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# Conserving biodiversity using risk management: hoax or hope?

Susan Hummel<sup>1\*</sup>, Geoffrey H Donovan<sup>1</sup>, Thomas A Spies<sup>2</sup>, and Miles A Hemstrom<sup>1</sup>

Biodiversity has been called a form of ecosystem insurance. According to the “insurance hypothesis”, the presence of many species protects against system decline, because built-in redundancies guarantee that some species will maintain key functions even if others fail. The hypothesis might have merit, but calling it “insurance” promotes an ambiguous understanding of risk management strategies and underlying theories of risk. Instead, such redundancy suggests a strategy of diversification. A clearer understanding of risk includes comprehending the important distinction between risk assessment and risk management, acknowledging the existence of undiversifiable risk, and recognizing that risk and uncertainty are not synonymous. A better grasp of risk management will help anyone interested in assessing the merits of different biodiversity conservation strategies. At stake is the adequacy of conservation strategies for mitigating human-caused biodiversity losses.

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Uncertainty is intrinsic to the human experience and its consequences have been pondered by philosophers, artists, and scholars for centuries. Over time, their observations have informed considerable research on the topic, including the economic theories of risk that underlie many public policy decisions (Kahneman and Tversky 1979). Entire industries, such as banking, gambling, and insurance, draw on these theories, and an extensive literature exists on the subject of managing risk.

Despite its established history, ecologists are borrowing terms from risk management and using them imprecisely. This practice adds to existing confusion over the meaning of risk in conservation. Here, we scrutinize risk management, a process that uses risk assessment results in strategic decision making, and consider its role in mitigating human-caused biodiversity losses. We explain the flaws in the statement, “biodiversity may provide natural risk insurance to ecosystem managers and investors” (Koellner and Schmitz 2006), and argue that the “insurance hypoth-

esis” (Yachi and Loreau 1999) is ambiguously named. The confusion is not just semantic: it can undermine the development of effective conservation strategies. A weak grasp of risk management and its underlying theories means tough decisions might be sidestepped, thereby inducing unacceptable losses. With the aim of explaining how this could happen, we begin with some basics about risk before we turn to what they imply for conservation.

## *Probabilities and outcomes distinguish risk from uncertainty*

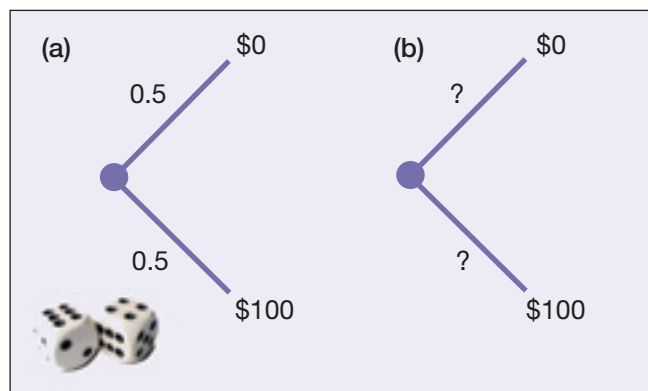
In everyday speech, we often mention risk as something to avoid (eg the risk of flu, at the risk of sounding stupid). It therefore seems inherently bad. For example, in a comprehensive book on risk assessment for conservation, Burgman (2005) defines risk as “the chance, within a time frame, of an adverse event with specific consequences”. In economic theory, however, the outcome of a risky decision can be good or bad; the existence of risk means only that we do not know the outcome with certainty (Bannock *et al.* 1979). Acknowledging that risk can be both positive and negative is vital for using risk assessment results to accomplish an objective. Consider playing poker or investing in the stock market; you might receive a windfall or you could lose your life savings. How you feel about the uncertainty associated with a given decision – and what you think of the possible outcomes – influences the choices you make. Collectively, our individual choices can influence public policy.

The theoretical language of risk can be daunting. Nevertheless, it is important for ecologists to become familiar with some key concepts and, thus, to gain insight into the limitations and opportunities for conservation associated with different risk management strategies.

### **In a nutshell:**

- Risk assessment and risk management are not the same; risk assessment is a process for estimating the probability and frequency of an event while risk management identifies an acceptable level of risk and minimizes exposure to unwanted risk using methods of control or transfer
- The “insurance hypothesis” of biological redundancy is poorly named, as insurance is a management strategy for transferring risk, while redundancy controls risk through diversification
- Diversification cannot eliminate all risk

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**Figure 1.** (a) Risky decisions have known outcomes (here, \$0 or \$100) with known probabilities. (b) In contrast, uncertainty means that the probabilities of the outcomes are unknown.

One key concept is risk aversion (Nicholson 1995). People differ in their comfort level with making decisions under conditions of uncertainty, yet studies of human behavior reveal common tendencies. Economists have long observed that people are more likely to accept a smaller gain with certainty than a larger expected gain with uncertainty; you are more likely to accept a guaranteed \$100 than risk losing it by taking a double-or-nothing bet. With losses, the opposite is true. It may seem counterintuitive, but people are more likely to accept a bigger loss with certainty than a smaller expected loss with uncertainty. An added twist is that most people have difficulty estimating probabilities (Tversky and Kahneman 1981). In general, we overestimate the probability of unlikely events and underestimate the probability of likely ones (Lichtenstein *et al.* 1978). If aversion to risk and uncertainty were not a prevailing human tendency, insurance companies would not be in business. This is not to say that risk aversion is irrational, merely that it can be observed and measured as an expression of individual preference. Avoiding uncertain situations is a powerful motivator, particularly if the outcome might be bad. Of course, an outcome that seems negative to one person might be bearable to someone else, which is why insurance policies are available to cover different events.

Another key concept is that uncertainty and risk differ from each other. In economic theory, an uncertain decision has a known number of outcomes, but the probability of each outcome is unknown. In contrast, risky decisions have known outcomes with known probabilities, like the roll of dice. In other words, uncertainty indicates that the probabilities of outcomes are unknown, whereas risk indicates the probabilities are known (Bannock *et al.* 1979; Figure 1). The distinction is important because, in ecology, the probabilities of events are often unknown and outcomes may change in ways that are not easily predictable, especially at varying spatial or temporal scales. A further complication is that all possible outcomes – and the probability of the occurrence of each – might not be known. This situation is addressed in the literature on surprise and ignorance (see Haynes and Cleaves 1999).

The probability of a particular event and the severity of its associated outcomes can be estimated by a process called either risk analysis or risk assessment. The first term is often used by industries (eg insurance) in which outcomes are expressed in money, whereas the second is more prevalent in sectors (eg public health) that use other units. The important distinction is not between the two terms, but between the probability of an outcome and the outcome itself. We emphasize this distinction because it underscores the potential limitations in using risk management for biodiversity conservation and the reasons to stop calling biodiversity a form of insurance.

### What is insurance?

Insurance is a risk management strategy that does not change the probability of an event; it remedies the outcome. For example, a life insurance company consults a mortality table to estimate the probability of your death at different ages and uses this to calculate the premium you must pay to obtain coverage. Mortality tables are built from population death statistics. Rather than asking, “What is the probability of my death?” as you consider life insurance, you are no doubt asking, “What would be the impact of my premature death?” A primary wage earner might buy life insurance because the impact of early death will be loss of income for the family. Nevertheless, in purchasing insurance, you do not change the probability of the event. Instead, you soften the outcome for your dependants if you do die young. In contrast, changing the statistical probability of your death (lowering it by healthful measures or increasing it by aging) alters the formula used to calculate your premium. This reflects the changed probability that your insurer will have to pay on your policy.

The same logic holds for other types of insurance. The probability of your house burning down might be low, but if it does happen, a claim check would assist in rebuilding it. The concept of risk aversion explains why you will bear the certain loss of your premium against the uncertain loss of your house. Insurance companies will gamble on you because they reduce their own odds of loss by pooling them across a population of customers. Companies generally specialize in insuring events that have a low probability of occurring, but against which many people are risk averse: catastrophic illness, homelessness, premature death. For some people and in some places, insurance is not available, because the probability of the event happening is too high. If the probability of an outcome is unknown and the outcome cannot be priced, then the event is not insurable.

### Agreement about biodiversity does not exist

Biodiversity has different meanings (eg Mayer 2006; Figure 2). It can be a non-quantifiable expression of the total variety of life at many levels of biological classifica-

tion. It can also be quantified in measures or indices that partially express biological variation, such as species richness or abundance. We limit ourselves here to quantifiable measures, which are essential for risk assessment (eg Kerns and Agar 2007), itself a necessary (but not sufficient) step in developing risk management strategies to conserve biodiversity.

The existence of debate over the definition of biodiversity does not detract from our main point, namely that those who wish to conserve biodiversity will benefit from delving into the multi-disciplinary literature on risk and uncertainty. An open-ended question in ecology is the extent to which established methods of risk management can be applied when conditions that fulfill theoretical definitions of risk are rarely observed in natural systems.

#### ■ Risk cannot be eliminated, but it can be managed

##### *Minimizing exposure to loss*

Decisions are guided by our perception of the likely outcome from a given choice and our personal level of aversion to risk and uncertainty. This is evident when we contemplate the future with questions such as: Should I attend a family reunion instead of a professional meeting and, either way, should I fly or drive? Given a seemingly universal penchant to avoid risk and uncertainty, over time humans have devised some ingenious ways to live with it, to convince somebody else to shoulder part of it, and to reduce it.

The process of figuring out how to bear some acceptable level of risk and to minimize exposure to unwanted risk is called risk management. This process can be accomplished by various methods, which are grouped into two general categories: “control” and “transfer” (Figure 3). Control implies that risk is retained, while transfer means it has been shifted elsewhere (DOT 1990). Methods of control include (1) avoiding high-risk activities, (2) hedging by undertaking an offsetting risk, and (3) diversifying by not putting all of your eggs in one basket. The main method of transfer is insurance.

Risk management strategies are used on Wall Street, in retirement savings, and in conservation. Depending on the level of biological organization targeted (eg genes, species, ecosystems), various conservation strategies manage risk dif-

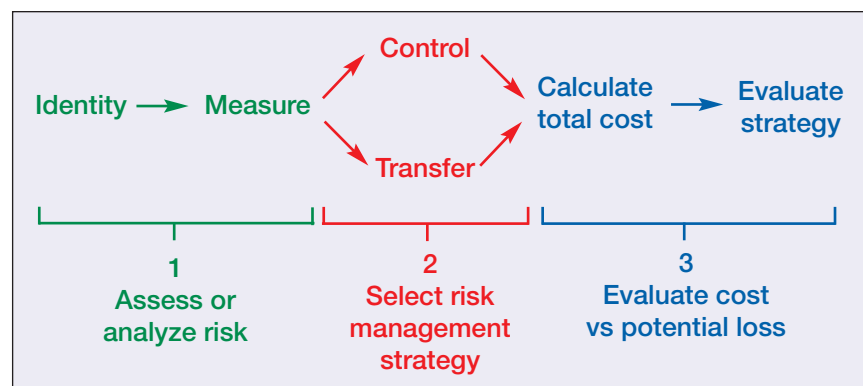


**Figure 2.** As portrayed in this artwork, the concept of biodiversity can be expressed in many ways. The multiple scales (eg taxonomic, geographic) over which biodiversity is defined complicate using risk management strategies in conservation.

ferently (Figure 4). For example, a hedging strategy is used in breeding programs that leave some individuals in the wild while removing others to controlled settings, such as zoos. Conservation-area planning and gap analysis of “hotspots” (eg Kiester *et al.* 1996) are examples of a diversification strategy when sites are selected in a deliberate attempt to cover a range of ecosystem types. Not surprisingly, such strategies fall under the control category of risk management. The transfer category has evident shortcomings for biodiversity conservation, as we discuss next.

##### *Insurance does not change probabilities*

A contemporary proposition in the ecological literature suggests that biodiversity confers a sort of insurance in ecosystems. This idea, known as the “insurance hypothesis”, proposes that redundancy in ecosystems insures them



**Figure 3.** The process of risk management involves at least three steps. Management strategies include retaining and controlling risk using methods such as diversification or transferring risk using methods such as insurance.



**Figure 4.** Tagging green sea turtles (*Chelonia mydas*) can yield life history information useful for conservation decisions.

against functional declines. The presence of many species is theorized to guarantee that some species will maintain key functions even if others fail. For example, Loreau *et al.* (2003) suggest that “biodiversity acts as insurance for ecosystem functioning against temporal environmental change, because functional compensations among types provide enhanced and more predictable aggregate ecosystem properties”. Moore (2005) adds, “the insurance hypothesis holds that ecosystem diversity is a good thing, because diversity confers overall stability in the face of stressful conditions”.

Ecosystem redundancy might confer internal control on functional declines, but insurance is a misnomer. Ambiguity in the meaning of the term leads to confusion, if not a false sense of security. The notion of “natural risk insurance” (Koellner and Schmitz 2006) is problematic, because insurance: (1) is a financial strategy for managing risks that can be priced, such as the loss of timber value due to a hurricane (Holec and Hanewinkel 2006), (2) covers events whose outcomes and probabilities are known or can be estimated to an acceptable level of accuracy, and (3) is a strategy of transferring exposure to loss, rather than retaining and controlling it.

As a strategy for managing risk, insurance does not match the goal of conservation, which is to change the probability of loss. Furthermore, the human systems that created insurance as a risk management strategy rely on brokers and premiums and markets, which ecosystems do not have. There is no check in the mail to cover extinctions or dysfunctions. A different strategy is necessary to reduce human-caused biodiversity losses by altering the probability that they will occur.

#### ***Disturbance ecology offers a link***

A concept common in both risk assessment and in ecology is the importance of the frequency and magnitude of

an event with a specific outcome. In ecology, it is observable in disturbance regimes. Disturbance ecology therefore offers a link between risk management and conservation, because it provides information on the probability of events that could affect biodiversity. This common conceptual ground is promising, but there are at least two hurdles to the use of disturbance ecology in informing risk management for conservation: (1) the relationship between disturbance dynamics and biodiversity (eg McCann 2000; Moore 2005) and (2) the effects of scale on this relationship. We do not aspire to overcome these hurdles here. Our aim is to stimulate thought on the role of risk management in biodiversity conservation.

#### ***Managing biodiversity losses through diversification***

In contrast to insurance, diversification is a risk management strategy that alters the probabilities of outcomes. Modern portfolio theory (Markowitz 1952) is based on the concept that diversification can produce the same return for less risk. It assumes that investors in a portfolio share a common level of risk aversion. An investment fund comprised of government bonds, for example, will attract individuals who have a low tolerance for risk and prefer the security of highly probable, if modest, earnings. One of the main reasons for investing in a portfolio of stocks as opposed to a single stock is that if price fluctuations among the stocks in a portfolio are not perfectly, positively correlated, then the overall risk of a portfolio is lower than any of the individual stocks that make up that portfolio. If all else is equal, the lower the positive correlation among the stocks, the lower the portfolio’s risk.

Using portfolio theory to design biodiversity conservation strategies means looking for ways to reduce the overall probability of human-caused losses. It also means grappling with theoretical assumptions about the probability distributions of high-impact events (eg Taleb 2007) and agreeing on a common level of risk aversion. One application of portfolio theory (“bio-folio”) has been proposed as a way to manage risks to biodiversity (Figue 2004). It suggests that if genes, species, and ecosystems are assets, then risk can be pooled across a portfolio that contains them. Grasslands are used as an example by Koellner and Schmitz (2006) to analyze the bio-folio concept of treating species as assets in an ecosystem portfolio; their discussion holds at least two important messages about applying theories of risk management to ecology. Usefully, they remind us that (unlike between stocks and bonds) interactions can occur directly among species that influence overall ecosystem performance (Koellner and Schmitz

2006). Regrettably, the authors fail to make it clear that risk can be reduced, but it can never be completely eliminated. In economic theory, this is known as systematic or undiversifiable risk (Sharpe 1964).

■ **Risk cannot be diversified away, but it can be managed**

***Risk management in public policy***

An important implication of undiversifiable risk in public policy is that somebody has to decide the acceptable level of risk for any given outcome. A familiar case is public health. The Consumer Product Safety Commission, an independent agency in the US, is charged with “protecting the public from unreasonable risks of serious injury or death” ([www.cpsc.gov](http://www.cpsc.gov)). But what is unreasonable? Individuals may advocate a zero-risk policy, such as with permissible lead levels in school lunchboxes. After all, the rule-of-thumb “one-in-a-million” policy common in public health could still cause the death of thousands in a large enough population. In practice, true zero risk can only occur with suppression of the risk-causing activity, which can be costly, jeopardize civil liberties, and create unintended consequences. It might be impossible to reach zero risk, as with exposure to naturally occurring elements. Setting acceptable risk levels in public policy means that individual differences in risk aversion are subsumed into a collective level of risk that is often expressed as a standard (clean air) or a limit (highway speed). Such decisions require acting on information and estimates provided by risk assessment. Either the estimates take into account information on the number of individuals exposed (population risk) or they do not (individual risk).

It is not always clear who gets to decide what level of risk is acceptable in public policy. Such decisions can involve tough choices about “acceptable loss”. The concept of acceptable loss is illustrated by the risk management handbook of the US Department of the Army (DOA 1998). The Army formally adopted risk management in the early 1990s to reduce accidental deaths, which had outnumbered deaths from “enemy action” since the Vietnam War (Table 1).

No mention is made in the Army handbook of how many accidental deaths are permissible, but such an omission is not unique to the military. Open discussion of acceptable outcomes that include human death is generally taboo – whether it is mortality associated with food and workplace safety standards, public vaccination programs, or highway laws. The implied acceptable loss levels can often only be worked out with hindsight. Discussing acceptable loss is no less taboo when the death in question is non-human, yet using risk management for biodiversity conservation implies confronting the topic.

**Table 1. Battle and non-battle casualties (DOA 1998)**

Causes	World War II 1942–1945	Korea 1950–1953	Vietnam 1965–1972	Desert Shield/Storm 1990–1991
Accidents	56%	44%	54%	75%
Friendly fire	1%	1%	1%	5%
Enemy action	43%	55%	45%	20%

***Risk assessment and risk management differ***

Additional hurdles exist when using results from quantitative risk assessment to develop diversification strategies for managing risk to biodiversity. Two formidable ones include determining scale effects (eg taxonomic, spatial, temporal) and deciding on acceptable loss levels.

No agreement exists on what taxonomic level of biodiversity loss is most significant, how to measure it, or what weight to give different levels in different ecosystems. The species level predominates, in part because operational definitions of components above the species level – eg communities and ecosystems – are poorly defined, are not static, are open to flows of species and to disturbances, and vary with location and spatial scale (Orians 1993).

In addition, no agreement exists on how to rank the consequences of losses in biodiversity and no mechanism exists to determine what level is acceptable. A zero-risk policy makes little sense when we consider that extinction is part of natural selection and evolution. Unless knowledge from risk assessment is put into a framework that links the probabilities of outcomes with a way to evaluate and rank them, it will remain difficult to use diversification strategies thoughtfully and proactively in biodiversity conservation.

Until we can identify the probabilities of events affecting biodiversity, it will be difficult to design effective conservation strategies using risk management. Put another way, such strategies might be conceived with assumptions about frequency and severity of disturbance that: (1) assume potential outcomes are known, (2) might be wrong about frequency or severity of potential outcomes, or (3) might have been right for current or past conditions, but are influenced by changing drivers such as climate. Using probabilistic terms (stating the possible range of outcomes and estimating the likelihood of each occurring) leads directly to the problem identified by Thuiller (2007), namely that of recommending a particular course of action for particular circumstances. This revives the issue of determining acceptable loss levels.

***Undiversifiable risk and biodiversity conservation***

Diversification offers an opportunity to explicitly include spatial and temporal scale effects when designing management strategies that minimize exposure to unwanted risk.



**Figure 5.** Setting a price on species (here, red-osier dogwood [*Cornus sericea*]) in a market. Would establishment of ecosystem goods and services markets change the applicability of risk management strategies to biodiversity conservation?

While this is true both for investment and ecological portfolios, their respective time horizons can differ markedly. The taxonomic component in ecological portfolios further complicates identification and management of acceptable loss levels using diversification methods. In ecological portfolios, high levels of collective risk may be acceptable for well-represented ecosystems or species, whereas only low levels might be acceptable for rare or declining ones.

In the case of forest biodiversity, a landscape of continuous structure and composition may be at a higher risk from fire or disease than a patchier landscape. Looking at it another way, if a landscape is considered a portfolio, it is more difficult to diversify the portfolio when the landscape is continuous. At a regional level, the Northwest Forest Plan (USDA/USDOJ 1994) is an example of a conservation strategy that relies on diversification across land allocations to manage genetic, species, and ecosystem diversity and to reduce their exposure to loss. Nonetheless, human aversion to risk, together with the species emphasis of federal law, can create unwillingness to take actions that might harm a threatened species even if changing disturbance regimes imply greater system losses in the future. Lee and Irwin (2005) observed this behavior surrounding proposals for reducing fire severity in habitat occupied by spotted owls (*Strix occidentalis*). It illustrates risk aversion in biodiversity conservation: a bigger loss now (site-specific habitat loss and potential death of individual birds) is preferred over an uncertain but potentially smaller loss to a greater area of habitat or to a population.

### ■ Summary

Risk cannot be eliminated completely, but it can be managed. The risk management strategy of diversification offers the best hope for designing conservation strategies

that reduce the probability of human-influenced biodiversity losses. In contrast, the risk management strategy of insurance does not alter the probabilities of such losses.

Diversification could help moderate exposure to losses of biodiversity associated with uncertain or surprising events and processes, such as disturbance, climate change, invasive species, or changing land use. In contrast, if we rely on biodiversity to sustain ecosystem function, unacceptable exposure to loss could accrue, for at least two reasons. First, such a strategy assumes that sufficient funds will be spent to accomplish a collective goal of zero risk to biodiversity and, second, that the disturbance regimes mediating biodiversity do not change. Ample evidence exists to show that both these assumptions are false. A

potential result is that any investment that does occur might not be focused where loss can be demonstrably reduced. Clearly, varying social values are attached to different components of biodiversity and people weight them differently (Figure 5). Although consensus on the acceptability of different loss levels might be impossible to achieve, such weights already exist in public policy because resources are scarce.

We close with two questions: (1) which elements of risk theory and management apply to conservation and which do not and (2) would establishment of ecosystem goods and services markets change the applicability of risk management strategies to biodiversity conservation and, if so, how?

### ■ Acknowledgements

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