The Safe Minimum Standard of Conservation and Environmental Economics

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Critics within environmental economics argue that the mainstream paradigm is not sufficiently cautious to support sound decision making about the long-run future of environmental resources. Rather than basing choices on benefits and costs, these upstarts, beginning with Ciriacy-Wantrup[2] (1968), argue that decision-makers should consider imposing a safe minimum standard of conservation (hereafter the SMS). The SMS has intuitive appeal. Where loss or degradation of environmental resources could have large adverse economic consequences, safety-first makes common sense. The SMS continues to be discussed in the professional literature[3] and has found its way into some textbooks.[4] However, the SMS has not achieved wide acceptance among environmental economists.

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2) Wantrup began with those renewable resources that have a "critical zone" measured in terms of their current stocks. If stocks fall within the critical zone further reductions in stocks entail the risk of irreversible loss of the resource itself. For example, for a species of plant or animal, the critical zone is encountered when there are so few members of the species left or so little habitat remaining that its future viability is in doubt. He defined the SMS in terms of possible violations of the critical zone. "... a safe minimum standard is achieved by avoiding the critical zone—that is, those physical conditions, brought about by human action, which would make it uneconomical to halt or reverse depletion." (p. 253).

3) See Bishop 1993; Castle and Barrens 1993; Farmer and Randall 1998; Pearce and Atkinson 1998; Randall and Farmer, 1995; Perrings et al. 1992; Rolfe 1995; Norton and Toman 1997; and Woodward and Bishop 1997.

4) See Costanza et al. (1997); Hanley, et al. (1997); Gowdy and O'Hara (1995); Howe (1979); Pearce and Turner (1970); Randall (1987); and van Kooten (1993).

In this paper, we review and augment the case for the SMS. Following Wantrup, who recognized plant and animal species as archetypal examples of resources where the SMS should be considered, we use species diversity to frame the discussion. But the SMS may have much wider applicability. Wantrup included a broad range of renewable resources in his thinking. He personally applied the SMS to prime agricultural land (Ciriacy-Wantrup 1985a) and water quality (Ciriacy-Wantrup 1985b). He also explored, in a preliminary way, how the concept might apply to soils, groundwater, grazing lands, forests, and other resources (Ciriacy-Wantrup 1968, p. 258). Although we limit discussion here to species diversity, possible application of the SMS to other resources will be among the issues for future research discussed at the end of the paper.

Those who write on the SMS exhibit significant differences in viewpoint, but they build their arguments on three premises that are discussed in detail in the paper's opening section. 1) Irreversible harm to environmental resources may produce large, even catastrophic or disastrous, losses in the long run. 2) Whether large losses will be incurred is uncertain. 3) Intergenerational fairness should be explicitly included in economic analysis of long-term environmental issues. According to SMS advocates, these premises imply that decision-makers should place a high priority on avoiding irreversible harm to environmental resources, including biodiversity. As we shall see in the paper's second section, this conclusion has, at various times, been rooted in intuition about safety-first, game theory, and appeals to ethical reasoning.

The third section is motivated by a rhetorical question: Why hasn't this seemingly sensible idea gained greater acceptance among those in the mainstream of the discipline? Our answer will to some extent be speculative and inferential. Literature where the SMS has been openly criticized is rare. Mainstream economists writing on environmental issues mostly ignore it. Still, inference and personal conversations point to four sources of doubt. 1) Those in the mainstream question whether large losses from extinction are really plausible. 2) They view the safe minimum *standard* as a command-and-control (CAC) approach to policy, which is bound to be inefficient compared to incentive-based strategies. 3) Many in the mainstream object to explicitly considering intergenerational fairness in environmental economic analyses. 4) The SMS is an ultraconservative strategy for dealing with uncertainty. Those in the mainstream place their confidence in probabilistic approaches. To the extent that risk preferences enter in, they should be accounted for through risk aversion premiums.

The following points will be stressed as the argument unfolds:

- It is possible that fears about large losses are overdone, but there is still tremendous uncertainty on this score. The fact that natural scientists working in such fields as biotechnology are among the strongest supporters of environmental protection should turn environmental economists away from glib technological optimism.
- Safe minimum "standards" and pollution "standards" represent an unfortunate overlap in the jargon of environmental economics. The SMS is a proposed objective of environmental policy, not a CAC strategy per se. It is more akin to emissions goals such as total SO_2 emissions for Europe or North America than to environmental standards for the technologies that must be applied in power plants, for example.
- Regarding explicit consideration of intergenerational fairness in policy analysis, those in the mainstream may have misunderstood SMS advocates. We are not advocating a rigid constraint on economic activities that must be honored under all circumstances. Up to a point, at least, the SMS might better be thought of as a "soft constraint" that is imposed for analytical purposes. The SMS is useful in estimating the "price tag" for not imposing uncertainty on future generations rather than as a rigid constraint on economic activity that must be honored no matter what.
- SMS advocates eschew probabilistic methods for environmental decision making under uncertainty in favor of approaches that may seem ultraconservative. This is a point of serious disagreement with the mainstream. Probabilistic approaches to uncertainty hold the theoretical high ground in mainstream economics, making arguments favoring the SMS suspect. But however elegant and reasonable probabilistic methods are for addressing many economic problems, they do not fit here. Moreover, significant progress has been made toward nonprobabilistic theories of choice, and this emerging literature provides new support for cautious strategies like the SMS.
- As part of our efforts to go beyond probabilistic approaches, we propose a new and more realistic concept we call "nescience." Under nescience, analysts and decision-makers do not know all possible

states of the world (i.e., surprises are possible) and probabilities, even subjective probabilities, are not sufficiently well understood to calculate expected values. We argue that real world decision-makers addressing questions affecting species survival face a state of knowledge that is much more akin to nescience than to conventional concepts of risk and uncertainty.

- All this leads us to move toward a normative theory of bounded rationality. Human decision-makers confronted with nescience about the large potential losses associated with erosion of biodiversity may have to construct simplified models of reality in order to make decision problems tractable. A full theory of bounded rationality will require further research. Nevertheless, maintaining the SMS as one rule of thumb for environmental decision making seems sensible in this context.

Premises of the SMS

Those who would apply the SMS in endangered species policy share three premises:

First Premise: Loss of Biodiversity May Lead to Large Future Losses.[5] Erosion of species diversity reduces the reservoir of potential resources (Bishop 1978). From the beginning, humans have drawn on living resources for a wide variety of goods and services. We will continue to do so into the foreseeable future. Loss of biodiversity means loss of potential resources that might otherwise have proven quite valuable. In addition, erosion of biodiversity threatens ecosystems that provide many kinds of life-support services.

Consider crops like corn and wheat. At first glance, production simply requires planting seeds and properly caring for the crop over the growing season. Underneath the surface, myriad environmental services support crop production. A host of creatures large and small

5) For example, Ciriacy-Wantrup (1968, p.252-253) spoke of "retarded and abnormal growth" and "stagnation and death" of civilizations. Farmer and Randall (1998, p. 297) consider an economy whose trajectory of activity will generate a breach in the threshold of a resource considered "vital to decent human survival." Norton and Toman (1997, p.554) speak of "important thresholds of scale" of economies such that "human activities can, by stressing ecosystems in ill-advised ways, set in motion large-scale and irreversible losses in the functioning ecological and physical systems."

live in the soil and support natural waste recycling, fertility, retention of soil moisture, and other functions. On a larger scale, plant and animal communities affect erosion rates and the timing, quantity, and quality of water available for crops. Thus losses of biodiversity could adversely affect crop production either directly, if crop varieties or wild ancestors are lost, or indirectly if life support services necessary for crop production are adversely affected. The result could be catastrophic crop failures. Other examples might focus on pharmaceutical products, energy sources, aesthetic resources, air and water quality, and environmental services that depend on plants and animals.

Second Premise: Whether or not large losses will actually occur is uncertain. From its inception, advocates of the SMS have viewed it as a strategy to deal with uncertainty (see, for example, Wantrup 1968; Bishop 1978; Castle and Barren 1996; Norton and Toman 1997). The uncertainty confronted here is thought to be of a most virulent sort, requiring approaches to decision making that do not depend on probabilities. Wantrup maintained a distinction between risk and uncertainty, as Knight (1921) used those terms, and stressed that it was uncertainty that motivated the SMS.[6] Under Knight's concept of uncertainty, alternative outcomes and payoffs are known, but the decision-maker does not know the probability of a given outcome. We refer to this as "pure uncertainty" (Woodward and Bishop 1997, p. 494). Doing so will distinguish it from the watered down version of uncertainty common in modern economic writing, which treats all decision problems as variations of games of chance.

Third Premise: Intergenerational fairness is a social goal. Combining the first two premises, extinction imposes large uncertainties on future generations. As a matter of fairness, it would seem that the current generation should try to refrain from imposing such uncertainties. On the other hand, preservation of species can involve costs, costs that must be borne at least initially by current generations.[7] Hence choosing whether or not to preserve species can involve important issues of

6) "In the former [i.e., risk], the mechanism of chance is known, as in throwing a coin. In the latter this mechanism is not known, or only known in part. Nearly all uncertainties of concern in this study are of the latter kind." (Ciriacy-Wantrup 1968, p. 111).

7) Bishop (1978) called attention to two possible types of costs. "Out-of-pocket" costs are incurred when money must be spent directly on preservation efforts. Examples might include expenditures for patrols to prevent vandalism and illegal hunting, research to help define preservation strategies, and artificial propagation. "Opportunity

intergenerational fairness: How much is it fair to ask current generations to sacrifice in order to reduce the uncertainties that future generations face? Those advocating the SMS (e.g., Bishop 1978; Norton and Toman 1997; Farmer and Randall 1998) reject the notion that equity issues, and particular equity across generations, ought to be excluded from environmental economics. Too many citizens and decision-makers are asking whether current choices compromise the wellbeing of future generations. Can we really justify limiting our analyses to narrowly conceived efficiency goals?

This is not to say that the goal of economic efficiency has been absent from the thinking of SMS advocates. Indeed, the SMS as Wantrup conceived it has roots in neoclassical efficiency. He considered maximization of net social benefits a theoretical benchmark for resource management (Ciriacy-Wantrup 1968, pp. 231-234). He believed that in practice this ideal could be approximated through incremental steps to increase net benefits over time. Given uncertainty, he believed (p. 250, emphasis added) that the SMS could be thought of as "a still more radical reformulation" of the efficiency goal, "which in many cases is the *most practical approximation of the social optimum.*" Bishop (1978) carried this theme into his early work on the SMS. In particular, in discussing the practical approach of maintaining the SMS unless costs were unacceptably large, he pointed to the futility of trying to directly apply benefit-cost analysis to species preservation projects because the benefits are so uncertain. The smaller are costs, he pointed out, the more likely it is that the benefits exceed the costs. Rolfe (1995 p.66) is another writer who linked the SMS to efficiency:

> The important role for the SMS rule to play may not be to recommend a new form of decision making, but to flag the preservation issues that are worthy of more detailed attention. However, in this role, the SMS rule can be justified in terms of costs and benefits.

Randall and Farmer (1995) have taken a different tack by viewing the SMS as an ethically motivated caveat when decisions are otherwise to be based on conventional benefit-cost analysis.

So when they confront long-term environmental issues like erosion of biodiversity, SMS advocates reject the mainstream economic approach on two counts. First, they question whether it adequately addresses the

cost" are incurred when an endangered species and its habitat cannot be used for certain purposes that would otherwise be economically beneficial. To this list might be added costs associated with damages done be the species as when wolves prey on livestock.

uncertainty that arises in environmental decision making. Second, they question whether intergenerational fairness ought to be left on the sidelines. The SMS, in their view, meets both concerns.

The Nature of the SMS

Advocates of the SMS argue that if the three premises are true, then it follows that extinction of plant and animal species should be avoided. In practice, the SMS would be achieved when sufficient populations and habitats are maintained to make extinction very unlikely.[8] Taken as a whole, writers on the SMS argue that both efficiency and fairness would be enhanced. Efficiency would be augmented through rational choices about the allocation of scarce resource where future prospects are very uncertain. Intergenerational fairness would be enhanced through reductions in the uncertainty that future generations face, provided the costs of maintaining the SMS in specific cases do not impose an unfair burden on those currently alive.

Does this mean that the SMS ought to be maintained no matter what? Here, too, writers on the SMS are not always explicit. Nevertheless we suspect that most could imagine circumstances where society ought to choose extinction. The SMS is not a constraint that would bind regardless of the situation. Wantrup described the SMS as "an *objective* of conservation policy" (1968, p., emphasis added); presumably, there are other objectives that could take precedence. Bishop (1978) echoed this view when he called for maintaining an SMS unless the costs were unacceptably large. He clearly opened the door to extinction if social decision-makers judged costs to be excessive.

Similarly, Norton and Toman (1997) envision a two-tiered framework for environmental decision making. First-tier choices are those that have modest or short-lived potential effects; these would be made on a business-as-usual basis. On this level, economic choices would be made in markets, supplemented by public policies to address market failures and intragenerational inequities. On the second tier, where choices have potentially large, long-term irreversible conse-

8) Survival of a species over long time spans is never a sure thing. The SMS evolved under an assumption of certainty about survival odds. Abstracting from uncertainty in this way is a time honored practice in economics. In practice, the SMS would be achieved when survival is assured with very high probability.

quences, decisions would be made in the public policy arena and focus on possible implementation of the SMS. But the possibility remains that choices on the second level could go against the SMS.

In the same spirit, Randall and Farmer (1995) advocated an "extraordinary decision process" to address the intergenerational ethical issues that arise in environmental policy making. They suggest (1995, p. 35), for example, that "...the SMS constraint would not accord trump status to biodiversity, but would trigger a serious and searching decision process before it could be relaxed." They identified three major schools of ethics with different perspectives on environmental issues, and showed that all three support considering SMS policies that protect the interests of future generations. Presumably, an extraordinary *decision* process involves making choices about how far to go in enforcing the SMS vis-à-vis other goals.

Hence rather than imposing a fully binding constraint, SMS advocates want to augment conventional efficiency criteria with criteria that more adequately address intergenerational fairness and efficiency where knowledge is very limited. They suggest that preservation might be a very sensible choice even if benefits, measured as best one can, fall short of costs. Randall and Farmer (1995, p. 34) put it this way, "The SMS rule places biodiversity beyond a reach of routine tradeoffs, where to give up 90 cents worth of biodiversity to gain a dollar's worth of ground beef is to make a net gain."

This leaves the SMS in a state that many find confusing or downright unsatisfactory. Most environmental economists who have addressed policies toward endangered species and biodiversity more broadly defined have applied conventional benefit-cost concepts supplemented by recently developed concepts like option value, and quasi-option value, and bequest value (e.g., Krutilla and Fisher (1975), Fisher and Hanemann (1987), Brown and Swierzbinski (1988), Hanemann (1988)). They would account for each of the premises of the SMS within their analysis. If large losses from extinction may be in the offing, they would be accounted for in the benefits and costs of alternative policies. Uncertainty requires only that option and quasi-option values be included in costs and benefits. If intergenerational fairness is a goal, then like all equity issues, it should be addressed from outside the economic framework. Who needs the SMS?

Those who choose to ignore the SMS concept either explicitly or implicitly raise four questions that we address in turn: 1) Are large losses sufficiently plausible to be taken seriously? 2) Isn't the SMS merely a command-and-control (CAC) strategy and thus subject to all the criticism that economists have leveled at CAC approaches to environmental regulation? 3) Should intergenerational fairness be allowed to share center stage in economic analysis? 4) Should the probabilistic approach be abandoned and, if so, what is the alternative?

Are Large Losses Sufficiently Plausible To Be Taken Seriously?

Biologists continue to debate how many species exist on earth with most estimates in the tens of millions. Somewhere between 1million and 2 million have so far been described. With so many species, it is only natural to ask whether we ought to be concerned if a few or even a great many disappear. There will still be so many remaining. Particularly in a world where ever smaller shares of national economies depend on biological resources, should the first premise of the SMS be accepted? Are large losses from erosion of species diversity really sufficiently plausible to drive policy?

Simpson and co-authors (Simpson and Craft 1996; Craft and Simpson 1999) have made by far the most rigorous attempt yet to estimate the potential economic values associated with species diversity. They tried to quantify, at least roughly, the social marginal value of species as potential sources of future pharmaceutical products. In one scenario, using assumptions that many would agree are generous in the direction of raising species values (such as a discount rate of 3 percent), Simpson and Craft (1996) estimated the marginal value of a species for pharmaceutical research at about $33,000. Broadening to consider a 25 percent loss of the earth's species led to projected economic losses of $111 billion in present value terms. This is about 0.01 percent of projected gross world product. The relatively small percentage of GWP remains robust under different assumptions. They conclude (Simpson and Craft 1996, p. 3, emphasis added):

Our finding is that *incremental losses of biological diversity will not cause great social losses* with respect to the needs of new pharmaceutical product development. There are a number of considerations that motivate this conclusion, but they can all be summed up in the statement that there is a sort of diamonds-and-water paradox at work. Biological diversity is sufficiently abundant that incremental losses are unlikely to have much effect on social welfare.

This result raises doubts about the first premise of the SMS.

Strong conclusions against the SMS would be premature, however, for a number of reasons. As the Simpson and Craft (1996) recognized, only pharmaceutical values were considered. Other contributions, such as those related to future energy sources, agricultural applications, and the like, not to mention life-support functions, were not considered. And there is more to consider than that.

Efforts to quantify the value biodiversity may be overly constrained by current and easily foreseeable levels of knowledge and technology. Many believe that we stand at the threshold of a biotechnological revolution.[9] Inexpensive, clean fuels that make no net contribution to global warming are even now in the offing. How we feed ourselves may change dramatically in the next few decades. Agricultural substitutes for petrochemicals and plastics may not be far behind. In health care, prevention may well displace treatment to a large degree. The economic transformation could be huge.

The implications of current rates of species extinction for the biotechnological revolution are uncertain. If our ability to capitalize on biological resources explodes, it may make individual species worth even less than Simpson and Craft imagined. But values could go the other way as well. Standing today on biotechnology's frontier, one is reminded of our ancestors who saw the New World as an inexhaustible treasure trove of resources. Perhaps that is how potential natural resources always appear from a frontier perspective. As exploration and exploitation expand into the hinterland, resource limits become much clearer and more constraining. And marginal values of resources grow accordingly.

In addition, a high degree of substitutability among pharmaceutical products is assumed in the analysis of Simpson and Craft (1996). Over-the-counter pain relievers make the point that drugs can have relatively close substitutes. Yet the overall degree of substitutability across drugs can easily be misjudged based on such examples. Simpson and Craft (1996) suggested that "Even if a new drug proves to be vastly superior to existing treatments, it is generally the case that the new drug displaces some existing product. Aspirin does not cure AIDS, but it is helpful for as least some of the symptoms." We would not want

9) It goes almost without saying that biotechnology could go the way of electric power too cheap to meter. Uncertainty abounds at every turn.

to be the ones to comfort AIDS victims by pointing out the existence of aspirin. Aspirin has not been sufficiently effective to convince medical researchers to abandon the search for drugs to treat AIDS or arthritis or migraine headaches or influenza. Patients evidently consider it a rather limited substitute for drugs that do more to treat their specific ailments.

Interestingly, the most recent paper (Craft and Simpson 1999) addresses this issue head-on. Along with the theoretical model underlying Simpson and Craft (1996), which is based on the model of monopolistic competition by Salop (1979), they also consider an alternative model by Dixit and Stiglitz (1977). Salop's model assumes a high degree of substitutability among product produced by monopolistic competitors while the Dixit-Stiglitz model does not require this assumption. They ultimately conclude that the social value of a marginal species "remains both model-dependent and parameter specific" (Craft and Simpson 1999, p. 20). At this point, we do not have sufficient empirical information to choose between models, much less to estimate parameters with confidence.

So large losses from extinction cannot be ruled out based on economic arguments built on the abundance of species and substitutability, at least not yet. Rather such losses remain a possibility although there is great uncertainty about them.

Note also that there is no attention to intergenerational fairness in calculations such as those performed by Simpson and Craft. The uncertainty associated with extinction falls mostly on future generations. A discount rate of 3 percents grinds inexorably away at any losses that will ultimately be incurred. Despite decades of debate, fears about the intergenerational fairness of discounting persist even among economists (Portney and Weyant, 1999). To many among the economic laity, the answer is obvious. The present value of a dollar in losses a century from now weighs into today's decisions at a mere $0.05. How can it be fair to count a dollars worth of a drug to someone a hundred years from now as worth only $0.05 today? We return to intergenerational fairness below. The point here is that the analysis of Simpson and Craft is very much in the economic tradition that leaves fairness to one side. Its relevance for the SMS, which is proposed as a step toward fairness, is thus muted.

We are also not convinced that many insights are to be gained from comparison of the potential values of pharmaceuticals to gross world product. Such comparisons do challenge us to clarify what we mean when we say that losses from erosion of species diversity could be "large." Economics does not currently have a widely agreed upon counterpart to the Richter scale. Surely, however, percentages of gross world product cannot satisfy this need. An earthquake that does horrendous damage in one region of the globe is hardly felt elsewhere. On average, from a global perspective, the ground hardly shakes at all. Likewise in the diverse economies of the developed countries or the aggregate world economy, serious socioeconomic losses in one region and for one group may register as only a small ripple in aggregate global economic activity.

Consider AIDS. Many would argue that this disease should be viewed as a very serious problem in the U.S. and European countries, yet its impact on national GDP in these countries must be small. Though the number of affected people is small in relative terms, it is large in absolute terms and affected individuals suffer large losses. Even adding Africa, where AIDS is truly rampant, and the rest of the world, the effects of the disease on gross world product must be modest. Several countries are taking it very seriously, devoting substantial resources to discover methods of treatment and prevention. In our terms, losses are deemed to be large enough to drive public choices toward countervailing measures.

Of course, in the end, potential losses from AIDS or erosion of biological diversity or other problems could be spread across a wide range and may not separate themselves neatly into those that are large and those that are small. We can only say that the size of losses increases with the number of people who are potentially affected and the seriousness of the effects that they face. Ultimately which losses are deemed large enough to warrant explicit attention in public policy is a judgment call. But as the AIDS example illustrates, percentage impacts on economic aggregates are not a very helpful criterion.

Our descendants may ultimately discover that loss of biodiversity had little effect on economic prospects. Or, to the extent that we are able to prevent extinction, they may avoid large losses. We do not know enough to say whether the number of species currently in existence combined with technological progress necessitates or obviates the desirability of preserving species now on the brink.

Isn't the SMS a Command-and-Control Strategy for Endangered Species?

As anyone who takes introductory environmental economics quickly learns, CAC strategies to control pollution drive up costs and reduce or eliminate incentives to innovate. Common approaches to pollution abatement such as technology-based effluent standards are thus roundly criticized. Economists and noneconomists alike now acknowledge the potential superiority of incentive-based approaches, such as emissions taxes, abatement subsidies, and transferable discharge permits, to address externalities.

The SMS might appear to be a CAC strategy. In practice, efforts to preserve species commonly do involve prohibitions on the "taking" of specimens, bans on importing and exporting products from endangered species, and restrictions against habitat modifications. Such steps appear to have a lot in common with technology standards.

A better interpretation of the SMS is possible, however. The SMS has more in common with the emissions goals than technology standards. That is, the goal under the SMS is to maintain sufficient numbers and habitat to assure survival. This is not a strategy for achieving a target, but rather the target itself. For this reason, we might have avoided a pitfall or two over the years if Wantrup had called his concept the safe minimum *state* of conservation.

As noted, CAC strategies are currently common for endangered species. But this is not necessarily a violation of the principles of environmental economics. Accepting the general rule that incentive-based mechanisms are economically superior strategies for pollution abatement does not rule out exceptions. For example, banning a highly toxic pollutant could be optimal if enforcement costs for incentive-based control mechanisms are substantial. Similarly, it may turn out that CAC strategies are the most cost-effective way to assure survival of species, although more might be done to explore the feasibility of incentive-based strategies to achieve the SMS.[10] But whatever tactics are found to work best, the strategic role of the SMS as a proposed objective of policy will remain unchanged.

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10) Following up on this theme, when Woodward and Bishop (1995) explored possible application of the SMS to global warming, they focused on carbon taxes as the mechanism for abatement.

Should Intergenerational Fairness Share the Main Stage in Economic Analyses?

As a strategy for their continued employment, environmental economists ought to build intergenerational equity into their analyses. Fairness to future generations has been a major theme in debates over environmental and resource policy throughout the Twentieth Century. It is *the* central issue in the sustainability debate that occupies so much public attention these days. Economists who choose to ignore this will risk having their work viewed as trivial or irrelevant by noneconomists. Yet many economists are very comfortable with the traditional distinction between equity and efficiency. How can they build intergenerational fairness into their analyses without making difficult value judgments? Interestingly, for endangered species, the SMS offers a way.

The SMS can be thought of as a constraint within which economic optimizing can proceed (Ciriacy-Wantrup 1968, pp. 267-268). We will show shortly that this is an incomplete view, but it is useful as a stepping stone to a more complete concept. As we have seen, the SMS should not be viewed as a constraint that is binding under all circumstances. It is better viewed as a constraint that is useful for analytical purposes, what we are calling a soft constraint. Economists do not know how to trade off equity against efficiency. Hence, if benefits from species preservation fall short of costs, they cannot directly evaluate the tradeoff between equity and efficiency that preservation may entail. The SMS helps guide analysis by posing the *rhetorical* question: How much would it cost to avoid potential harm to future generations by actively promoting the survival of species that are currently endangered? Assuming an SMS constraint on near-term economic activities helps one to evaluate how much current generations would have to sacrifice to fully protect future generations from extinction uncertainty. In short, an SMS constraint helps determine the price tag of full preservation.

We want to give further consideration in a moment to how economists might begin to define what is intergenerationally fair. First, though, we need to pause and ask whether fairness across generations is a valid issue at all. After all, the last two hundred years of global economic growth suggests that the future rich will be much better able to take care of the future poor than we are. Why not strive for efficiency and let future growth take care of the needs of the future disadvantaged? This stock cornucopian argument ignores two important complications.

The first is the well-documented problem of using growth in gross domestic product (GDP) to measure growth in actual welfare (Daily and Cobb, 1989). GDP is a biased measure. It fails to account for environmental externalities and depreciation of both human and natural capital, and it is augmented by defensive expenditures (such as pollution clean-up, prisons, and police) that do not add to welfare but rather prevent its erosion. If GDP were adjusted for these factors, our recent history of apparent economic growth might appear at least somewhat less rosy. How much less rosy is open to debate; it is, on the face of it, an empirical issue. Still, that GDP is a biased measure of economic welfare suggests that the evidence from the past should be judged with a more critical eye. If economic progress in the past is less rosy than many have believed, optimism about the future may need to be tempered accordingly.

The second, and more important problem is that no one knows how long the recent explosion of economic activity, however measured, can be maintained. Cornucopians propose to view the past two hundred years as a guide to the future, while ecologists and biologists continue to urge that the past is a poor guide given present strains on ecological systems. These are issues about which reasonable people may disagree. But the fact that reasonable people disagree suggests that uncertainty does indeed plague the issue. Given uncertainty, then, the question becomes what to do about it. Blind optimism seems a questionable strategy.

But if economic growth is not a panacea, on what basis can economists address intergenerational fairness? Many mainstream economists have a strong predilection for remaining agnostic on issues of fairness, insisting that economics lacks to tools to address them. Though economics has a long way to go, we would argue that we have the wherewithal to consider in at least a tentative way fairness between generations. One approach is to consider ethics, as Randall and Farmer (1995) have done. Scott (1999) has suggested another, perhaps complementary tack, which we will summarize because it appears to bear directly on the efficacy of the SMS.

We begin with the often-stated view that we are *trustees* of the earth's resources on behalf of future generations. What are the implications of this view? A trustee manages property in a responsible and prudent manner on behalf of others. Making decisions on behalf of others is one of the important distinctions between problems of intergenerational and intragenerational fairness: future generations are not here to say what they would like, while the poor of the present are. Once one asks how decisions on behalf of others might differ from decisions on behalf of ourselves, a rich body of thinking becomes available in the United States law of trusts.

Trust law has evolved from common law, and so respects both legal precedent and current norms. Particularly important concepts, such as the requisite standard of care for trustees, were first articulated over 100 years ago and have earned a strong degree of conformity across jurisdictions

Trust principles suggest that decisions on behalf of others require a greater degree of risk aversion than employed when conducting ones own affairs. Bogert and Bogert (1993) explains that "A trustee ... would not satisfy the court by showing merely that prudence which a business man would exercise in trade or speculation" (§541; p. 174). Pennsylvania's Supreme Court put it succinctly: "The primary duty of a trustee is the preservation of the assets of the trust and the safety of the trust principal" (In re Flagg's Estate, 365 Pa. 82, 91, 73 A.2d 411, 416 (1950)). Similar language can be found in statutes of the vast majority of states of the U.S. (Bogert, 1987; §106; p. 386).

The foregoing suggests two points, both of which are in harmony with the spirit of the SMS. First, to the extent that current generations view their responsibilities to the future in terms of an intergenerational trust,[11] an especially high priority should be placed on conserving trust assets. Second, because husbanding trust principal is accorded such weight, trust doctrine indicates that concern for the future may preclude trying to maximize growth. When decisions are made on behalf of others, responsible (prudent) trustees are to exercise more caution than when making decisions on behalf of themselves; more attention should be paid to conserving capital rather than maximizing returns.[12]

So we do not share the view that economists must remain agnostic on intergenerational fairness. Instead, we can explore analytically the implications of views expressed by the public such as natural resource

11) See Scott (1999) for evidence affirming such a view.

12) The asymmetric emphasis that prudent trustees place on gains and losses is reminiscent of prospect theory (Kahneman and Tversky, 1979).

trusteeship. For biodiversity, using the SMS as a soft constraint will allow us to explore questions of great policy relevant.

We suspect that if SMS advocates were content to apply conventional methods to species preservation problem except for a soft constraint, they would have fewer quarrels with their colleagues in the mainstream. But this is not the end of the story. The uncertainty surrounding extinction leads most SMS advocates to depart from orthodoxy more radically. They would go beyond the soft constraint version of the concept to help decision-makers cope with the uncertainty that surrounds extinction. They run into heavy sailing against the mainstream as they reject the probabilistic approach to decision making under uncertainty that is inherent is such tools as benefit-cost analysis.

Should the Probabilistic Approach Be Abandoned? What Is the Alternative?

The probabilistic approach to decision making under uncertainty has a distinguished pedigree. It also boasts the advantage of being easy to apply in models. In concept, if consequences of actions are uncertain, the economic agent places probabilities on them and chooses the action that maximizes expected utility. Risk preferences – and hence option values from species preservation – can be readily accommodated by choosing a utility function with the appropriate curvature. The value of information – and hence quasi-option values – can be accounted for by embedding the analysis in a dynamic framework. This procedure is so entrenched in the mainstream view of environmental economics that its appropriateness is rarely questioned.

Yet, as indicated earlier, there are good reasons to think that applying the expected utility hypothesis to problems of biodiversity is inappropriate. For a host of reasons – not least being the fact that species extinction involves unique events – objective probabilities on the costs of extinction are lacking. The economic agent's problem thus changes from maximizing expected utility to maximizing *subjective* expected utility. Here is where problems begin.

First, decision-makers may be unable to assign subjective probabilities to the costs of species extinction. Biological and ecological sciences are not up to the task of delineating the structural and functional role of a given species within an ecosystem context (Norton 1987). Without such knowledge the possible instrumental value of a species to the production of goods and services cannot be forecast. Further, analysts generally are not well able to predict the course of technological change, yet the value of biodiversity may hinge critically on future developments in biotechnology. This suggests that the subjective expected utility hypothesis may place cognitive demands on decision-makers that simply cannot be met.

What are the alternatives? One option is to view problems of pure uncertainty as games against nature. Not long after publication of the seminal work on game theory of von Neumann and Morgenstern (1944), several researchers considered game theoretic approaches for problems where probabilities are lacking. Luce and Raiffa (1957) provided an overview of this literature. Writing in the late 1940's and early 1950's, Wantrup's adopted this framework for tackling problems of resource management (Ciriacy-Wantrup 1968, p.89):

It [the SMS] may be regarded as the conceptual relative of the min-max solution or saddle-point in a two-person, strictly determined game ... —as "man playing against nature" in an almost literal sense.

This theme was repeated often in Wantrup's writings[13] and carried over into Bishop's work on the SMS as well. In turning to game theory Wantrup, and later Bishop (1978), rejected of the probabilistic approach to uncertainty. The theory of games against nature pointed toward strategies that maximize the minimum gain. This is the "maximin" strategy or, equivalently the "minimax losses" strategy (i.e., the strategy that minimizes maximum possible losses).

This tack subjected the SMS to the more general criticism that maximin strategies in games against nature are excessively pessimistic (Luce and Raiffa 1957). The theory of games against nature assumes

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13) For example, writing about the California tule elk, a threatened subspecies of wapiti, Ciriacy-Wantrup and Phillips (1985, p. 238) explained,

... the objectives of conservation policy—and of many other public policies—can often be compared with the objectives of an insurance policy against serious losses that resist quantitative measurement. Here the objective is not to maximize a definite quantitative net gain but to choose premium payments and benefits in such a way that maximum possible losses are minimized. As a special case of this strategy, a "safe minimum standard" of conservation, specified in such a way that maximum possible future losses are minimized, is frequently a valid and relevant objective of policy.

that nature, as a player in a zero-sum game, maximizes its return by doing the human opponent as much harm as possible. Nature may do us harm to be sure, but surely it is not actively out to get us (Tisdell, 1990). So a maximin-based SMS may be overly defensive. Conceptually, it would dictate choosing to preserve a species so long as the costs of doing so are one dollar less than the worst conceivable loss from extinction.

Other alternatives to subjective expected utility maximization, which are not grounded in games against nature, have flourished. As Kelsey and Quiggin's (1992) excellent review of the literature shows, maximin and maximin-like strategies continue to attract attention. The motivation for such strategies stems from consonance with empirical behavior and from common intuition regarding reasonable responses to decision problems marked by inadequate or nonexistent probability distributions.

The paper by Arrow and Hurwicz (1972) is a notable example. They consider the problem of making decisions when the decision-maker is cognitively unwilling to place subjective probabilities on events. (This is the problem we referred to earlier as pure uncertainty.) Proponents of probabilistic approaches urge that decision-makers apply the Principle of Insufficient Reason, which dates to Bernoulli, regardless of squeamishness they might feel about assigning probabilities. This principle suggests that, when information is lacking as to which event is more likely, decision-makers should place equal probabilities on all events. The inverse of the number of events becomes the probability of each event. But this principle may actually make little sense. The difficulty comes when we notice that, in the real world, the number of events cannot be uniquely defined.

Suppose, for example, that a proposed dam project has the potential to wipe out a species of fish that lives downstream. Downstream water temperatures will change as a result of the dam and this fish is known to respond discontinuously to changes in water temperature: above a threshold it will do fine but below the threshold it will be unable to spawn and, all else equal, it will become extinct. Although the dam is expected to lower water temperatures to within the vicinity of the threshold, empirical data and hydrologic theory simply cannot offer the precision necessary to predict whether water temperatures will fall below the threshold. Let us assume that the issue is further clouded by the fact that sedimentation rates will also be altered and this may (or may not) make new spawning habitats available downstream where the water will be warmer. Whether the new habitat will be created and whether the fish will adapt is also not known. Thus we assume that there is no basis to assign even subjective probabilities to water temperatures and new habitat creation.

One way to frame this problem is to say that there are two future events that could transpire as a result of the dam, extinction and survival. Applying the Principle of Insufficient Reason, the analyst would assign probabilities of _ to each of these events. The other is to say that there are three different events, extinction, survival because the water temperature remains above the threshold, and survival because of new habitat that the fish can use. Now the Principle of Insufficient Reason points toward assigning a probability of 1/3 to extinction and 2/3 to survival. Which probabilities are to be used? The choice seems arbitrary. We have simply described the same situation in two different ways. That the probabilities differ raises disturbing questions about whether the probabilities can meaningfully be assigned once pure uncertainty is admitted.

Arrow and Hurwicz propose a framework for conditions of pure uncertainty that avoids such intuitively peculiar positions. They propose four axioms of rationality that seem sensible,[14] and derive some interesting conclusions.[15] In particular, they find that the rational decision-maker would make choices based entirely on extreme outcomes. The maximin and the maximax are examples. While the axioms were not sufficient to declare any one of these criteria superior to the others, the conclusion that the maximin is among the rational approaches would seem to counterbalance fears that the maximin is "irrationally conservative".

In a similar vein, Gilboa and Schmeidler (1989), Kelsey (1993), and other writers have worked to characterize rational decision making under conditions sometimes referred to as "second-order uncertainty." Here decision-makers do have some information about uncertain events. They hold subjective probabilities, but feel uncertain about them. Such uncertainty is manifest whenever one is tempted to say that the probability of event A is, say, "between 40 and 60 percent".

14) As they put it (p. 1), they sought conditions for rational choice where "there is no *a priori* information available giving any state of nature a distinguished position."

15) For further discussion see Woodward and Bishop (1997).

Work on second-order uncertainty has tended to focus on providing an axiomatic basis for rational (that is, consistent) decisions. Slightly different axiomatic structures have been proposed, but the decision rules that emerge are analogous to the maximin and will be referred to here as "maximin-like strategies."

Woodward and Bishop (1997, p. 506), after considering literature on pure uncertainty and second-order uncertainty, urge environmental economists

[T]o reassess our marriage to the probabilistic structure of the expected utility hypothesis. The literature on choice under pure uncertainty shows that the ability to formulate the outcomes in terms of probabilities is not a necessary condition for rationality. In fact, if the decision-maker does not possess well-defined probabilities, then the use of ad hoc probabilities may not be rational. Policy advice built on the assumption of probabilities, therefore, may be misguided.

For them, the success of maximin and maximin-like strategies in meeting rationality axioms is clear support for the SMS.

Though concepts such as pure uncertainty and second-order uncertainty, where states of the world and associated payoffs are assumed to be known, are quite useful for theoretical purposes, we believe that environmental economists would do well to go beyond them in seeking strategies to address environmental issues. As we seek alternatives to the probabilistic approach, it is worth reminding ourselves that such concepts as pure uncertainty and second-order uncertainty lack realism. This is where our concept of nescience enters the picture.

Decision Making Under Nescience

Like other concepts of knowledge, nescience needs to be defined in terms of what is known about states of the world and probabilities. Under nescience, not all possible future states of the world may be known. Surprises can happen and decision-makers know it.[16] This

16) We have in mind here a concept that has much in common with the way Shackle (1961, p. 7) defined uncertainty. "We do not confine uncertainty to the mere existence in the decision maker's mind of plural hypotheses of the outcome of some available act, if such plural hypotheses are understood to compose a list known to be complete.

comes closer to describing the situation faced by real world decision-makers who confront choices about endangered species. We know on a general level that species contribute to life support and the reservoir of potential future resources, but the specifics are vague at best. Species may turn out to be resources or serve life-support functions in ways that we today would find surprising. Taxol from the Pacific yew, penicillin from a mold, and digitalis from foxgloves must all have been totally unanticipated at some point not long before their discovery. That a seemingly worthless endangered species might hold totally unanticipated treasures is plausible.

Furthermore, even for known states of the world, a mind-boggling list of questions confronts the analyst who would calculate payoffs for preservation and extinction alternatives. We may know, for example, that a certain species could hold the cure for some form of cancer, but much more would be needed before a payoff or even a range of payoffs could be assigned to that outcome. When would the cure be developed? What will be the frequency of the particular form of cancer at that time and thereafter? What sorts of substitute treatments will become available over time? How large will incomes be in the future? How will tastes and preferences for health care evolve? The analyst who must consider such questions over decades and centuries will find it hard to estimate payoffs convincingly.

As for probabilities, nescience—like pure uncertainty–assumes that probabilities are unknown. Given that nescience is designed to more closely approximate the knowledge-level of real world decision-makers, this assumption may seem extreme at first. It is plausible to suppose that a decision-maker might believe that major adverse repercussions from erosion of biodiversity seem unlikely over the next fifty years. Or, she might be willing to guess that plants in one group are more likely to become important resources than plants in another group. But to assign subjective probabilities to such feelings of likelihood with any rigor appears hopeless. The sum of the probabilities of known events would have to equal unity minus the probability of surprises. Yet how can one know the probability of surprises? By definition they involve unanticipated events the

For in the first place we claim that such knowledge is unattainable and cannot exist. But more relevantly we claim that the possible outcomes of any act do not, in general, constitute a limited and finite set such as would exist if we were concerned with a game with stated rules."

characteristics of which are unknown. Even if this problem can be overcome, calculating expected values would require information about payoffs that may not be available. So, nescience will assume that probabilities are unknown. How might decision-makers confronting nescience proceed?

In his version of the "precautionary principle," Perrings (1991) has probably gone as far as anyone toward addressing nescience as defined here. He recognized the possibility of surprises and proposed to address the problem in an interesting and novel way. Suppose a proposed action would generate uncertain environmental costs. To evaluate whether the action should be pursued, decision-makers applying Perrings' framework would begin by assessing how much historical experience and current scientific knowledge are available to be drawn upon. If history and science are sufficient to make decision-makers confident that outcomes, probabilities, and payoffs are well understood, traditional probabilistic methods would be used. If not all events can confidently be assigned a probability, however, decision makers would begin by establishing the so-called "focus loss" associated with an action.[17] An action's focus loss is determined when a decision-maker imagines the action's set of associated future states, and forms "an opinion on nonprobabilistic grounds about the degree of disbelief they would have in the occurrence of each." (Perrings, pp.160-161) Degrees of disbelief are based on how surprised the decision-maker would be if the future state turns out to be true. An action's focus loss is then defined as the largest loss resulting from an associated future state that is "believable". Costs of a proposed action would be calculated by summing its focus loss (if any) with its *expected* costs, where the expectation is taken using probabilities placed on those events for which probabilities may be meaningfully assigned.[18]

17) See also Shackle (1961).

18 To illustrate how costs would be determined under the precautionary principle, suppose a factory is proposed at a site where it would affect water quality in a particular river. Suppose further that recreational fishing will be affected. Within Perrings' framework, if decision-makers felt confident, based on past experience, that the possible effects on fishing would be either trivial or predictable to a satisfactory degree, costs there would be calculated as expected values. Suppose, though, that the increase in pollution will also cause the demise of an endangered aquatic species. Suppose scientists have learned that this species may hold clues for cancer treatment. (This is not so farfetched. For example, North American freshwater clams, some of which are endangered, have attracted the attention of researchers because they rarely

Total environmental costs could then be compared to the benefits of the action under consideration.

The precautionary principle merits attention as one of the first steps toward addressing nescience. However, as a fully workable approach, it has some shortcomings. For one, payoffs are needed if costs, as just defined, are to be calculated. Under nescience, as we have seen, calculating payoffs can be problematical. Even if this problem can be overcome, we find Perrings' way of approaching surprise unconvincing. Though we did not highlight it in our summary, changing information over time is central to Perrings' thinking. The list of outcomes decision-makers would find surprising and the degree of surprise that would be associated with any one outcome are likely to change as the future unfolds, a point that Perrings explicitly recognized. Knowing this, would a sensible decision-maker act on the basis of costs calculated in the way Perrings prescribes? Or would such a decision-maker try to make allowances for the possibility that what seems plausible may change dramatically in the future? Basing decisions on what today seems "plausible" would seem to lead too little emphasis on choices that avoid irreversibility.

Thus, going only on the basis of intuition, functioning in a nescient world would require that alternatives with irreversible, potentially surprising consequences of large magnitude be approached with caution. Where nasty payoffs, either from known outcomes or surprises, are possible, safety-first seems like a sensible course. This intuition is reinforced by the literature just reviewed. Moving from risk to pure uncertainty, second-order uncertainty, and now the precautionary principle repeatedly focused attention on maximin and maximin-like strategies.[19] Such strategies are designed to cope with extreme adverse outcomes. Surely moving on toward nescience would not involve a relapse toward probabilistic approaches.

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have cancer. The same is true for North American alligators.) Decision-makers find the evidence for this possibility to be compelling, but worry that there are insufficient historical precedents to assess with confidence the probability that cancer treatments will actually be found if the species is preserved. If loss of cancer treatments is the worst possible loss from extinction that decision-makers deem plausible, then the focus loss is the value of the potential cancer cures. Perrings would calculate costs as the expected value of recreational effects plus the focus loss from extinction of the species.

19) We include the precautionary principle under maximin-like strategies because the focus loss is equal to the worst plausible loss.

At the same time, maximin and maximin-like strategies are probably not fully applicable to nescience either. All such strategies presume that the state space is well defined, whereas nescience allows wholly unexpected events to transpire. Allowing the most terrible consequence that anyone can conceive of to dominate choices – as the maximin would tend to do – is probably not a sufficient foundation for making choices. New approaches are in order if nescience is to be effectively addressed.

Perhaps a normative theory of bounded rationality is needed. Consider Simon's (1957 p. 198) starting points for his theory of bounded rationality:

The capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behavior in the real world—or even for a reasonable approximation of such objective rationality.

Thus, according to Simon (1957 p. 199), an actor who wants to make a rational choice must inevitably construct "a simplified model of the real situation in order to deal with it." One response to the need to simplify is to apply rules of thumb. Simon sought to predict human behavior by studying how the "simplified model" was constructed, assuming that people act rationally within its bounds. Such models may seem arbitrary when judged against standard models of economic optimizing, but rules of thumb may be rational in the context of lack of complete information, limited time to research alternatives, and people's limited abilities to organize and digest information.

Our goal is different from Simon's. His was a *positive* theory of human behavior. He was interested in "the fact that there *are* practical limits to human rationality, and that these limits are not static, but depend upon the organizational environment in which the individual's decision takes place." (Simon 1957, pp. 240-241, emphasis added) We are searching here for a *normative* theory of how people ought to reasonably make choices under nescience when endangered species and other such problems confront them. If human rationality is bounded in Simon's organizational environments, how much more limited are the grounds for deciding whether to preserve endangered species. We face profound limitations imposed by the unpredictability of natural and social variables over long spans of time and the current primitive state of science in the face of nature's huge complexities.

How might rational social decision-makers encumbered by their human limitations confront choices involving endangered species? Future progress toward a theory of decision making under nescience should help address this question. In the meantime, we wonder whether such a decision-maker would adopt the SMS as a rule of thumb. Routine day-to-day business could be carried on using ordinary tools of economics. Markets could be allowed to allocate resources with necessary corrections by government, informed as needed by benefit-cost analysis. However, this process would be bounded by the SMS whenever routine activities threaten a species' survival. We have come full circle and arrived back at Bishop's rule of "preserve unless the costs are judged excessive", to the second tier in Norton and Toman's decision framework, and Randall and Farmer's extraordinary decision process.

Conclusions

We set out to review and augment the case for making the SMS an integral part of environmental economics. Surely those in the mainstream cannot object to the use of the SMS as a soft constraint. SMS advocates are not imposing a rigid "standard" on economic choices, but are responding to the widely held view that fairness to future generations ought to be an important objective of environmental policy. If society at large holds such an objective, surely economists should do what they can to help explore its implications.

Admittedly, going the extra step of advocating the SMS as a full-fledged objective of endangered species policy is more controversial. Those in the mainstream are not likely to give up probabilistic approaches without a fight. Still we have shown that those advocating the SMS are not alone in distrusting probabilistic approaches. There is a continuing undercurrent of doubt in economics about the potency of expected utility maximization where there is not enough information to form complete objective or subjective probability distributions, to estimate payoffs, and perhaps even to envision complete sets of outcomes for alternative actions. In dealing with some of economics' most long-term issues, we environmental economists ignore this branch of the literature at our peril. It matters little whether the solutions we ultimately find are rooted in the SMS, the precautionary principle, or some new as yet undiscovered concept. But it matters a great deal that we begin to ask the right questions. Complacently assuming that probabilistic strategies are satisfactory, or even the best that can be done, means disciplinary stagnation in a world that badly needs to come to grips with nescience.

Progress is needed in two directions. We have only scratched the surface when it comes to a theory of decision making under nescience; indeed, we have really only described the problem. Perhaps further work from the perspective of bounded rationality will help. Work on evolutionary games may offer insights. And the increasing power of computers suggests that simulation exercises may prove useful for investigating the *ex post* consequences of different decision rules when applied to problems of nescience. While the theoretical challenges are formidable, progress in addressing real world problems requires concerted effort.

Beyond that, SMS advocates need to adapt the concept to better fit situations other than species extinction. Species are particularly adaptable to the SMS as Wantrup conceived of it because of the extinction threshold. For practical purposes there is little oversimplification in assuming that a species either is or is not extinct. But species diversity is only one of the levels of biological diversity. How the SMS might be defined for genetic diversity within species and for diversity of communities and ecosystems has not been worked out. The problems are magnified when the analyst turns to other environmental problems such as global warming, ozone depletion, contamination of groundwater, etc. What would it mean to maintain the SMS for each of these resources? What sorts of strategies are available to achieve an SMS once it is defined? General misgivings about our current course of conduct, platitudes about safety-first, and sympathetic feeling toward future generations will not convince those in the mainstream that the SMS concept is worth their attention. It will be necessary to get down to the specifics across a wide range of issues.

References

Arrow, Kenneth J., and Leonid Hurwicz. 1972. An Optimality Criterion for Decision-Making Under Ignorance. In *Uncertainty and Expectations in Economics: Essays in Honour of G.L.S. Shackle,* ed. C.F. Carter and J.L. Ford. Oxford: Basil Blackwell.

Bishop, Richard C. 1978. Endangered Species and Uncertainty: The Economics of a Safe Minimum Standard. *American Journal of Agricultural Economics* 60 (1):10-18.

Bogert, G. G., and G. T. Bogert. 1993. *The Law of Trusts and Trustees: A Treatise Covering the Law Relating to Trusts and Allied Subjects Affecting Trust Creation and Administration.* St. Paul, Minn: West Publishing. 22 v.

Bogert, G. T. 1987. *Trusts.* 6th edition. St. Paul, Minn: West Publishing.

Brown, Gardner M., Jr., and Joseph Swierzbinski. 1988. Optimal Genetic Resources in the Context of Asymmetric Public Goods. *Environmental Resources and Applied Welfare Economics: Essays in Honor of John V. Krutilla.* Edited by V. Kerry Smith. Washington D.C.: Resources for the Future, Inc., pages 91-118.

Castle, Emery N., and Robert P. Berrens. 1993. Endangered Species, Economic Analysis, and the Safe Minimum Standard. *Northwest Environmental Journal* 9:108-130.

Ciriacy-Wantrup, S.V. 1985a. The "New" Competition for Land and Some Implications for Public Policy. In *Natural Resource Economics: Selected Papers.* Edited by Richard C. Bishop and Stephen O. Andersen, Boulder, Colo. and London: Westview Press, pages 247-59. Previously published: *Natural Resource Journal* 4:252-267 (1964).

Ciriacy-Wantrup, S.V. 1985b. Water Quality: A Problem for the Economist. In *Natural Resource Economics: Selected Papers.* Edited by Richard C. Bishop and Stephen O. Andersen. Boulder, CO and London: Westview Press, pages 231-46. Previously published: *Journal of Farm Economics* XLIII(5): 1133-1144 (1961).

Ciriacy-Wantrup, S.V. 1968. *Resource Conservation: Economics and Policies.* 3rd ed. Berkeley: University of California, Division of Agricultural Sciences, Agricultural Experiment Station.

Ciriacy-Wantrup, S.V., and William E. Phillips. 1985. Conservation of the California Tule Elk: A Socioeconomic Study of a Survival Problem. In *Natural Resource Economics: Selected Papers.* Edited by Richard C. Bishop and Stephen O. Andersen, Boulder, Colo. and London: Westview Press, pages 231-46. Previously published: *Biological Conservation* 3(1): 23-32 (1970).

Costanza, Robert, John Cumberland, Herman Daly, Robert Goodland, and Richard Norgaard. 1997. *An Introduction to Ecological Economics.* Boca Raton, FL.: St. Lucie Press.

Craft, Amy B., and R. David Simpson. 1999. The Value of Biodiversity in Pharmaceutical Research with Differentiated Products. Unpublished Paper, Resources for the Future, Washington, D.C.

Daly, H., and J. Cobb. 1989. *For the Common Good*. Boston: Beacon Press.

Dixit, Avinash, and Joseph Stiglitz. 1977. Monopolistic Competition and Optimum Product Diversity. *American Economic Review* 67:297-308.

Farmer, Michael C., and Alan Randall. 1998. The Rationality of a Safe Minimum Standard. *Land Economics* 74 (3):287-302.

Fisher, Anthony C., and W. Michael Hanemann. 1987. Option Value and Extinction of Species. In *Advances in Applied Microeconomics*, Vol. 4. Edited by V. Kerry Smith, Greenwich, CT: JAI Press.

Gilboa, Itzhak, and David Schmeidler. 1989. Maxmin Expected Utility with Non-unique Prior. *Journal of Mathematical Economics*. 18(2): 141-53.

Gowdy, John, and Sabine O'Hara. 1995. *Economic Theory for Environmentalists*. Delray Beach, FL: St. Lucie Press.

Hanemann, W. Michael. 1988. Economics and the Preservation of Biodiversity. *Biodiversity*. Edited by E. O. Wilson. Washington, D.C.: National Academy Press.

Hanley, Nick, Jason F. Shogren, and Ben White. 1997. *Environmental Economics: In Theory and Practice*. New York: Oxford University Press.

Howe, Charles W. 1979. *Natural Resource Economics : Issues, Analysis, and Policy*. New York: Wiley.

Kahneman, D., and A. Tversky. 1979. Prospect Theory: An Analysis of Decision under Risk. *Econometrica* 47 (2):263-291.

Kelsey, David. 1993. Choice Under Partial Uncertainty. *International Economic Review* 34 (2): 297-308.

Kelsey, David, and John Quiggin. 1992. Theories of Choice Under Ignorance and Uncertainty. *Journal of Economic Surveys* 6 (2):133-53.

Knight, Frank H. 1921. *Risk, Uncertainty and Profit*. Boston: Houghton, Mifflin Co.

Krutilla, J.V., and Anthony C. Fisher. 1975. *The Economics of National Environments: Studies in the Valuation of Commodity and Amenity Resources*. Baltimore: John Hopkins Press.

Luce, R. Duncan, and Howard Raiffa. 1957.*Games and Decisions: Introduction and Critical Survey*. New York, Wiley

Norton, Bryan G. 1987. *Why Preserve Natural Variety?* Princeton, NJ: Princeton University Press.

Norton, Bryan G., and Michael A. Toman. 1997. Sustainability: Ecological and Economic Perspectives. *Land Economics* 73 (4): 553-568.

Pearce, David, and Giles Atkinson. 1998. Concept of Sustainable Development: An Evaluation of Its Usefulness 10 Years after Brundtland. *Environmental Economics and Policy Studies* 1(2): 95-111.

Pearce, David W., and R. Kerry Turner. 1990. *Economics of Natural Resources and the Environment*. New York and London: Harvester Wheatsheaf.

Perrings, Charles. 1991. Reserved Rationality and the Precautionary Principle: Technological Change, Time and Uncertainty in Environmental Decision Making. In *Ecological Economics: The Science and Management of Sustainability*. Edited by Robert Costanza. New York: Columbia University Press, pp. 152-167.

Perrings, Charles, Carl Folke, and Karl-Göran Mäler. 1992. The Ecology and Economics of Biodiversity Loss: The Research Agenda. *Ambio* 21(3):201-211.

Portney, Paul R., and John P. Weyant, Editors. 1999. *Discounting and Intergenerational Equity*. Washington, D. C.: Resources for the Future.

Randall, Alan, and Michael. C. Farmer. 1995. Benefits, Costs, and the Safe Minimum Standard of Conservation. In *The Handbook of Environmental Economics*. Edited by Daniel W. Bromley. Cambridge, UK: Blackwell.

Rolfe, J.C., 1995. Ulysses Revisited—A Closer Look at the Safe Minimum Standard Rule. *Australian Journal of Agricultural Economics* 39 (1): 55-70.

Salop, Stephen. 1979. Monopolistic Competition with Outside Goods. *Bell Journal of Economics* 10:141-156,

Scott, Antony. 1999. Trust Law, Sustainability, and Responsible Action. *Ecological Economics*. In press.

Shackle, G.L.S. 1961. *Decision, Order, and Time in Human Affairs*. Cambridge, UK: Cambridge University Press.

Simon, Herbert. 1957. *Models of Man*. New York: Wiley.

Simpson, R. David, and Amy B. Craft. 1996. The Social Value of Using Biodiversity in New Pharmaceutical Product Research. Discussion Paper 96-33, Resources for the Future, Washington, D.C.

Tisdell, Clem. 1990. Economics and the Debate About Preservation of Species, Crop Varieties and Genetic Diversity. *Ecological Economics* 2: 77-90.

van Kooten, G. C. 1993. *Land Resource Economics and Sustainable Development: Economic Policies and the Common Good*. Vancouver: UBC Press.

von Neumann, Johann, and Oskar Morgenstern. 1944. *Theory of Games and Economic Behavior*. Princeton, NJ: Princeton University Press.

Woodward, Richard T., and Richard C. Bishop. 1997. Uncertainty-Based Choice Rules in Environmental Policy. *Land Economics* 73 (4):492-507.

Woodward, Richard T., and Richard C. Bishop. 1995. Efficiency, Sustainability and Global Warming. *Ecological Economics* 14(2): 101-11.