to economic assessment than other measured impacts, such as changes in immune response and the reproductive capacity of mussels that may be leading indicators of collapse in the shellfish population. But economic assessment of immune responses and reproductive effects begs the question: how do these measures ultimately affect the population?

This is why it is important to focus ecological damage assessment on the measurement of ecological endpoints. First, by design endpoints are concretely meaningful to society and thus amenable to valuation. Second, endpoints include the value of systems and inputs on which they depend. Third, if we do not distinguish between endpoints and inputs the damage calculation may double-count damages.

[15] They may be valuable inputs to other endpoints, of course, including water quality.

Causality and Biophysical Production Functions

Once these ecological endpoints—the environmental features and qualities identified as being important to welfare—are identified, natural science is required to tell us how those endpoints were affected by a marine accident or other resource-damaging incident. Natural science is also important to establishing causality. In the case of marine damages to public natural resources, the causal linkage between an event and damages can be described by a set of biophysical production functions. These functions must be demonstrated both to establish a causal linkage between a liability-generating action or accident and damages and to estimate the magnitude of those damages.

Production functions describe the manner in which an output is related to the quantity and nature of inputs used to create it.[16] For example, a production function describes the way in which a company can deploy labor and capital investments to manufacture a final product. Ecological analysis, of course, is concerned with the biological, chemical, and hydrological relationships that determine biological production.[17] An ecosystem's structure, including size, vegetation, and boundaries, and its functional aspects, such as the ability to absorb floodwater or remove contaminants from surface water, are biophysical contributors—as inputs—to the services the habitat generates.

Biophysical production functions describe the effect of one natural resource damage to subsequent damages to other resources that may arise at a distance or over time. In marine cases, the biological and physical linkages between an oil spill and the consequences of the oil spill must be described via these production functions. This goes beyond the question of fate, transport, and deposition of pollutants that arises in other legal settings.

In the recent words of Alaskan trustees working on the aftermath of the Exxon *Valdez* spill: "Through hundreds of studies conducted over the past 20 years, we have come to

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[16] See *The New Palgrave: A Dictionary of Economics,* 1998, at 995: "The traditional starting point of production theory is a set of physical technological possibilities, often represented by a production or transformation function. The development of the theory ... leads to input demands (and output supplies) constructed from an explicit consideration of the underlying technology."

[17] There is also a long history of integrated economic and biological production function analysis in agricultural and natural resource economics. Among other things, agricultural studies show how substitution of one farm input for another (e.g., land for fertilizer, tractors for man-hours) affects production levels, or how landscape characteristics affect yields. For a general overview, see *Introduction to Agricultural Economics,* edited by John Penson et al., Prentice Hall, 1999.

understand that the Prince William Sound ecosystem is incredibly complex and the interactions between a changing environment and the injured resources and services are only beginning to be understood."[18]

It is worth reflecting on why this is true. First, many marine accidents result in damages over a wide geographic area (in the *Valdez*'s case, 200 miles of shoreline were obviously affected, but measurable biological effects have been found over 1,300 miles of coastline) and over long time periods (20 years after the spill, fewer than half the species affected have recovered to pre-spill levels).[19] The effect on water quality of such a spill can have a range of side effects that develop over a period of years or decades. In the short term, oil spills will deplete herring and other cornerstones of the marine food chain. In turn, this effect on food stocks affects the viability of species dependent on them, such as certain bird species. These biological effects can take years to play out and in turn, human uses dependent on these ecological endpoints may be affected for years as well.

Consider damages to habitat. Habitat can be thought of as a natural asset, where restoration represents investment in the asset and damage represents divestment. Similar to manmade capital assets, habitats are durable, implying that changes today affect physical and economic rates of return in the future. Damages (and restoration) therefore are inter-temporal phenomena in both physical and economic terms. Habitat regeneration takes time. Often restoration projects replicate natural system functions only after a period of years. And even if full replication of a more natural system is assured, there are damages associated with the interim loss in the ecological asset's function.

Also of special importance to the science of ecological damages (both the physical and economic science) is the importance—and difficulty—of geographic measurement. From an ecological perspective, geography matters because natural systems are in constant motion. This movement creates a significant empirical challenge for damage assessment. With nature is a constant state of flux, it is difficult to measure baseline conditions. It is even more difficult to relate changes in conditions to a particular oil spill or other incident. There is no baseline data that covers the miles and miles of shoreline and thousands of birds and fish that existed before the BP and Exxon *Valdez* explosions. But precisely because there are so many biophysical

[18] http://www.evostc.state.ak.us/recovery/status.cfm

[19] www.evostc.state.ak.us

linkages across space, a full accounting of damages must somehow take the geography of effects into account.

The challenge for ecosystem scientists and managers is to empirically demonstrate cause and effect when the cause-and-effect relationship is spatial. These *spatial production functions*, tell us how an action (good or bad) in one place affects the production of ecosystem goods and services in another. Of particular importance in the marine environment are notions of resource patchiness and heterogeneity, biophysical linkages, and dispersal mechanisms connecting patches.[20] This research has led to a new class of bio-economic models that are composed of a group of subpopulations distributed across a set of patches linked by dispersal processes.[21]

In the marine context, we need spatial production functions that describe:

- the dependence of fish species on the configuration of habitats—marine, estuarine, and freshwater, depending on the species—needed for their reproduction, forage, and migration;
- the dependence of avian and inland species on marine food stocks (fish and smaller organisms);
- the dependence of coastal groundwater supplies and quality on near-shore water quality and wetlands;
- the fate and transport of pollutants as a function of temperatures, currents, and natural attenuation;
- biological uptake of pollutants, particularly toxic agents, and consequences for the food chain; and
- the biological effects of non-native populations introduced by shipping.

The statistical demonstration of causality—the relationship between a marine incident and economically meaningful endpoint changes that can arise over large areas and long time

[20] The spatial nature of ecological relationships is an important topic in ecology generally (not just in marine applications). For example, the quality of a habitat asset can be highly dependent on the quality and spatial configuration of surrounding land uses. The ability of areas to serve as migratory pathways and forage areas typically depends on landscape conditions over an area larger than the habitats relied upon directly by the migratory species. The contiguity of natural land cover patches has been shown for many species to be an indicator of habitat quality and potential species resilience.

[21] See, for example, Sanchirico and Wilen (1996, 2001).

periods—is the missing piece that inhibits a full, accurate accounting of social damages. These causal relationships can only be tested using rigorous, data-intensive empirical and scientific methods but they are difficult and costly to perform. Second, non-uniformity means that even if you establish a causal relationship in one location, that relationship may not hold in other locations.

Particularly in the immediate aftermath of a spill or grounding, the prediction of effects is difficult to make with confidence. NRD assessment, though, allows for long-run monitoring of effects and adaptive management and restoration in response new information. These long-run assessments are fundamental to the science underlying damage calculations. Long-run monitoring geared toward economically meaningful endpoints is the key to economic damage assessment.

From Physical to Economic Damages

How do you translate changes in ecological endpoints into economic damages? Alone, ecological endpoints tell us nothing about their relative importance or value: they must be paired with information relating to their economic importance. In order to translate ecological endpoints into social welfare measures, economists require knowledge of both economic production functions and society's underlying preferences for certain ecological conditions versus other things we care about, such as money and jobs. Underlying preferences are not directly observable—hence the use of non-market valuation techniques. If economic experts are called on to estimate the social costs of a biophysical damage they will rely on two general methods: revealed and stated preference methods.[22]

Revealed preference studies look at the price people are willing to pay for marketed goods that have an environmental component. From those prices, inferences about the environmental benefits associated with the good can be made. For example, when people purchase a home near an aesthetically pleasing ecosystem home prices reflect that environmental amenity.[23] Alternatively, when people spend time and money traveling to recreation they reveal a willingness to pay the time and travel costs to access the recreational services. Travel cost studies are used to make a benefit estimate based on such expenditures.[24] This approach requires

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[22] For a good overview of these methods, see Freeman, 1993.

[23] Hedonic analysis is used in this type of study. See, e.g., Mahan, Polasky, and Adams, 2000.

[24] There is a large methodological literature on this subject. See, e.g., McConnell, 1992.

data and analysis linking the number of trips to a site with the quality, size, or location of a site. Changes in these attributes can be valued if there is a perceptible change in the number, length, or cost of trips taken to the site.

Of course, not all environmental benefits are captured in market prices or in easily observable individual choices. One way around this problem is to move away from reliance on preferences revealed in markets. Stated preference studies are one such alternative. Stated preference studies ask people, in a highly structured way, what they would be willing to pay for a set of environmental improvements. Contingent valuation (CV) studies are an example. Stated preference surveys are expensive, controversial, and are most reliable when the questions concern specific ecological services provided in specific contexts. The more complex and holistic the improvement, or change, the more difficult the methodological challenge. A principal drawback to this approach is the risk that people may misunderstand the precise service being valued when undisciplined by the need to spend their own real money. For the same reason, they may also overstate their willingness to pay.[25]

For this reason, an independent panel was convened in 1993 to assess the validity of the CV methodology to measure nonuse values. The so-called NOAA Panel established a set of guidelines for the use of CV methods and concluded that CV can provide a valid economic measure of value associated with resources people do not actually use but whose existence they may nevertheless value.[26] The guidelines now permit CV for estimating use and nonuse values but only when no use values can be determined.[27] The method is controversial, however. A common feature of U.S. NRD "reform efforts" is the restriction or elimination of recovery for lost nonuse values[28] and prohibitions on the use of the CV method to value NRDs.[29] Some

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[25] See generally Kopp et al, 1997, presenting a collection of articles relating to the contingent valuation method.

[26] The panel concluded that "[contingent valuation] produces estimates reliable enough to be the starting point of a judicial process of damage assessment, including passive-use values (i.e., nonuse values)." Report of the NOAA Panel on Contingent Valuation, 58 FR 4601, January 15, 1993, at 4610.

[27] 43 CFR 11.83(c)(2)(vii).

[28] See S.8, Part 403, 105th Cong., A Bill to Reauthorize and Amend the Comprehensive Environmental Response, Liability, and Compensation Act of 1980, introduced January 21, 1997 (there will be "no recovery under this Act for any impairment of nonuse values"), and S.1537, 106th Cong., Superfund Amendments and Reauthorization Act of 1999, introduced in the Senate August 5, 1999.

[29] See S.8, note 28 *supra*, which states that a trustee's claim for recoverable assessment costs "may not include the costs of conducting any type of study relying on the contingent valuation methodology."

states limit the methodologies that can be used to calculate the scale of NRDs.[30] It should also be noted that the most controversial valuation methods, such as CV, have in actuality been employed infrequently.[31] Nevertheless, these methods are a distinct improvement relative to evaluation techniques that ignore social preferences.[32]

A more general problem is that econometric, monetary assessment of non-market goods is expensive, technically difficult, and time-consuming. The methods used to place dollar estimates on natural resources are specific to certain kinds of benefits. This means that a comprehensive assessment of benefits (or costs) requires deployment of a wide range of economic techniques. Accordingly, it is near impossible to monetize with econometric techniques the full range of public good losses arising from a particular incident.

The second problem is that studies may have limited applicability from one case to another. Even if the physical damage (changed ecological endpoints) is identical in two different locations, the economic damage arising from them may be very different. Consider the *Valdez* and *Prestige* cases. Even if the physical damages were identical (they were not) the *Prestige* spill's location in the populated Bay of Biscay in Spain meant that many economic impacts would be greater than in the relatively remote Alaskan Prince George's Sound.

In translating physical damages to economic damages, geography is again a central part of the analytical challenge. A property of ecosystem goods and services is that society cannot easily move them; they are akin to real estate. Like houses and factories, a coral reef, fishery, or bird population cannot simply be moved to where it is most valuable. These kinds of goods are not "spatially fungible," in economic parlance. As with homes, economic value is as much a

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[30] Michigan law establishes liability for natural resource injury (Act 451, MCL 324.20126a). However, contingent valuation methods cannot be used for damage calculations "unless a determination is made by the department that such a method satisfies principles of scientific and economic validity and reliability and rules for utilizing a contingent nonuse valuation methods or a similar nonuse valuation methods are subsequently promulgated." MCL 324.20104(3).

The state of Texas lists a set of acceptable valuation methods. The list includes contingent valuation but requires that contingent valuation studies be undertaken only in accordance with guidelines established by NOAA. 31 TAC § 20.32(f).

[31] See testimony of Douglas Hall, NOAA, Subcommittee on Water Resources and Environment, House of Representatives, July 11, 1995. "There have only been six contingent valuation studies completed to date, and only one in which the Federal Government was involved in litigation."

[32] See Carson, et al, 2001 for a review and defense of contingent valuation's role in the evaluation of environmental goods and services.

function of neighborhood as of house's physical structure. As the saying goes in real estate, three things matter to value: location, location, location. The same is true for most ecosystem goods and services. Their economic value depends on their location relative to communities, businesses, and people looking for recreation opportunities.

The consumption of services often occurs over a large scale; examples include recreation and commercial harvests of fish or game, where users may not be confined to the ecosystem good's physical location. This triggers the need for social analysis of users who may travel to or otherwise experience the ecosystem service at a distance. Another reason the location of ecosystem services matters economically is that the benefit of services often depends on where and when the complements to and substitutes for those services arise. As an example, marine areas may have recreational value only if there are complementary assets such as public beaches, trails, or docks are present.[33] Substitutes have the opposite effect. Many ecosystem services have no substitutes: nothing can replace the existence value of wilderness or an endangered species. Other services do have substitutes, however. If shellfish beds are abundant, the damage to a particular shellfish bed will—all else equal—be less than if shellfish beds are scarce.

In other words, ecosystem services exhibit the basic properties of any economic good. All else equal, greater scarcity or rarity and a relative lack of both natural and man-made substitutes increases the value of an ecosystem service—and economic damages if the good or service is damaged. Because the value of ecosystem services is inversely related to resource scarcity, valuation requires a marginal analysis of ecosystem benefits, which examines the way in which a service's benefits vary with the aggregate level of the service available.80

These complications in the economic damage assessment phase create hurdles to econometric damage calculation. There are alternatives to monetary damage estimation worth considering, however.

Economic Damage Indicators

An alternative to econometric estimation of economic damages—particularly when juries are involved in the determination of damages—is the use of damage indicators. These indicators are social and physical data that help describe the economic impact of ecological damages, such

[33] Other types of benefits, such as the existence benefit of a wilderness area do not require and indeed may be reduced by the presence of such features.

as the number of people affected, the value of property damaged, and the scarcity of the resource in a particular location. Because they are indicators, rather than derived monetary estimates, they can be deployed more cheaply and easily in order to give courts information relevant to economic damages. Location-specific economic damage indicators (EDIs) can help courts understand the larger social and physical landscape to better assess the economic importance of particular losses to ecosystem goods and services.

EDIs are a marriage of easily measured social and physical data to basic principles of economic assessment. For example, with all else equal, we can always say the following:

- The scarcer an ecological feature, the greater its value.
- The scarcer are substitutes for an ecological feature, the greater its value.
- The more abundant are complements to an ecological feature, the greater its value.

Geographic scarcity is straightforward to measure with modern geospatial mapping and measurement tools (Boyd and Wainger, 2002, 2003). Substitutes are also easy to measure and convert into indicators, such as the number of non-marine public parks and recreational opportunities in an area. Complementary factors, such as access points, can often easily be measured.

Depending on the ecological feature, we can often go further than this. For example, the social value of some environmental features is often a direct and increasing function of the number of people with access to them. Similarly, the social value of some environmental features is often a direct and increasing function of the economic value they protect or enhance. Accordingly, we can often—but not always—also say the following:

- The larger the population benefiting from an ecological feature, the greater its value.
- The larger the economic value protected or enhanced by the feature, the greater its value.

With all else equal, a beach with 10,000 visitors a year is more recreationally valuable than a park with 100 visitors a year. Similarly, a recreational fishery's value will be greater, given the larger the number of households able to access it. Wetlands that provide flood protection to property worth $10 million are more valuable than one protecting property worth $1 million.

The reason to consider EDIs is that they are relatively simple measures to develop and apply to a particular case. Data can be drawn from geo-coded data sets, including satellite imagery; local, regional, and national growth, land use, or transportation plans; environmental agencies; private conservancies and nonprofits; and census data. Short of full-blown economic assessment, EDIs provide economic information useful to courts. They are a practical, quantitative middle ground between no economic analysis and full-blown econometric value estimation.

5. Conclusion

Maritime law often allows for the measurement and assignment of damages arising from lost public natural resources. Damaged environmental resources, even if they are public goods, can trigger subsequent economic damages to individuals, businesses, and communities. Given the goal of liability laws to "make the public whole" the natural resource damages question boils down to this: how do physical damages propagate through physical ecosystems and thereby create subsequent biophysical damages that reduce human welfare? Courts must understand biophysical damages that can take years to develop and may arise over broad geographic scales. They must also be able to translate those biophysical damages into economic terms.

In the United States, where NRD law is well-established and applicable to marine incidents, linked ecological and economic assessment has not yet been able to fully meet this aspiration for damage assessment. Instead, government trustees have relied on more practical—and thus entirely defensible—alternatives to the calculation of the actual social costs of pollution: namely restoration costs. The focus on restoration of resources that are obviously damaged is a natural first step and yields concrete damage estimates based on the costs of restoration.

The ecological problem with this approach is that not all biophysical damages are obvious or predictable. This raises the possibility that physical damages are under-estimated given the challenge of demonstrating causally related effects. The economic problem with the approach is that costs are not the same as benefits. A focus on restoration costs as the measure of damages can lead to both over- and under-deterrence, depending on the relationship of restoration costs to the true social cost of the physical damages.

The measurement of ecosystem goods and services is an increasingly important theme in both academic and government inquiry into environmental assessment. It involves both biophysical analysis of actions and causes and their effects in the biophysical realm and the economic interpretation of those effects. It is therefore focused directly on the analytical problem posed by natural resource damage calculations designed to "make the public whole" as a result of environmental accidents.

Measuring ecosystem goods and services analysis is not easy and it is often not practical except where funding for large-scale monitoring and statistical assessment is possible. However, development of these methods is proceeding. When the physical and social science of ecosystem good and service evaluation develops into a more mature phase, the implications for marine liability damages will be direct and material to plaintiffs, trustees, and courts.

The insights and principles behind ecosystems services research are also of immediate relevance to trustees who want to be in a position to calculate the most accurate damages possible (in order to serve the deterrent and compensatory goals of liability law). Assessment based around ecological endpoints will lead to more coordinated, comprehensive, and cost-effective biophysical and economic analysis of damages.

But it deserves emphasis that the ecological and economic damage caused by the BP *Deepwater Horizon* spill is likely to be very significant and far reaching, even if it is difficult to calculate with precision. This leaves us with a knotty question for public policy and the courts: how do we appropriately penalize a polluter when we may never actually know the damage they caused? A meaningful penalty is surely called for. But given current scientific and economic knowledge, the scale of that penalty is more likely to be resolved through political judgment than technical calculation.

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