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Uncertainty in biodiversity science, policy and management: a conceptual overview

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Abstract

The protection of biodiversity is a complex societal, political and ultimately practical imperative of current global society. The imperative builds upon scientific knowledge on human dependence on the life-support systems of the Earth. This paper aims at introducing main types of uncertainty inherent in biodiversity science, policy and management, as an introduction to a companion paper summarizing practical experiences of scientists and scholars (Haila et al. 2014). Uncertainty is a cluster concept: the actual nature of uncertainty is inherently context-bound. We use semantic space as a conceptual device to identify key dimensions of uncertainty in the context of biodiversity protection; these relate to [i] data; [ii] proxies; [iii] concepts; [iv] policy and management; and [v] normative goals. Semantic space offers an analytic perspective for drawing critical distinctions between types of uncertainty, identifying fruitful resonances that help to cope with the uncertainties, and building up collaboration between different specialists to support mutual social learning.

Keywords

Uncertainty, biodiversity science, biodiversity management, biodiversity policy, semantic space, dimensions of uncertainty, social learning, learning cycle

Introduction

Uncertainty is an essential ingredient of science, manifested in all phases of conducting research, drawing conclusions, and putting the conclusions into societal practice (Funtowicz and Ravetz 1990). However, in biodiversity science uncertainty has been addressed mainly with a narrow focus on the precision of various numerical estimates. The Millennium Ecosystem Assessment (2005), for example, was an effort to come to grips with the global dimension of the loss of biodiversity. Somewhat paradoxically, though, the Millennium Assessment was made in such a generalized mood that uncertainty did not find a natural niche in the results. In Chapter 4, "Biodiversity", the report takes up uncertainty only in connection with estimates of species numbers. A similar lack of specificity is detectable in the important reviews published by *Nature* on the eve of the Rio+20 conference in early summer 2012 (Barnosky et al. 2012; Cardinale et al. 2012; Ehrlich et al. 2012). Every one of them mentions uncertainty as an important theme but in none of them is uncertainty specified except loosely in a contrast space between reliable knowledge vs. lack of knowledge.

This is insufficient. Biodiversity is such a multidimensional and complex issue that different sorts of uncertainties are inherent in many dimensions of the ecosystems themselves and of biodiversity research. Specifications are needed as to what, precisely, is uncertain, what is the reason for the uncertainty, and whether the uncertainty matters. Further below, we use the notion of semantic space to explore key aspects of uncertainty in the context of biodiversity science, policy and management (see also Haila et al. 2014).

Biodiversity is a knowledge intensive concept. The concept was conceived by biologists worried about the consequences of accelerating human-induced changes in the ecological conditions of the Earth; the story is well known (Wilson and Peter 1988; Takacs 1996; Haila 2012). Conservation biology originated as a new biological sub-discipline at the same time (Soulé 1985). The founding ethos is well-taken: there is no way to come to grips with the human ecological predicament without adequate knowledge basis. But this statement, of course, implies that the uncertainties of knowledge concerning biodiversity have to be analyzed seriously. The goal of policy relevance brings into the picture yet other dimensions of uncertainty that pertain to social and political implications of the knowledge produced.

Let us add a clarification on this point. There is nothing uncertain in the assertion that biological diversity is a critical feature of the life-support system of the Earth, to use Eugene P. Odum's phrase (Odum 1989). Neither is there any uncertainty on a general level that the increasing human encroachment on the Earth's ecosystems causes deterioration of biodiversity. But these general statements do not mean that any claim or prescription concerning biodiversity is valid. First of all, there is a discrepancy between the "bigness" of the issue and the level of detail needed to address it (Haila 2004). Another major dimension concerns the feasibility of policy recommendations that are offered to the society. As political scientist Giandomenico Majone stresses, the (in)feasibility of one or another policy goal is not a natural given. Drawing conclusions on what is feasible and what is not is a part of the research setting. In Majone's view, feasibility analysis aims at changing the conditions of feasibility (Majone 1989). There are no shortcuts: promoting a simplistic solution in a situation riddled with uncertainties may lead to unanticipated and counterproductive consequences (see also Mitchell 2009).

There is a deep ambiguity in the human ecological predicament: whatever we do we change the environment, and we cannot avoid also detrimental effects – in fact, we often do not know precisely, what is detrimental. Furthermore, what is detrimental in one set of conditions may be favourable in another set of conditions. Variability in mechanisms that maintain soil productivity provides examples: what works at one place may be positively harmful somewhere else. In other words, the relationship between generality and precision needs concern. The situation resembles that encountered in debates about climate policy (Pielke 2007, Hulme 2009), but it is also different in interesting ways. We will get back to this point below.

To chart the whole field, two round-table discussions were held at Helmholtz Centre for Environmental Research, UFZ, Leipzig, in autumn 2011 under the title *Exploring uncertainties in biodiversity science, policy and management.* The perspective was pragmatic: the aim was to produce an overview from a bottom-up perspective on how natural and social scientists involved in biodiversity research have come across uncertainty in their working practices and how they have coped with it. We dubbed the domain of the workshop *biodiversity praxis* (Haila et al. 2014).

The work of Silvio Funtowicz and Jerry Ravetz (1990, 1991) offered us basic inspiration while we made preparations for the workshops. A particularly useful part of their work is the distinction they draw between quantitative and qualitative aspects of uncertainty. They specify what kind of categories an assessment of the qualitative uncertainty of scientific information should take into account: "(F)or a general understanding, we have to distinguish among the technical, methodological, and epistemological levels of uncertainty; these correspond to inexactness, unreliability and "bordering on ignorance," respectively." (Funtowicz and Ravetz 1991).

For assessing different types of uncertainties in scientific knowledge Funtowicz and Ravetz (1990) developed a scheme that is known by the acronym NUSAP. This figured at the background of our project, and we were greatly helped by later systematic applications (van der Sluijs et al. 2005, 2008) but we refrained from organizing the discussion according to the scheme as we wanted to explore a more open-ended agenda.

In the paper that follows this introductory essay we present the materials of the first workshop, held on 3–4 November 2011. Most of the 18 participants were working within the auspices of the EU 7th framework project SCALES (*Securing the Conservation of Biodiversity across Administrative Levels and Spatial, Temporal and Administrative Scales*) (Henle et al. 2010), but the group was complemented with a few staff-members of the UFZ who brought into the discussion their specialized perspectives. The discussions were recorded and transcribed. The transcriptions were used to reconstruct main themes that came up during the workshop.

The SCALES project offered a promising framework for the endeavour. It is broad and ambitious enough to provide a good overview of themes for which uncertainty matters. Furthermore, the project addresses explicitly uncertainty in several research tasks. Another workshop was organized on 7–8 December. The compilation of papers collected in this special section of *Nature Conservation* includes, in addition to this introductory text, a thematic overview of the November workshop (Haila et al. 2014) and specific "standpoint" essays that were invited from the participants of both workshops. Magnusson (2014) discusses the uncertainties one has to deal with in the planning of in-situ monitoring programs from study design to data collection and analysis to management of programs and to linkages with stakeholders. He concludes that to be successful monitoring programs need to take these uncertainties into account already at the early conceptual stage. Pe'er et al. (2014) take up another attitude to uncertainty and elaborate upon the possibility that uncertainty could be embraced. They spell out several ways in which the effort exclusively to reduce uncertainty may be counterproductive, and demonstrate that well articulated uncertainty can have positive effects in knowledge production.

On uncertainty: Pre-analytic starting points

Uncertainty needs not be formally "defined". It is best regarded as a cluster concept, which gets different specific shapes in different contexts. In general terms, uncertainty pertains to the cognitive relationship of human agents to choices on what they do or prepare to do in a particular situation at a particular time. The inherent complexity of real world systems humans are faced with is a major source of uncertainty. In this broad sense uncertainty has a pervasive presence in all practical decisions people make both in daily routines and when getting prepared for the future either individually or as agents in institutions (Tversky and Kahneman 1974; Kahneman and Tversky 2000).

Our perspective implies that uncertainty has an ambiguous character. Uncertainty comes in many different guises, and in any particular situation it may be difficult to pin down what, specifically, is uncertain. Economists, in particular, have been aware of this ambiguous nature of uncertainty – quite understandably, in fact, as they have been interested in human economic actions oriented toward future that is never known in advance (Knight 1921, Keynes 1937, Shackle 1955). The extent to which the future is predictable is a key issue in this regard. A distinction needs to be drawn between measurable and unmeasurable aspects of uncertainty about future events; Knight (1921) drew the distinction as follows: "(i)t will appear that a measurable uncertainty, or "risk" proper, as we shall use the term, is so far different from an unmeasurable one that it is in effect not an uncertainty at all."

The dream of measurability of future events was given a formal supporting argument by French mathematician Pierre Laplace in the 18th century. He claimed that a demon with perfect knowledge of the world would be able to predict the future with perfect accuracy. However, the Laplacean dream has been put to rest by the research on nonlinear dynamics that had its origin in the work of Henri Poincaré in the late 19th century. Since then, both formal-mathematical and conceptual studies of complexity, non-linearity and chaos have made considerable progress. With the help of the huge increase in computing power during the last few decades, a lot has been learned about qualitatively specifiable features of uncertainty in different types of chaotic systems (e.g., Ekeland 2006; Smith 2007).

The general lesson is: uncertainty does not mean that anything can happen anywhere anytime. In other words, the set of possible ways a particular system can change is bounded, but the tightness of the bounds is relaxed with increasing time (Lorenz 1993). In addition, the studies on complexity and chaos bring forth more specific messages. First of all, the structure of the system gives hints about the shape of its possible future change. Physicist Leo Smith (2007) specifies three aspects of knowledge that have a decisive influence on our ability to assess the future trajectories of any system of interest: first, the current state of the system; second, the identities and values of critical parameters; and third, the adequacy of the structure of the model we have of the system.

In practical terms, the model adopted of the system of interest is critical. Philosopher Sandra Mitchell (2009) promotes an epistemological strategy she calls integrative pluralism to cope with complex research problems. "(T)he history, the context, and the dynamics of systems play leading roles" in the strategy. Her points are remarkably similar to the three points of Smith (2007). We can conclude that there is a direct link between the type of model adopted and the semantic space of uncertainty affiliated with that model.

It is useful to think of a semantic space in terms of dimensions, as always is the case with abstract spaces. The dimensions of a semantic space can be identified using the idea of a contrast space as a means. Alan Garfinkel (1981) articulated the idea using physical phase space as an analogy. A contrast space is defined by axes that stand for alternative perspectives for making the phenomenon of interest understandable. The overall view of the phenomenon "moves" in the abstract space depending on assumptions concerning these alternatives; this application of the idea draws upon Dyke (1988, 1993), see also Haila (1998).

In accordance with the contrast space perspective, we adopted a few distinctions that were used as a background for the workshops. These were regarded pretty much as self-evident in the discussion. The first such distinction was between uncertainty and risk. Economists have been well aware of this contrast since the 1920s, as we noted above. The second distinction was between epistemic uncertainty pertaining to knowledge and stochastic uncertainty pertaining to ontology of the world, customarily drawn in the context of sensitivity analysis (e.g., Saltelli et al. 2008). The third relevant distinction stems from the criteria of making decisions about uncertainty at a cutpoint, as is routinely done in scientific practice, by drawing a distinction between type I (rejecting a true null hypothesis) and type II (accepting a false null hypothesis) error. This distinction has been amended by naming an error of third type that brings up qualitative aspects of uncertainty: type III error is made if the question asked is incorrect or irrelevant (e.g., Dunn 2001; Kriebel et al. 2001).

The three distinctions presented above correspond to three dimensions of the semantic space of uncertainty. The dimensions are relatively independent of one another.

It is, for instance, perfectly legitimate to ponder upon type I vs type II error irrespective of whether the uncertainty assessed is epistemic or ontological. When organizing the workshops, we were mainly interested in substance-specific dimensions of uncertainty in biodiversity research. We present a preliminary model of the semantic space in the final section of this paper.

On the specificity of biodiversity research

The general features of unpredictability presented above are pertinent as regards the ecological realm where conditions are changing all the time in unpredictable ways. In its youth in the late 19th century, the science of ecology viewed nature through a "balance of nature" metaphor, but it was soon realized that ecological conditions are in a continuous change. Alfred Lotka's classic *Elements of Physical Biology* (Lotka 1924) was a landmark in this regard. Incidentally, Lotka was greatly inspired by Poincaré's work. More recently, this view has broken through in thinking about human relationships with the rest of nature (e.g., Botkin 1990).

To approach the semantic space of uncertainty of biodiversity praxis, a comparison between biodiversity and climate change is instructive. There is a clear difference between these fields stemming from the different nature of the medium: the Earth's atmosphere is a unified geophysical system whereas the biosphere is divisible into different sections or subsystems, geographically, taxonomically and ecologically. Furthermore, the divisions are descriptively complex (Wimsatt 1974), that is, when alternative criteria are used to carve a particular section of biodiversity into components, different kinds of patterns result.

A practical comparison clarifies the example. When compiling background data on climate change, it is possible to take estimates of green-house gas discharges of single countries such as, say, China, Canada and Guatemala, and extrapolate the effect of each of them to the global atmospheric balance. In the case of biodiversity, no comparable extrapolation is possible. Also the social consequences of biodiversity loss are much more unequivocal than of climate change. The question of contextuality is raised: symptoms, probable consequences, and policy implications of threats vary in a much more context-specific fashion in biodiversity policy than in climate policy (not denying that socio-economic differences across countries are relevant in climate policy, too).

The driving motivation of the workshops at the UFZ was the need to specify types of uncertainty in biodiversity praxis. There is no single way to reach this goal. We have to proceed along several mutually complementary lines. A good start is to ask the three simple clarifying questions we referred to in the opening section of this paper: What, precisely, is uncertain? Why, specifically, is this thing uncertain? And finally, does the uncertainty matter, and if it does, in which sense? Every ecologist with field-work experience can come up with examples of such a chain of questions, pertaining to a specific research project, for instance, the taxonomic composition of the samples collected, or the correspondence between the samples and the populations sampled, and so on (Magnusson 2014).

However, such a purely empirical specification of uncertainty covers only one theme at a time. Generalizable concepts are needed. More interesting distinctions can be drawn by utilizing a theory of conceptual spaces developed by cognitive scientist Peter Gärdenfors (2004). In cognition, a "what" is a representation. The scheme of Gärdenfors builds upon a three-partite distinction between different types of representations that make up conceptual spaces. His terms for these types are 'subconceptual', 'conceptual' and 'symbolic'. The original work includes polemics against rival views within the cognitive science but we can use the scheme without going into these debates.

Gärdenfors demonstrates the differences between the three types of representation using as an example a jungle where people try to find their way. The first form, 'subconceptual' representation consists of what they come across and record, often without articulation: "dynamic interactions between people and their environment" (p. 34). The second, 'conceptual' representation gives order to what they record, using abstract categories; in the example: "representing traveling information in a spatial form" (p. 34). The third, 'symbolic' representation is used when the road is marked with name-tags that will be recognized and interpreted in a consistent way by the people involved, "it is also required that there is common knowledge of what places the names refer to" (p. 35).

The three types of representation can be affiliated with three types of uncertainty. Uncertainty on the subconceptual level is about whether observations are recorded properly. The conceptual level relates to whether the spatial representation is usable. The symbolic level relates to the consistency of the shared knowledge inscribed in the collection of name-tags. These distinctions are applicable to biodiversity science in a straightforward fashion: subconceptual is about methods used in collecting data, conceptual is about patterns detected in the data, and symbolic is about the credibility and social relevance of the conclusions.

To make the analogy more concrete, let's note that Gärdenfors' distinctions have a clear affiliation with the standards adopted to mitigate different types of errors in empirical reasoning. Type I and type II errors correspond to the conceptual level. The decision made as to the type of error that is of main concern has a major influence on how the resulting pattern may be used in further research or in management. Statistical tests aiming at avoiding type II error (assuming no effect while there actually is an effect) customarily accept 20% error rate as a standard, but this may be too strict in the case of useful rules of thumb that can be used in management, for instance (Kriebel et al. 2001). Type III error, on the other hand, relates to the symbolic dimension. The conceptual edifice constructed on the basis of research may not correspond at all to the question that is of concern (Henle 1995; Haila 2004; Henle et al. in press).

We use the analogy between cognitive types of representation outlined by Gärdenfors and dimensions of uncertainty when constructing a preliminary model of the semantic space of uncertainty in the final section.

Further clarification of the nature of uncertainty

We referred above to economists as pioneers in thinking explicitly about the implications of the unpredictability of future in the social domain. Their thinking about uncertainty has advanced a lot since the groundlaying work of Knight and Keynes almost a century ago and offers some further lessons.

In particular, the view on the nature of risks in the markets has undergone great changes in the last half a century or so. Journalist Justin Fox (2009) who is well informed in recent economic history tells the story by tracking the development in the views of academics in economics and finance up to the first decade of the 21st century. Briefly put, there have been two main issues that dominate the story: first, the rationality (or not) of the markets, and second, the possibility (or impossibility) to beat the markets by a clever investment strategy. One of the cornerstones in the discussion has been the view, generally held since the mid-20th century, that variation in market values follows random walk, at least in the short run. It is consistent with the rational markets hypothesis through a variant of the law of large numbers: given enough traders, all discrepancies in market valuation of different assets supposedly even out – almost in real time, given efficient enough investment tools. This argument is in line with the view promulgated by free markets champions such as Frederick von Hayek and Milton Freedman that the markets constitute the best possible means to handle economic information. As Fox (2009) shows, models used to analyze variation in market values have become incredibly sophisticated in the course of the last few decades.

The efficient markets hypothesis makes the distinction between risk and uncertainty all but vanish. In the domain of random walk, there are no qualitative distinctions between types of uncertainties. Everything is akin to quantifiable risk and can be taken into account in advance, given good enough models.

However, the economic life in the last three decades has not agreed with these assumptions. The recessions of 1987 and 1998 and the dot.com bubble in the early 2000s, not to speak of the latest crisis that the world plunged into in 2008, contradict the rational markets hypothesis and the models built upon that hypothesis. In other words, parallel to the development in thinking about the markets, the nature of radical systemic uncertainty inherent in the markets has been clarified. There is an element of ontological uncertainty in this setting: new forms of financial assets change the behaviour of market actors, which changes the behaviour of the markets in turn. In fact, Daniel Kahneman and Amos Tversky pointed out this possibility already decades ago (see the essays in Kahneman and Tversky 2000).

There is another, even more important implication of the change in thinking about the economic life that is breaking through the established orthodoxy: an emphasis on contextuality. Context-specificity of human reasoning itself is the starting point of Silva Marzetti Dall'Aste Brandolini and Roberto Scazzieri (2011) in their exploration of what they call "fundamental uncertainty". The classical work of John

Maynard Keynes on probability (*Treatise on Probability*) is at the background of their work. In several ways, their approach is remarkably similar to the one we adopted at the Leipzig workshops.

If uncertainty is inherently contextual, making sense of uncertainty in specific situations requires that we take into account several aspects of cognitive work and social reality. On the cognitive side, a good starting point is offered by the work of Peter Gärdenfors (2004) we referred to above. To clarify social and political aspects of the setting, problem framing is a useful methodological device. Framing means defining the scope or focus of the problem on the one hand, and the context in which the problem is perceived on the other hand (Fischer 1995, 2003; Schön and Rein 1994; Hajer and Laws 2006). As Schön and Rein (1994) argue, many intractable controversies about the environment, for instance, follow from the fact that different people frame the problems in different ways (see also Henle et al. 2013a). The idea of framing draws upon the view that social problems are defined discursively, as a result of contestations and struggles among different actors as regards the significance of the problems. An important aspect is disagreement concerning types of warrants that support different views of the problems: what kind of evidence is accepted as sufficient and valid (Majone 1989, Chandler et al. 1995).

Hence, an appropriate framing of problems includes an assessment of factors that back arguments concerning the nature of the problem, one way or another. Fischer (1995) introduced a useful scheme consisting of four potential types of warrants that can be used to argue for a case. Fisher's categories are primarily about the nature of knowledge and public acceptability. He dubbs the most concrete level "type and quality of specialist knowledge"; it is self-explanatory. The second one is "technical and management expertise" which takes up the availability of the necessary practical skills. The third level is "societal vindication or public consent" which broadens the societal sphere considered to include public participation, stakeholder opinions and so on. The fourth level is "ideological acceptability" which addresses the question whether what is demanded is concordant with shared societal goal-settings.

Fisher's scheme offers a good starting point to elaborate upon types of uncertainty related to specific issues of biodiversity protection. As an example, consider managing human wildlife conflicts (Klenke et al. 2013). Elements of Fisher's first level of warrants are provided by ecological analyses of the diet, behaviour and distribution of wildlife and contested resources. Elements of the second level are about management skills in terms of techniques to deter wildlife, to analyse management effects on wildlife viability, and funds to compensate for loss caused by wildlife. Elements of the third level are about getting landowners and other users of the area to consent with the aims and rules of wildlife protection. The fourth, most general level comprises views on the general acceptability of biodiversity protection as a societal ethical imperative.

We present a suggestion on how the schemes of Gärdenfors and Fischer fit together in Figure 1.

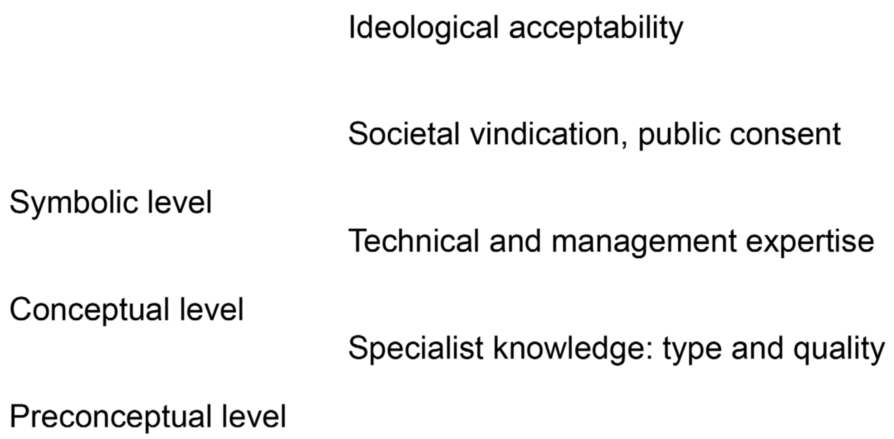

Figure 1. A scheme depicting the correspondence between levels of cognitive representation (Gärdenfors 2004; on the left) , and types of warrants of claims-making (Fischer 1995; on the right), from more concrete (below) to more abstract (above).

Toward collective collaborative assessment

Nobel economist Wassily Leontief (1971) expressed his view on the relationship of theoretical and empirical research in economics as follows:

"True advance can be achieved only through an iterative process in which improved theoretical formulation raises new empirical questions and the answers to these questions, in their turn, lead to new theoretical insights. The "givens" today become the "unknowns" that will have to be explained tomorrow. … An example of a healthy balance between theoretical and empirical analysis and of the readiness of professional economists to cooperate with experts in the neighbouring disciplines is offered by agricultural economics as it developed in this country over the last fifty years. … Close collaboration with agronomists provides agricultural economists with direct access to information of a technological kind. When they speak of crop rotation, fertilizers, or alternative harvesting techniques, they usually know, sometimes from personal experience, what they are talking about. … While centering their interest on only one part of the economic system, agricultural economists demonstrated the effectiveness of a systematic combination of theoretical approach with detailed factual analysis."

Leontief's passage is a clarion call to an integrative knowledge strategy. The spirit is identical with our view on the challenge that biodiversity praxis is facing. But we want to get further than only note the similarity. The next step to take is to identify main dimensions of specialized work that need to be integrated together in biodiversity praxis. In the preceding sections we took up two conceptual schemes that can be used to this end: the layers of cognitive space presented by Peter Gärdenfors, and the layers of social and political warrants of claims-making specified by Frank Fischer (see Fig. 1). When preparing the November workshop, we developed with the help of these devices a scheme of main dimensions of the semantic space of uncertainty in biodiversity praxis, using our previous experience on biodiversity research as an additional resource; this scheme is presented in Figure 2.

It seems natural to order the dimensions from more concrete to more abstract. In the beginning, there is the *data*, and issues concerning representativeness, methodological consistency, and so on: the "preconceptual" level in the scheme of Gärdenfors. Primary data have to be compressed so they give relevant information for the issue at hand. *Proxy* (or *indicator*) is a shorthand for this. Proxy is a representation, which raises the question of adequacy: does it reliably stand for the phenomenon of interest? A whole range of proxies have been used in biodiversity research, from very general ones, such as species number and habitat area, to very specific ones, such as the presence of indicator or "umbrella" species. There is a rich discussion on the relative merits of different proxies (Pereira et al. 2013, Henle et al. 2013b). A proxy basically corresponds to the "conceptual" level of Gärdenfors.

But the credibility of a particular proxy does not depend on the empirical background alone, as important as this is: background *concepts* enter the picture. A workable proxy requires conceptual support. The situation is utterly familiar in biodiversity research, as it already was in the early stages of exploratory research on species–area and species–abundance -patterns from the early 20th century on. This is the "symbolic" dimension of Gärdenfors: a question about the coherence of the way the understanding of the problem is phrased. Schematic models, such as the species–area curve, obtain the role of symbols in scientific work (Haila 1986).

The last two dimensions in Figure 2 move toward the societal sphere. We connect them primarily to Fischer's scheme. The fourth dimension depicted in Figure 2 represents a conglomerate of factors pertaining to societal decision-making: assessing the situation, setting targets, formulating policies for reaching the targets, and implementing the policies into practical management. This is, of course, a huge and complex conglomerate, but to keep the idea of the semantic space of uncertainty transparent, we collapse the whole into one dimension in this context. As it stands, it covers relatively well the third level of Fischer's scheme: "societal vindication or public consent". As the fifth dimension we depict the normative background, which corresponds to Fischer's "ideological acceptability".

The scheme in Figure 2 turned out to be useful as a preliminary structure for the discussion in the November workshop. The companion paper (Haila et al. 2014) gives additional and detailed substance to the idea. In addition, we want to make a couple of further points drawing upon Figures 1 and 2.

First of all, there are interactions between the axes of the semantic space presented in Figure 2, of course, but the point of the figure is to offer an analytic perspective for drawing interesting distinctions. The "cluster concept" nature of uncertainty implies that it is impossible to pool all important aspects together in any case; Andy Stirling (2006) makes a similar point in an analysis of the potential role of public participation in assessing complex issues. Our preliminary assumption is that particularly interesting variants of uncertainty "reside" at the interstices of the dimensions where particular types of uncertainties are transformed into and mingled together with other types of uncertainties.

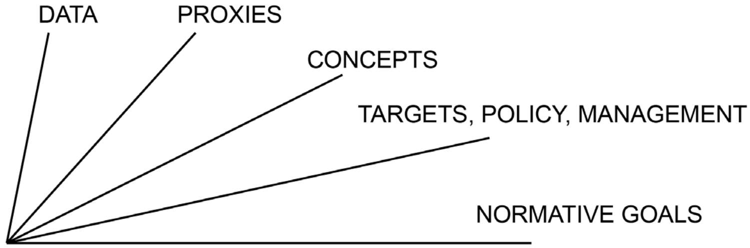

Figure 2. Main dimensions of the semantic space of uncertainty in biodiversity research.

As a means to specify further what is going on at interesting zones of transformation, we take up the idea of closure. As regards a knowledge-intensive issue, such as biodiversity protection, closure of knowledge and closure of policy go hand in hand; this view builds upon Chuck Dyke (1988) on knowledge, and Maarten Hajer (1995) on policy (see Haila 2008). The importance of closure is demonstrated by international goal-setting in biodiversity policy, which is burdened by too general targets that lack closure. For instance, the current target set by the European Union is to stop the deterioration of biodiversity by the year 2020. The previous target year, that was not reached, was 2010. The target of 2020 will not be reached either. The target does not include a clear idea about what its realization would actually mean for development trends, such as urban sprawl, increase in traffic volume and spread of traffic infrastructure, intensification of agriculture and forestry, and so on. In cynical moments, one tends to think that no lessons are drawn, instead, a formal agreement is reached to replace 2020 with 2030, and so on.

Another aspect of the model presented in Figure 2 is that science and policy are both integral elements in it, but the model also shows a way to keep them separated. There is a transition in the scheme in this regard between the first three and the last two dimensions, corresponding to a transition from the cognitive dynamics depicted by Gärdenfors to the social and political framing depicted by Fischer (see Fig. 1). The term "interface" often used in this context can be understood as a rich, multidimensional intersection between knowledge production and political action, allowing for joint construction of feasible management and policy goals (van den Hove 2007). The connections between knowledge and policy reach deep down in specific forms along the dimensions of the semantic space. Methodological decisions on collecting background data for monitoring, for instance, have political implications, but these are mediated by the selection of the proxy and its conceptual status and reliability (Magnusson 2014). On the other hand, uncertainty can be a trigger for acquiring increasingly relevant background knowledge as well as promoting discussion (Haila et al. 2014, Pe'er et al. 2014).

The normative backing is all-important, as was made clear in the workshop discussion (Haila et al. 2014). This relates to what we noted above on feasibility analysis, with reference to Majone (1989). Issues of feasibility versus infeasibility of particular policy schemes are raised primarily with respect to the last two dimensions, but this is not the whole story. Problems of technical feasibility reach, of course, all the way to the first dimension, for instance to the question: What sort of data is it possible to collect? Moral and ethical views and convictions of people also influence greatly what can and will be done. In other words, the situation has a shade of the "fundamental uncertainty" discussed by Silva Marzetti Dall'Aste Brandolini and Roberto Scazzieri (2011): what happens now, perhaps for purely contingent reasons, will influence what happens next.

As a final note: in the spirit of Leontief's recommendation cited above, a general consensus grew out of the discussions at the Leipzig workshops that successful and meaningful coping with uncertainty depends ultimately on a learning cycle that covers the whole recursive chain cycling through science–management–policy–science. We elaborate a learning cycle view in the concluding section of the joint workshop report Haila et al. (2014).

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