Perspective

The Challenge of Degraded Environments: How Common Biases Impair Effective Policy

Alan Berger,[1] Case Brown,[2] Carolyn Kousky,[3,*] and Richard Zeckhauser[4]

Economic activity can damage natural systems and reduce the flow of ecosystem services. The harms can be substantial, as our case studies vividly illustrate. Most degraded landscapes have at least some potential to be reclaimed. However, uncertainty plagues decision making regarding degradation and reclamation, in relation to the extent of the damage, the success of reclamation, and how exposure will change in the future. We examine how a range of observed decision biases can lead to far-from-optimal policies regarding how much degradation to allow and when, as well as how and how much, to reclaim degraded sites. Despite our focus on degraded landscapes, we believe these are generic biases present in a wide range of risk situations. Our three case studies show these biases at work. The first two studies are of mining operations in the United States and Canada, and the third is of climate change.

KEY WORDS: Biases; climate change; decision making; mining; neglects; reclamation

1. INTRODUCTION

Natural systems produce ecosystem services—the benefits people obtain from ecosystems.[1,2] Economic activity can sometimes impair natural systems or subject them to risks, reducing the expected amount and type of services flowing from them. In extreme cases, degradation can turn a valuable system into one that generates harms on net. After such degradation, it may be possible to reclaim the site, reestablishing or enhancing a flow of ecosystem services. Reclamation refers to any process that moves a site from degradation to an improved state. In practice, decisionmakers are often uncertain about how much reduction in value or how much damage an ac-

[1] Massachusetts Institute of Technology, Department of Urban Studies & Planning, Cambridge, MA, USA.
[2] Department of Planning & Landscape Architecture, Clemson University.
[3] Resources for the Future, Washington, DC, USA.
[4] Kennedy School, Harvard University, Cambridge, MA, USA.
[*] Address correspondence to Carolyn Kousky, 1616 P Street NW, Washington, DC 20036, USA; tel: 202-328-5188; fax: 202-328-5024; kousky@rff.org

tivity will cause, as well as the extent to which reclamation activities will be successful.

This article looks at the decision making surrounding degradation and reclamation of altered or degraded landscapes. When and how should we reclaim a degraded area? How much reclamation should be done? If it is known before the degradation occurs that reclamation is feasible, how does that alter optimal levels of alteration? In these situations, decisions should be made according to the rational-choice model, which involves using probabilities (usually subjective assessments), valuing and including all the benefits and costs flowing to others as well as to selves, accurately employing statistics to assess data and make predictions, and considering all possible alternatives, with no thumb on the scale for the original situation.

This article focuses on a set of seven common biases that impede our thinking about degradation and reclamation decisions, often leading to suboptimal outcomes. We have referred to the first five previously as "neglects."[3] The first bias, probability neglect, is the failure to consider appropriately

the probabilities of consequences. Decisionmakers focus too heavily on outcomes, ignoring their likelihood of occurrence. The second bias, consequence neglect, is its complement: decisionmakers focus on the probability without considering the impact of the outcomes. The third bias, statistical neglect, occurs when decisionmakers fail to use data to predict the distribution of outcomes. The fourth bias, solution neglect, refers to the tendency to fail to consider the full range of possible solutions to a problem. The fifth bias, external risk neglect, applies when agents do not consider the benefits or costs their actions impose on others.

Sixth, we consider status quo bias, a seemingly undue preference for the current situation, even when change may be preferable. A specific form of status quo bias relevant to reclamation decisions is authenticity bias. Authenticity bias reflects a preference for a former status quo, even when the original state has been lost. Loss aversion can contribute to status quo bias, as individuals calculate the loss of what they have as greater than the gain to be received, leading them to reject any changes from the status quo.[4] A particular form of loss aversion, multiattribute loss aversion, arises when evaluating alternatives with multiple dimensions. In this case, individuals will not accept a loss from their current position on any one aspect, even if in doing so, they could move to a superior position overall by gaining more of another attribute that is of greater value. Multiattribute loss aversion often prevents the adoption of socially superior solutions that impose a loss (even if compensated) on a subset of individuals.

The seventh and last bias we discuss is faulty treatment of tail probabilities. Unlike a normal distribution, a fat-tailed distribution occurs when extreme outcomes—those that are more than three standard deviations from the mean—have a nonnegligible probability. The faulty treatment of tail probabilities is a common failing that arises when people simply assume that the relevant risk is normal, when the distribution is, in fact, fat-tailed. Statistical assessments are then based on assumptions that are appropriate for normal distributions but not for fat-tailed distributions. With a normal distribution, an event three standard deviations or more from the mean occurs once every 370 trials; a four standard deviation event happens once every 15,787 trials. But events this extreme occur much more commonly in environmental contexts, say, on the size of oil leaks, or lives

lost to natural catastrophes. Fat-tailed distributions apply. Once fat tails are present, further difficulties arise. Analysts often focus on the most likely or high, medium, and low outcomes. However, with fat-tailed distributions, extreme outcomes account for most of the expected value.

Two other heuristics push in the opposite direction, toward overly cautious thinking. Drawing on common economic models of utility, such as a logarithmic utility function, people can mistakenly assume that extreme negative outcomes cause infinite or near-infinite losses. (The logarithm of 0 is $-\infty$.) Like the heuristic of relying on the normal distribution, this represents the failure to validate a commonly used function with empirical experience. Simply put, we are not willing in practice, and should not be in theory, to sacrifice nearly everything to reduce a small probability, but one that carries extreme negative risk, to zero.[5] The worst outcome does not bring infinitely negative utility. Finally, probability neglect can lead to faulty tail thinking by inclining people to focus too heavily on the outcomes in the tail of a distribution, while neglecting the probability of their occurrence. In short, faulty tail thinking can range from neglecting or severely underestimating the tails when they are critical, to giving them greatly excessive weight.

This article discusses how theoretically optimal decisions regarding degradation and restoration should be made, and then how the confluence of these seven biases leads to departures from this preferred approach. These biases can lead entities to degrade a natural system too much; after the damage is done, they can lead those entities to neglect reclamation or to focus too heavily on complete restoration to the original state. In practice, it may be preferable to reclaim less, more, or not at all. As we will elaborate, decisions regarding excessive degradation or suboptimal reclamation rarely flow from a rational-choice strategy.

We illustrate the role of these biases in influencing decision making with three case studies. The first two examine mining reclamation sites, one in the United States and one in Canada. While we focus attention on reclamation of degraded landscapes in much of the discussion below, the biases we assess could hinder decision making regarding broader questions. Our third case study, therefore, discusses climate change as a degradation and reclamation problem, and shows how our range of biases hinders optimal policy response.

2. MAKING RECLAMATION AND DEGRADATION DECISIONS

2.1. A Rational-Choice Approach

Assume that an area has been degraded. Should it be reclaimed, and if so, to what extent? Following a rational-choice model,[6,7] reclamation should be undertaken whenever the expected benefits—in terms of enhanced ecosystem services or reduction in damages—outweigh the expected costs to all parties of conducting the reclamation. Reclamation is always an uncertain process; therefore, benefits and costs should be computed in expected values, with risk aversion recognized if magnitudes are significant. Upfront costs of some reclamation activities, such as reforestation, can be high, with benefits accruing over many years into the future.[8] In these cases, the benefits should be appropriately discounted. Moral concerns about maintaining a sound environment must be given due weight in the benefit calculations.[5]

When considering a site that is about to be altered or degraded, a joint decision should be made about anticipated degradation and after-the-fact reclamation. In some cases, slowing degradation may be optimal; in others, when there are economies of scale to reclamation, periodic reclamation once degradation reaches a certain threshold may be a preferred approach.[9] In many cases, decisions are further complicated by uncertainty about how much harm alteration will create, how costly and effective reclamation will be, and also whether decisionmakers will choose wisely in the future. Given such uncertainties, subjective probabilities should be used to choose the degradation-restoration combination that offers the highest expected net benefits.

An ideal Bayesian analysis would look at the entire distribution of losses. However, to do so is usually beyond what is feasible for most decision problems. In that case, scenario analysis has great virtues as a method of trimming the analysis while still adequately recognizing uncertainty. A similar approach was taken by the "Whiz Kids" systems analysis group created under Robert McNamara, at the Defense Department in the early 1960s, the pioneering organization in this field in the U.S. government.[6] With this approach a few, often three, detailed analyses are prepared. Developing multiple scenarios represents a big leap forward as opposed to just proceeding with one set of assumptions, often the most likely one, or with a single set of assumptions done conservatively to be safe and avoid blame. Still, the scenarios must be sensibly chosen.

Consider the simplest situation, in which outcomes can be arrayed on some linear scale from best to worst, ranging from the 100th percentile to the 1st percentile; and assume three scenarios will be studied. In this context, the best scenarios are rarely a major concern. We concur with Warren Buffett, who remarked: "Even if perfection in assessing risks is unattainable, ... it is essential to remember that virtually all surprises are unpleasant."[10,7] Following this insight, let us assume that one investigated scenario is set at the median, and the others toward worse outcomes. Should those latter scenarios be at the 25th and 10th percentiles, the 10th and 1st, or perhaps even lower?

How low in the percentiles we should go will depend on the product of likelihood and losses, where the product can be expressed as expected loss of utility. If one is making a highly risky but limited liability investment, say, as an angel investor in a startup company, there is no need to go deeply into the tail. The worst that can happen is that one loses one's initial investment. But with the potential for severe environmental degradation, as the examples in this article make evident, the bottom outcome can represent very serious consequences. The basic principle should be to delve into the percentiles as long as the expected losses below that point are large relative to the losses as a whole.

Therefore, our recommendation is to try a percentile and do a rough sketch of consequences. Then, take a much lower percentile and repeat the process. If the latter losses are still large relative to the former, it makes sense to use the lower percentile, or indeed one far lower. Let us provide a crude illustration. You consider 10th percentile losses by assuming that the losses at the 5th percentile, the midpoint, are representative. The expected losses at this point are $A = 0.10(L_5)$, where L represents losses and the subscript indicates the percentile. You then consider the 1st percentile by making the same assumption to get $B = 0.01(L_{.5})$. If B > A, then the 1st percentile merits attention as a scenario more than does the 10th percentile.[8] Through a rough iterative process, one can decide where to focus attention and do a detailed analysis of losses.

---

[5] We recognize that doing so involves ethical inquiry well beyond the scope of this article.

[6] Personal experience of one of the authors.

[7] Buffett was writing in the context of insurance, but his assessment almost always applies when the focus is on losses.

[8] Our calculation uses losses at half of each percentile as a way to give an indication of losses below some point rather than at some point.

Essentially, this process looks at the magnitude of elasticities. A situation is elastic if cutting the percentile in half more than doubles the losses computed at the two respective percentiles. Our recommendation is to go further down in the percentiles as long as the elasticity remains above or approaches 1. Note, following Summers and Zeckhauser,[5] we are not concerned that elasticities can remain above 1 no matter how low the percentile. Losses of utility do not become infinite, contrary to the prominent claim of Weitzman relative to climate change.[11] If they did, we would give up all income down to the survival level to avoid the tiniest probability of catastrophic loss.

After scenario analysis is used to determine policy choices, the decision must be revisited periodically. When possible, a learning-and-adaptive strategy is preferable, meaning that adjustments to the level of degradation or reclamation should be made over time in response to changing conditions or new information. This is akin to "adaptive management," an approach to resources management that recognizes uncertainty and thus designs all interventions as experiments. This approach provides a chance to learn about system behavior through the use of monitoring and information collection.[12–14] We stress here that conditions constantly evolve; therefore, the optimal course of action changes in response as uncertainties get resolved. Managers need to be able to draw on accumulated knowledge and have the flexibility to adjust their actions accordingly. Such changes are often politically difficult, leading to an unjustified commitment to actions that are no longer preferable.

While the prior paragraphs outline a rational-choice approach to reclamation and degradation decisions, in practice, decisions often deviate from the rational paradigm, as decisionmakers are influenced by one or more of the seven biases mentioned in Section 1. We turn next to a short discussion of how such biases can affect reclamation and degradation decisions. Section 3 then presents our case studies of mining reclamation and climate change. Each case study offers examples of how these biases have led to suboptimal decisions in a particular reclamation context.

2.2. The Influence of Biases on Degradation and Reclamation Decisions

In this section, we review the biases presented in Section 1 and discuss the influence they can have on degradation and reclamation decisions. We start with probability neglect. As stated earlier, this occurs when decisionmakers focus excessively on the outcomes and neglect the probabilities, which often occurs with risks that evoke emotions such as fear or dread.[15,16] If potential damages from an activity are particularly troubling or frightening, decisionmakers could fail to attend to the probability, which could be quite small, that the degradation would actually induce harm, and thus err on the side of excessive caution. The response to Love Canal may provide an example. It has been argued that, due to public fear over toxic releases at Love Canal, large sums were spent on removing toxic wastes, sums that could have led to much greater risk reductions if targeted at other threats.[17]

Consequence neglect represents the complementary error. In this case, individuals focus on a probability while neglecting the consequences. When probabilities are very low, decisionmakers sometimes treat the probability as effectively zero, even when consequences could be quite severe, making expected damages substantial. If the probability of degradation is thought to be modest, little care might be taken even if it would be valuable in expected-value terms. The oil spill in the Gulf of Mexico in the spring of 2010 provides a salient example. It has been reported that British Petroleum (BP) dismissed the probability of such a spill in its exploration plan, saying that it was unlikely a spill would occur, and that if it did, response capabilities would lead to no significant adverse impacts.[18] It appears that very few planning scenarios, if any, fully addressed the level or rate of oil leakage actually witnessed, or the possibility that the supposed fail-safes would not function properly. Apparently, because BP dismissed the consequences, it was not prepared with the technologies or safeguards to control the spill.[18]

Statistical neglect refers to the failure to accurately assess, update, and use information to influence probabilistic predictions that inform decision making. A large literature documents ways in which individuals misestimate probabilities and misuse probabilistic reasoning. (For a broad review of this literature, see, e.g., Kunreuther *et al.*[19]) For instance, individuals have been found to assess an event as more likely to occur if examples come easily to mind,[20] an error referred to as the availability heuristic. A common type of statistical neglect in reclamation decisions is the failure to update assessments of the degradation as new information becomes available. For instance, if population density

increases around a degraded area, the risk of harm occurring increases and the benefits of reclamation increase alongside. If we do not revisit past reclamation decisions when new information comes to light, we fail to make optimal adjustments.

Solution neglect refers to the failure to consider all potential responses to a problem, instead focusing attention on only one or a few responses that are particularly salient. Clearly, the optimal action cannot be chosen if it is not considered. Solution neglect often takes a particular form in reclamation decisions, that of focusing exclusively on singular-state solutions (singular in the sense that they have a single, unitary condition spread across the site, such as low-slope grass seeding). These singular-state solutions range from the expensive and complete restoration of the original condition to the lowest-common-denominator approach, which merges minimal cost and basic compliance with legal reclamation standards. Other reclamation options, which may be preferable, are unlikely to be considered.

The fifth bias is external-risk neglect. This is the failure to consider harms imposed on others, called negative externalities, due to self-interest or to a (possibly deliberate) failure to notice. Many forms of excessive contamination can be explained by external-risk neglect. Degradation can impose costs on nearby communities in terms of health risks from toxins, contamination of drinking water, and loss of myriad ecosystem services; the entities altering the natural systems fail to consider these harms because they are imposed on others. To make socially optimal decisions, these parties must be forced, by government regulation or financial incentives, to consider these harms in alteration decisions. After degradation occurs, the benefits of reclamation may also fall on external parties. Inadequate reclamation standards leave little room to determine optimal levels of reclamation for each site. Companies are likely to undertake only the level of reclamation that is required by law, even when greater reclamation would produce more net benefits to society as a whole.

Status quo bias flows from the combination of authenticity bias and multiattribute loss aversion. It can lead, as stated in Section 1, to an unrealistic wish to recreate original conditions. Underlying this bias in the reclamation setting is a nostalgia for past landscapes, nature myths regarding the best and "most natural" use of the land, and an urge to fix past degradations—especially those that are retro-spectively determined to have been poor choices. With authenticity bias, individuals disproportionally weight outcomes that are thought to be "authentic." This induces a desire for restoration of a site to its original condition, regardless of whether this is the option that generates the most net benefits. Samuelson and Zeckhauser[21] offer a telling example of a town in Germany that was completely relocated when strip mining began at its original location. While the townspeople had myriad options for planning the new town, they chose a layout like the old one, even though there was little logical justification for not designing improvements. Of course, individuals may derive value from the nostalgia or comfort of an original situation and this should be weighed as one benefit of attempting restoration. In most cases, however, this is done without any serious thought to the pros and cons of restoration versus alternatives.

Reproducing what formerly existed is rarely optimal. The enormous costs and uncertainties associated with creation of a facsimile of the prealtered state hampers the reclamation process. Among the difficulties, a typical site may have topography that has been extensively altered; microclimates that formerly supported certain species may no longer exist; populations of plants may have been extirpated; animals may have migrated away from the disturbances; and basic resources like water and minerals may be more or less available than in the prealtered state. Appropriate reclamation approaches will also vary, depending on the initial conditions of the natural system, the services desired from it, the timing, the physical scale, other stresses on the system, and financial constraints.[22] Given the dynamics of background conditions, seeking to reproduce a prior environment may be at best profligate, at worst futile. In many cases, we may not even have a deep enough understanding of the dynamics of the system to reproduce it.

Our seventh bias is faulty tail thinking. Numerous authors have called attention to the fact that we often assume we are in a normal situation when we are indeed in a fat-tail situation, or that we fail to focus on extreme outcomes when they may account for a large fraction of the expected value.[11,23] Fat tails can govern many reclamation and degradation decisions, as well. When tails are neglected, not enough attention is paid to extreme outcomes. This may lead to lax regulations governing degradation and to insufficient attention to reclamation.

3. CASE STUDIES OF RECLAMATION CHALLENGES

3.1. Mining

Ongoing and historic extraction activities present physical and environmental hazards. To appreciate how numerous and ubiquitous these activities are now and have been in the past, consider that there are over 12,860 active mines in the United States and that 100,000 to 500,000 abandoned mines dot the U.S. landscape.[24] Other countries face similar challenges. Mines, in their most basic form, extract underground resources through large-scale excavations. This leaves the land and ecological systems permanently altered. Mine operators start their work by stripping away the top layer of organic matter and its associated biological material and nutrients (called "overburden" in mining industry jargon). Environmental losses can be compounded because the newly scraped surface often exposes ecosystems and populations to new contaminants and harsh conditions. After extraction, the damage has been done, whatever the merits of the original mining decision. In the following two examples, one site in the United States and one in Canada, we examine how several biases led to excessive degradation and inefficient reclamation.[9]

Libby, Montana. In Libby, Montana, a mine in operation from the mid 1920s until 1990, produced 80–90% of the world's vermiculite, a light mineral used in insulation (such as the trademarked Zonolite form), concrete mixes, potting soils, and various industrial applications.[25] As a stand-alone mineral, vermiculite is harmless. However, the material mined in Libby was mingled with a naturally occurring asbestos fiber, forming a toxic material called Libby Amphibole asbestos (LA). The mine and processing plant workers were continuously exposed to the asbestos. Airborne material spread through the town and adjacent areas; contaminating material was found up to eight miles away, carried by prevailing winds into National Forests and other wilderness areas. The material also spread through the extensive use of the LA-contaminated vermiculite as construction material, reaching 270 processing centers around the nation and their customers. Homes, roads, and commercial properties continue to harbor the toxic material in their soils and structures.

The potential asbestos problem at Libby was known by the Montana State Board of Health as early as the early 1960s, as well as at the federal-level Bureau of Mines in the early 1970s, yet it took until 1999, when the *Seattle Post-Intelligencer* published an exposé, for the Environmental Protection Agency (EPA) to investigate the contamination. A 20-year study conducted by the Agency for Toxic Substances and Disease Registry found that community mortality resulting from asbestosis in Libby was 40–60 times higher than normal, prompting the agency to declare a public health emergency in the area and begin more intensive clean-up operations.[26] The site gained EPA Superfund designation in 2002. As part of the complex process of designating responsible parties, W.R. Grace and Co., the original mine operator, entered into an agreement in 2008 that established a substantial trust fund to handle the rising reclamation costs.[27] To date, over 2,000 properties have been cleaned up, with an additional 2,000 still in need of remediation. The tab has passed $120 million, with various clean-up activities still pending and an expected total cost near $250 million.[28] These costs should be compared with the estimated after-tax profits of $140 million collected by W.R. Grace and Co. from the Libby mining operations.[29] [10]

The first bias operating in this case is external-risk neglect, which led to excessive health risks being imposed on the Libby workers and community members. Asbestos litigation, begun in the early 1970s, is the longest running, most expensive mass tort litigation in U.S. history,[30] yet action was not taken in Libby until the end of the 1990s. Investigative reporters have charged that the company was aware of the risks of asbestos, but downplayed and covered up the risks.[31] This was a classic externality problem, in which the costs were borne by others and not addressed by the mining company.

Whether it was willful neglect, however, is a different and litigious question. The U.S. government's criminal case against W.R. Grace and its executives concluded in favor of the company in May 2009, exonerating it of willful wrongdoing. However, controversy surrounds the case because the federal judge barred the U.S. attorneys from presenting some potentially incriminating portions of their accumulated evidence against W.R. Grace to the court.[32] The responsibility now falls on the EPA and taxpayers to mend the damage.

---

[9] We will address the more complex ethical justifications and questions regarding mining in a forthcoming paper.

[10] We recognize that the profits had been earned earlier, and that the time value of money might have made the present value of the profits exceed the present value of the cleanup. But this neglects the tragedy of the high expected costs in human health.

The EPA failed to regulate asbestos-contaminated vermiculite in the 1980s and 1990s, despite awareness of the potential hazard. Such regulations could have limited asbestos exposure in Libby. This represents an example of solution neglect. EPA regulations under the Clean Air Act (1970) or the Toxic Substances Control Act (1976) were one possible solution for minimizing the negative health impacts of the degradation, yet they were not utilized to control asbestos-contaminated vermiculite. An EPA report investigated the reasons, faulting a combination of fragmented jurisdiction, ineffective communication, limitations of existing knowledge, and competing priorities for funding in the intervening years.[26] The fact that both the company and the EPA failed to curtail excessive degradation calls to mind the recent financial crisis, in which multiple parties contributed greatly to the disaster.

Among federal agencies (e.g., EPA, OSHA, or Mine Safety and Health Administration), there are widely differing standards regarding safe asbestos levels, from 0.01 to 2.0 fibers per cubic centimeter. A regulatory standard that is too lenient or strict often flows from a combination of the biases outlined above or from political concerns. In cases of uncertainty, statistical neglect can be prominent, as regulators fail to account appropriately for subjective probabilities. Another example of statistical neglect is a failure to update standards in the light of new information. When impacts are uncertain, as they have been with asbestos, as epidemiological knowledge develops, we must attend to the data, update our risk assessments and our standards, and avoid the pitfalls of statistical neglect.

Faulty tail thinking also prevented optimal degradation and reclamation decisions in the Libby case. The severe negative health and environmental impacts from the Libby mining could be classified as a tail event (although once the risks of the asbestos were understood, the impacts of doing nothing should have been seen as closer to the expected value of damages). However, this tail event was not considered; there was no preproduction reclamation planning. This is not unusual. The possibilities of severe contamination have rarely been factored into reclamation plans.

The nation's liability system does a poor job of handling tail events that take years to materialize. Liability systems only operate effectively when the original operator will be in business when the damage becomes known. Orphaned mines dot the western United States; most of their operators have disappeared and have escaped liability. The costs in Libby of reclaiming the asbestos-infused landscape partially fell on local residents and, through the EPA and its Superfund program, on the U.S. taxpayers. Taxpayers cover even more of the costs in cases where the original operator is gone. To prevent future neglect of tail outcomes, a constructive method of accounting for tail risks must be integrated into the mechanics and calculus of reclamation costing.

One approach that could potentially help address tail risk is bonding requirements, currently required by some states or federal agencies, to cover the costs of reclamation in the event of mine bankruptcy. This is a way to handle external-risk neglect and ensure that the costs are not passed on to others. The bonds' magnitudes, however, have proven to be insufficient in many cases, and certainly not high enough to cover extreme outcomes. Indeed, bonding requirements have generally proved insufficient to cover costs associated with the environmental standards imposed by the same state bodies that impose the bonding rules. We refer to such mechanisms that provide insufficient coverage as fig-leaf protection. In many situations, fig-leaf protection leads polities to believe that they are safe and are prepared for possible negative outcomes, when really they are not. Fig-leaf protection often occurs when tails are fat. Another example of what we might cynically label "pretend protection" could be the Pension Benefit Guaranty Corporation. In an extreme collapse, many pension funds would go down together, and the funding would be woefully insufficient.

One reason for low bonding requirements may be the mining lobby's efforts to pressure states to lower requirements, often by issuing threats to move mining to other jurisdictions or overseas.[11] For example, only after a series of very costly mining bankruptcies and over the objections of the mining industry, did the Montana legislature increase its bonding requirements for mine permitting.[34] Bonding had significantly underestimated various costs of managing

---

[11] This Montana narrative documents a challenging trend for policymakers in most mining states, as well as several extraction regions around the world. Because the objective of extraction is the production of global commodities, extraction companies will naturally seek jurisdictions of lowest cost and regulatory burden, the perpetual "path of least resistance."[33] This patchwork of differing standards and requirements places a downward pressure on effective policy, a kind of race to the bottom. Any policy to address the biases discussed here would thus need to be enacted cross-jurisdictionally and ultimately internationally if we are to avoid simply exporting the damages.

reclamation needs at several Montana mines during the 1990s, resulting in taxpayers bearing part of the costs of reclamation. This could also be an example of statistical neglect, in which risks are neglected when they are out of mind.[20] After an incident in which costs are much greater than anticipated, regulators may revise their risk assessments. One such example in Montana comes from a suite of heap-leach cyanide mine complexes, owned by the now bankrupt and dissolved Pegasus Gold. Reclamation of these complexes easily cost several times the value of the reclamation bonds, requiring infusions of funding from various taxpayer-supported federal agencies, such as the U.S. Forest Service and the Bureau of Land Management.[35]

Alberta oil sands. Although modern protections exist in name, current—and not just historical—extractive activities often neglect the risks they impose. Some massive projects are the worst offenders. The Canadian oil sands occupy 54,000 square miles in northern Alberta, an area close to the size of Florida. Current production from these oil sands, 2 million barrels a day, makes Canada the largest source of crude oil imported into the United States.[36] Unlike the desert-based Saudi Arabian oil fields, Alberta's oil sands are located in the middle of a vast, valuable ecological resource—boreal forest. With the projected production of 3.19 million bpd (barrels per day) by 2016, the Alberta Energy and Utilities Board expects output to triple from 2006 levels.[37] The mines, dams, tailings ponds, and other alterations associated with processing the oil-sands resource will be the colossal landscape legacy of the current extraction activities.

As with the mine in Libby, a key bias here is external-risk neglect. Both downstream and environmental consequences of oil-sands extraction have not been internalized by the mining companies. A time-series study of the regional water system has shown that cumulative changes in the water quantity and quality of the Athabasca River have already been confirmed as at least partially related to the oil-sands water usage and operations.[38] A vivid example of environmental damage comes from an incident at a Syncrude (the world's largest producer from oil sands) tailings pond. The pond, created by the largest dam in the world, was constructed to handle the chemical mixture of byproducts from the extraction and processing of the oil sands, including wastewater and various petroleum leftovers.[39] In the spring of 2008, a flock of migrating ducks—estimated to be 1,600—died soon after touching down in the tailings pond.[40] Officials found it difficult to provide a final count because the birds became immediately coated with petroleum and sank to the bottom. An independent panel of experts, convened by the Royal Society of Canada, hopes to evaluate the claims against the oil-sands development, including aquatic life effects, potential rising cancer rates in the adjacent First Nations populations, future groundwater contamination, and other potential harmful effects. (Report due in 2011.[41])

The incident at Syncrude also suggests tail risks that are being neglected. The known harmful substances in the waste tailings could breach the tailings impoundments, either through a failed barrier, such as what occurred at the Kingston Fossil Plant in Tennessee (for more information, see U.S. EPA Report[42]), or through groundwater seepage.[12] A failed impoundment, such as the Tar Island Dike located directly adjacent to the Athabasca River, would saturate a large area with the waste tailings, known to be toxic to most aquatic life, severely damaging a large ecoregion. Losses from such an event may include operational clean-up costs between $525 million and $825 million, unknown costs associated with additional class-action lawsuits brought by the impacted residents, and potential environmental fines, all for a site that is miniscule relative to the oil sands.[44] We have relatively little precedent for landscape transformation on this scale, with impoundments this large in a northern, boreal climate that is subject to potentially accelerated change over the coming decades. Thus, our conception of a normally distributed risk profile of impoundment failure may cause us to severely underpredict the potential for extreme alteration of the existing conditions in the oil-sands region.

The expanding production also requires a constant updating of the risk to avoid statistical neglect. The waste tailings, a byproduct of the hot water method of extracting the oil from the bitumen mixture, grow by 954,000 cubic meters annually, or approximately 236 acres of 1 m deep liquid every year. This entails a constant expansion of impoundments and, thus, a constant expansion of the total area and amount of fluid that will require reclamation in the future.[43] This requires a recalculation of the risk.

---

[12] Seepage transport pathways and rates are mostly unknown, potentially confounding current risk calculations, although one study described less-than-expected seepage through the containment structure.[43]

Reclamation of the oil sands is troubled in addition by authenticity bias and solution neglect. The Alberta Provincial Government states that the "aim of land reclamation is to restore disturbed land so that it is as productive or more productive."[13] The regulation requires a return to the boreal ecosystem. This exemplifies authenticity bias. The government is assuming that a return to previous conditions is the best alternative after extraction. This narrow prescription also represents solution neglect. Policymakers have simply not considered other reclamation scenarios. Returning such a vast landscape to the original conditions is both impossible in ecological terms, and impractical in programmatic terms due to wide-ranging alteration of the supporting conditions. As an indication of the infeasibility of such a requirement, in roughly 40 years of oil-sands mining, only a single reclamation certificate has been granted to an oil-sands producer; it was granted for a former wetland that was transformed into an overburden hill forest.[45] That is, the goal of restoration to original conditions could not be met, and this was on a site that should have been one of the easiest to reclaim. It was a mere overburden pile, devoid of the chemical legacy issues that plague the other processing areas.[46]

Finally, the distributed nature of the responsibility belies deeper problems with oil-sands development. Syncrude is actually a consortium of seven energy companies, and even its partners are combined entities. For example, Canadian Oil Sands Trust and Imperial Oil Ltd. own a majority stake in Syncrude, but Exxon controls Imperial. The rise of these colossal-scale extractions point to a related trend in politics and economics—the "too-big-to-control" phenomenon, which has three components: (1) current forecasting tools cannot easily assess the impacts of unfolding developments, so participants fall into statistical neglect, failing to update sufficiently; (2) even when accurate assessments are possible, the political muscle of some of the actors discourages such assessments from being made or from being made in an unbiased fashion; and (3) even if a negative assessment were to be made, this same political muscle would be used both to produce a contrary assessment, and to fight, quite possibly effectively, against major impositions.

13 See Alberta government website, http://environment.gov.ab. ca/info/faqs/faq5-oil_sands.asp, and Oil Sands Discovery Centre: Fact Sheet, www.oilsandsdiscovery.com/oil_sands_story/pdfs/enviro_protection.pdf.

3.2. Climate Change

While this article has been focused on degradation and restoration of surface landscapes, we believe these lessons are broader and can apply to a range of situations that, at least through analogy, are cases of degradation and restoration. Here we consider climate change, surely the current environmental degradation problem that has the greatest potential for imposing monumental costs, both in terms of losses of value and the costs of reducing or accommodating such losses. The anthropogenic emission of greenhouse gas emissions is causing degradation of the climate on a large scale, and policymakers are now weighing response options. These could include options to slow or eliminate the degradation by improving energy efficiency, reducing energy use, switching to low-carbon sources of energy, or instituting carbon capture and storage. Beyond methods to slow degradation, there is the potential for what are, in effect, reclamation options through various types of geoengineering. The most commonly discussed is solar radiation management, reducing the amount of sunlight reaching the Earth. More speculative are measures that would remove from the atmosphere carbon dioxide that has already been emitted. The consideration of reclamation also includes the option of not reclaiming at all, but instead of developing modes of adapting to the changing environment.

Three of the biases discussed earlier have plagued our institutions' ability to make optimal decisions regarding climate degradation levels. The first, as has been widely acknowledged, is external-risk neglect. Emitters of greenhouse gasses receive all the benefits but bear none of the costs. This has led to excessive emission levels. As Nicholas Stern has written: "[c]limate change is the biggest market failure the world has ever seen."[47]

The second bias is statistical neglect. As mentioned earlier, there is a large body of literature documenting the ways in which individuals fail to assess probabilities accurately and make useful statistical calculations. At least two assessment errors are relevant to the climate problem. First, individuals have been shown to be overly optimistic about negative events, estimating probabilities of these outcomes as too low.[48] With climate change, this can cause individuals and policymakers to underestimate the threats from anthropogenic emissions and thus tolerate too much degradation. Second, people are risk-seeking in losses and would rather gamble on a

substantial possible loss than accept a smaller, certain loss.[49] This is a form of consequence neglect, or at least of the slighting of consequences. This may explain the relatively small amount of abatement undertaken to date. Individuals would rather gamble on possible catastrophic climate change than incur the certain costs of an investment in abatement.

Two additional biases inhibit our decision making regarding how much to limit degradation and whether to attempt reclamation. The first is faulty tail thinking. As several authors have observed, notably Martin Weitzman,[11] the distribution of damages from climate change is extremely fat-tailed, yet many of our models have not addressed this extreme tail risk. Many economists and others are focusing on expected damages in determining an optimal abatement path. However, policymakers have not fully considered both the risk reduction benefits of abatement and the likelihood that extreme events may account for a substantial fraction of the expected value of losses.[50]

Status quo bias has also influenced the thinking regarding decisions on the extent of degradation or reclamation of the climate. Many stakeholders have expressed a desire to maintain the current climate or be able to return to the current climate by blocking sunlight, perhaps by injecting aerosols into the atmosphere. Given the long life of carbon dioxide in the atmosphere, some degree of continued climate change is almost certainly in our future. Maintaining the current climate may entail costs that far exceed the benefits of allowing some amount of warming. Advocates of geoengineering suggest techniques that could be used as a backstop if degradation were to exceed tolerable limits. While geoengineering is appealing as a backstop technology, its risks are unknown and possibly large. It is also unclear how effectively it could be used to reclaim the climate after the atmosphere reaches a critical concentration of greenhouse gas emissions. (For more on these issues, see D. W. Keith.[51])

4. CONCLUDING THOUGHTS

The biases we discuss here lead to suboptimal decision making in a range of cases where risks and uncertainties are present. These biases play a particularly pernicious role in decision making regarding degradation and reclamation. In dealing with a disease, the crucial first step is diagnosis. In dealing with biases, the crucial first step is recognition. Once we understand the ways we are biased in our deci-

sion making, we can design systematic methods to address the issues more effectively. This article has called attention to common biases to begin the process of recognition. We are not prescribing any specific methods for addressing the cases studied for two reasons. First, it would be premature to do so, given that we are just beginning to understand the nature of the problems. Second, different problems require different mechanisms for redress; the problems in each case study are distinct. We suspect, however, that the solutions will involve requirements for careful science-based analyses before new projects can proceed or old problems can be addressed. These cases also suggest that degrading environments on a large scale and only afterwards considering how to clean up the damages simply does not work. Landscapes— or the climate—are left permanently damaged.[52,53] Going forward, we can do better in the cases described here, and in a range of situations beyond these. We can be more rigorous and expansive when we assess probabilities and outcomes, better at considering fat tails, more able to set aside common decision biases, broader in our consideration of response measures, and more willing to adopt policies that effectively internalize externalities.

REFERENCES

1. Daily GC. Introduction: What are ecosystem services? In Daily GC (ed). Nature's Services. Washington, DC: Island Press, 1997.
2. Millennium Ecosystem Assessment. Ecosystems and Human Well-Being, A Framework for Assessment. Washington, DC: Island Press, 2003.
3. Berger A, Brown C, Kaisky C, Zeckhauser R. The five neglects: Risks gone amiss. Pp. 83–99 in Kunreuther H, Useem M (eds). Learning from Catastrophes: Strategies for Reaction and Response. Philadelphia, PA: Wharton School Publishing, 2010.
4. Tversky A, Kahneman D. Loss aversion in riskless choice: A reference-dependent model. Quarterly Journal of Economics, 1991; 106(4):1039–1061.
5. Summers L, Zeckhauser R. Policymaking for posterity. Journal of Risk and Uncertainty, 2008; 37(2):115–140.
6. Raiffa H. Decision Analysis: Introductory Lectures on Choices Under Uncertainty. Reading, MA: Addison-Wesley, 1968.
7. Savage LJ. Foundations of Statistics. New York: Dover Publications, 1972.
8. Lamb D, Erskine PD, Parrotta JA. Restoration of degraded tropical forest landscapes. Science, 2005; 310:1628–1632.
9. Keohane N, Van Roy B, Zeckhauser R. Managing the quality of a resource with stock and flow controls. Journal of Public Economics, 2007; 91(3–4):541–569.
10. Buffet W. Berkshire Hathaway Inc. Chairman's letter to shareholders, 1997 February 28. Available at: http://www.ifa.com/Library/Buffet.html, Accessed July 28, 2010.
11. Weitzman ML. On modeling and interpreting the economics of catastrophic climate change. Review of Economics and Statistics, 2009; 91(1):1–19.

12. Walters CJ, Holling CS. Large-scale management experiments and learning by doing. Ecology, 1990; 71(6):2060–2068.

13. Holling CS. Adaptive Environmental Assessment and Management. London: John Wiley and Sons, 1978.

14. Lee KN. Compass and Gyroscope: Integrating Science and Politics for the Environment. Washington, DC: Island Press, 1993.

15. Sunstein CR, Zeckhauser R. Overreaction to fearsome risks. Environmental and Resource Economics, forthcoming.

16. Sunstein CR. Probability neglect: Emotions, worst cases, and law. Yale Law Journal, 2002; 112(1):61–107.

17. Kuran T, Sunstein CR. Availability cascades and risk regulation. Stanford Law Review, 1999; 51(4):683–768.

18. Associated Press. BP Drill Plans Downplayed Risk of Rig Accident. 2010.

19. Kunreuther H, Meyer R, Zeckhauser R, Slovic P, Schwortz B, Schade C et al. High stakes decision making: Normative, descriptive and prescriptive considerations. Marketing Letters, 2002; 13(3):259–268.

20. Tversky A, Kahneman D. Availability: A heuristic for judging frequency and probability. Cognitive Psychology, 1973; 5:207–232.

21. Samuelson W, Zeckhauser R. Status quo bias in decision making. Journal of Risk and Uncertainty, 1988; 1:7–59.

22. Chazdon RL. Beyond deforestation: Restoring forests and ecosystem services on degraded lands. Science, 2008; 320:1458–1460.

23. Taleb NN. The Black Swan: The Impact of the Highly Improbable. New York: Random House, 2007.

24. U.S. Department of the Interior and U.S. Geological Survey. 2006 Minerals Yearbook: Mining and Quarrying Trends. Washington, DC: U.S. Geological Survey, 2008.

25. Centers for Disease Control and Prevention. NIOSH Fact Sheet: NIOSH Recommendations for Limiting Potential Exposures of Workers to Asbestos Associated with Vermiculite from Libby, Montana in DHHS (NIOSH), Publication Number 2003–141; Online at: www.cdc.gov/niosh/docs/2003-141. Washington, DC: Centers for Disease Control and Prevention, 2003.

26. U.S. EPA. EPA's actions concerning asbestos-contaminated vermiculite in Libby, Montana. Washington, DC: United States Environmetnal Protection Agency, Office of Inspector General, 2001.

27. Hanson AB. W.R. Grace Settles Asbestos Claims for $3 Billion. Helena, MT: Associated Press, 2008.

28. Supreme Court of the United States, W. R. Grace & Co., Kootenai Development Corporation, and W. R. Grace & Co.-Conn. v. United States of America. On Petition for Writ of Certiorari to the US Court of Appeals for the Ninth Circuit. Petition for Writ of Certiorari.Available at: www.scotusblog.com/movabletype/archives/W.R.GracePetition%28Apr.27%2C2006%29.pdf. 2006. Accessed on October 20, 2009.

29. U.S. EPA. News Release: W.R. Grace and Executives, Charged with Endangering Libby, Montana Community, Fraud, and Obstruction of Justice. Washington, DC, 2005.

30. Carroll SJ, Hensler DR, Gross J, Slass EM, Schonlau M, Abrachamse A et al. Asbestos Litigation. Santa Monica, CA: Rand Institute for Civil Justice, 2005.

31. Peacock A. Libby, Montana: Asbestos and the Deadly Silence of an American Corporation. Boulder, CO: Johnson Books, 2003.

32. Johnson K, C. Chemical company is acquitted in asbestos case. New York Times, May 9, 2009.

33. Freeman PS. An industry perspective on mining in New Mex-ico. P. 85 in Price LG, *et al.* (eds). Mining in New Mexico—The Environment, Water, Economics and Sustainable Development: Decision-Makers Field Guide. Socorro, NM: New Mexico Institute of Mining and Technology, 2005.

34. U.S. Geological Survey. The Mineral Industry of Montanta, in Minerals Yearbook (Volume II. – Area Reports: Domestic). Washington, DC: U.S. Government Printing Office, 1996.

35. McCullough W. Financial assurance and bonding: What happens when bankruptcy hits. In Price LG, et al. (eds). Mining in New Mexico—The Environment, Water, Economics and Sustainable Development: Decision-Makers Field Guide, Socorro, NM: New Mexico Institute of Mining and Technology, 2005.

36. Energy Information Administration. Petroleum Supply Monthly: January 2010. Washington, DC: Energy Information Administration, Office of Oil and Gas, Department of Energy, 2010.

37. Alberta Department of Energy (2007) Alberta's Oil Sands. Edmonton, Alberta: Alberta Department of Energy, 2006.

38. Squire AJ, Westbrook CJ, Dube MG. An approach for assessing cumulative effects in a model river, the Athabasca River Basin. Integrated Environmental Assessment and Management, 2009; 6(1):119–134.

39. Mining-technology.com. Syncrude Oil Sands Mine, Alberta, CA, February 23, 2010. Available at: http://www.mining-technology.com/projects/syncrude/, Accessed July 28, 2010.

40. Jones J. Syncrude duck deaths now triple initial tally. Reuters, March 31, 2009.

41. Vanderklippe N. Scientists seek truth on oil sands damage. Globe and Mail, October 10, 2009.

42. U.S. EPA. Action Memorandum (AM) Fact Sheet on Selected Engineering Evaluation/Cost Analysis (EE/CA) Alternative Kingston Fossil Fuel Plant Release Site. Washington, DC: U.S. Environmental Protection Agency, 2010.

43. Ferguson GP, Rudolph DL, Barker JF. Hydrodynamics of a large oil sand tailings impoundment and related environmental implications. Canadian Geotechnical Journal, 2009; 46(12):1446–1460.

44. Mansfield D. Cleaning Tenn. spill could cost $825m. Knoxville, TN: Associated Press, 2009.

45. Jones M. Reclaiming reality. This Magazine, Jan–Feb, 2009.

46. Hildebrand J. Reclamation illusions in oil sands country. Parkland Post, 2009; 11(2). Available at http://parklandinstitute.ca/post/story/reclamation_illusions_in_oil_sands_country/ Accessed July 28, 2010.

47. Stern N. Economics must be at the heart of any discussion of how to fight climate change. Boston Review, January/February, 2007.

48. Camerer CF, Kunreuther H. Decision processes for low probability events: Policy implications. Journal of Policy Analysis and Management, 1989; 8(4):565–592.

49. Kahneman D, Tversky A. Prospect theory: An analysis of decision under risk. Econometrica, 1979; 47(2):263–292.

50. Kousky C, Rostapshova O, Toman MA, Zeckhauser R. Responding to the threats of climate change mega-catastrophes. In RFF Discussion Paper 09–45. Washington, DC: Resources for the Future, 2009.

51. Keith DW. Geoengineering the climate: History and prospect. Annual Review of Energy and the Environment, 2000; 25(1):245–284.

52. Berger A (ed). Designing the Reclaimed Landscape. New York: Taylor and Francis, 2008.

53. Berger A. Reclaiming the American West. New York: Princeton Architectural Press, 2002.