Scientific Cultures of Non-Knowledge in the Controversy over Genetically Modified Organisms (GMO)

The Cases of Molecular Biology and Ecology

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How should science and society deal with the unknown, e. g., with risks that are not known or risks of which we do not even know that they are not known? The ways in which science produces knowledge also include specific practices of dealing with non-knowledge, which differ significantly between scientific disciplines such as molecular biology and ecology.

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GAIA 15/4 (2006): 294–301

Abstract
The limits of scientific knowledge are an emerging problem in the debates about technological risk. In an exemplary analysis of the controversy surrounding genetically modified organisms (GMO), we show that the epistemic settings of two involved scientific disciplines – molecular biology and ecology – entail different types of non-knowledge and deal with non-knowledge differently. Both of these "scientific cultures of non-knowledge" are analysed along five criteria: the way of dealing with unforeseen events, the way of dealing with complexity and uncertainty, the temporal and spatial scales of knowledge, the de- and re-contextualisation of knowledge, and the epistemic (self-)reflexivity. The scientific culture of non-knowledge in molecular biology can be described as control-oriented, while that of ecology can be described as uncertainty-oriented. This difference is mirrored in the societal discourses and regulations concerning GMO. A greater variety of cultures of non-knowledge seems likely, which calls for further analysis.

Keywords
agro-biotechnology, ecology, environmental research, epistemic cultures, GMO, molecular biology, non-knowledge, science policy, science studies

How to Respond to Non-Knowledge?

How can and how should our societies deal with potential – and possibly not even fully known and foreseeable – risks posed by innovations and new products in areas such as nanotechnology, agro-biotechnology, or chemistry? The editorial team of the European Environment Agency (EEA) report *Late Lessons from Early Warnings* gives a rather unusual advice: "Acknowledge and respond to ignorance, as well as uncertainty and risk, in technology appraisal and public policy making" (EEA 2001, p. 168). This recommendation is based on the analysis of fourteen cases of delayed recognition of environmental and health risks, amongst them chlorofluorocarbons (CFC) – which contribute to the ozone hole –, asbestos, and mad cow disease (BSE).

Considering these and other examples, we argue that environmental politics and research should take into account not only known and (more or less) well-defined risks and uncertainties, but also completely unknown, unanticipated and for a long time unrecognised effects. This corresponds with new insights from science and technology studies showing that the sciences do not only generate knowledge but also increase ignorance concerning the possible side effects of scientific innovations and their technological application (Ravetz 1986, Funtowicz and Ravetz 2001, Wynne 1992, Nowotny et al. 2001).[1] In order to clarify that such non-knowl-

1 For an overview, see Wehling (2006).

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edge is not simply "given by nature", but the result of the growth of knowledge itself, the British philosopher of science Jerry Ravetz has termed it "man-made" or "science-based ignorance" (Ravetz 1990; for the distinction of the terms "ignorance" and "non-knowledge", see below).

It is crucial, therefore, to deal adequately and reflectively not only with what we know, but also with what we do *not* know. Yet, of course, the EEA editorial team is fully aware of the apparently paradoxical and possibly unattainable character of its demand to "respond to ignorance": "At first sight, responding to ignorance may seem to ask the impossible. How can strategies be devised to prevent outcomes, which, by definition, are not known?" (EEA 2001, p. 170).

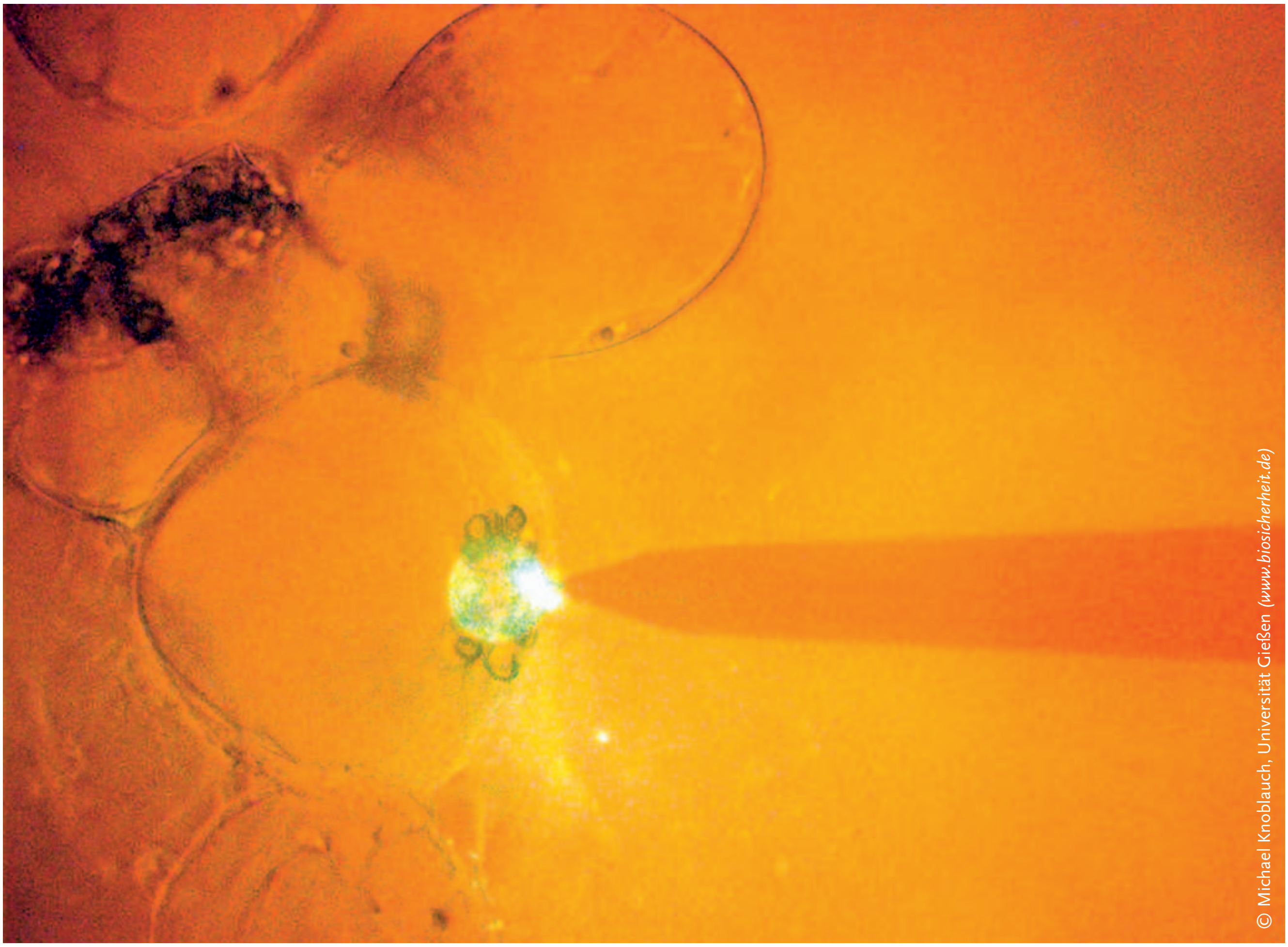
In this article, we introduce the concept of "scientific cultures of non-knowledge", which offers new and promising perspectives for dealing with this seemingly irresolvable question. The concept of cultures of non-knowledge refers to the practices by which different scientific (sub-)disciplines generate, acknowledge, and communicate non-knowledge. The term "non-knowledge" (see Weinstein and Weinstein 1978) indicates the general absence of knowledge, regardless of its further contextual implications. "Ignorance", in contrast, implies the theoretical availability of the knowledge in question; "uncertainty" and "indeterminacy" imply the recognition of a lack of knowledge, as well as its further qualitative specification.[2]

Our research project[3] aims at exploring new ways of self-reflectively dealing with non-knowledge in science and at contributing to a better understanding of public controversies. This requires outlining and acknowledging different modes of framing the unknown in science and society. We illustrate our approach using the example of agro-biotechnology and the controversy over genetically modified organisms (GMO). This field is characterised by a multiplicity of scientific disciplines and by particular atten- >

2 Unlike Walker et al. (2003, p. 13), we include epistemic uncertainty and variability uncertainty in a broad conception of non-knowledge.

3 The project *Cultures of Non-Knowledge* is conducted by the Environmental Science Center of the University of Augsburg (*www.wzu.uni-augsburg.de/Projekte/Nichtwissenskulturen.htm*) and supported by the German Federal Department of Education and Research (BMBF) within its programme *Knowledge for Decision-Making Processes – Research in the Context of Science, Politics and Society.*

Molecular biologists rely on controlled experimental conditions ...



tion to what is *not* known regarding the possible consequences of technological innovation. We analyse how molecular biology and ecology, the two most important scientific (sub-)disciplines in the area of agro-biotechnology, deal with non-knowledge. Based on this, we seek to outline societal implications of the fact that there are at least two discernible scientific cultures within the GMO debate, which differ significantly in the ways they deal with what is not known.

Cultures of Non-Knowledge: Conceptual Approach

Epistemic Cultures as Cultures of Non-Knowledge

Knorr Cetina (1999) has shown that two influential scientific (sub-)disciplines – high-energy physics and molecular biology – differ widely in their practices of "making knowledge". Thus, as she concludes, the sciences can be understood as being differentiated into various "epistemic cultures" or "scientific cultures of knowledge". These consist of and are constituted by sets of specific practices of generating, validating, and communicating knowledge, each of which is characteristic of its respective (sub-)disciplinary field. What is remarkable in Knorr Cetina's study is that these cultures of knowledge include specific practices of producing and dealing with *non*-knowledge. Thus they can also be interpreted as "cultures of *non*-knowledge".

As Knorr Cetina demonstrates, high-energy physics is very attentive to the limits of its knowledge: disturbances, distortions, errors, unexpected events, or uncertainties. Its epistemic strategy focuses on the active search for what she has termed "liminal knowledge", i.e., the expertise of dealing with the boundaries of knowledge. In contrast, molecular biology is not (indeed perhaps cannot be) very interested in the limits of its knowledge or in its self-generated non-knowledge. If experiments fail or expose unforeseen results, molecular biologists usually do not explore the causes any further, but vary the conditions of the experiment until the expected type of outcome emerges (Knorr Cetina 1999). To refer to this heuristic strategy, Knorr Cetina has coined the term "semi-blind variation" (Knorr Cetina 1999, p. 110). She argues that this should not be interpreted as a sign of epistemic sloppiness, but as a requirement of the specific research fields and objects of molecular biology.

Another strand in environmental research provides similar conclusions concerning cultures of (non-)knowledge. Based on a comparative analysis of the BSE crisis and the political and institutional responses to it in Great Britain and Germany, Wynne and Dressel (2001) differentiate between two (or more) "cultures of uncertainty": While a more empiricist-orientated British (Anglo-Saxon) institutional culture only accepts robust evidence (e.g., specified causal models) as justifying environmental protection, the general public in continental European countries (particularly Germany) is more willing to act on the grounds of uncertainty or even "merely" presumed non-knowledge in a precautionary approach (for the latter, see CEC 2000). Unlike Knorr Cetina, Wynne and Dressel do not refer to the scientific cultures of (non-)knowledge underlying the production of knowledge, but to national cultures of the evaluation of evidence underlying societal decisions.[4]

Dimensions of Non-Knowledge

To make the concept of cultures of non-knowledge applicable to empirical research, we need to specify and further develop it. A first set of rather general criteria for specifying different cultures of non-knowledge can be derived from sociological observation of the ways in which non-knowledge (often tacitly) is recognised, (often indirectly) defined, and (often implicitly) dealt with in various social contexts. As a means of specification, we propose three dimensions of non-knowledge (table 1; see also Wehling 2006):

- The first dimension refers to *knowledge (or awareness) of non-knowledge,* which spreads between full awareness of non-knowledge (we know what we don't know) and complete unawareness ("unknown unknowns").
- The second dimension, *intentionality of non-knowledge,* contrasts unintended non-knowledge with the conscious refusal of certain cognitions.
- The third dimension, *temporal stability (or reducibility) of non-knowledge,* extends from what is not yet known, but (presumably) does not present any substantial difficulties to cognition, to the entirely "unknowable" and therefore uncontrollable.

Detailed specifications of the quality of the unknown due to its various possible locations within this three-dimensional space are a constituent part of different (and sometimes competing) cultures of non-knowledge within the sciences as well as in the public sphere (Grove-White 2001).[5]

Characteristic Traits of Cultures of Non-Knowledge

A second set of analytic criteria is more specific to epistemic practices and routines within the sciences. Our basic idea is that practices of dealing with non-knowledge should be studied with regard to certain key issues that are crucial to experimentation and epistemic strategies. We elaborated five key traits of cultures of non-knowledge:

1. What temporal and spatial scale is considered adequate for knowledge to be valid, reliable, and complete in a particular scientific area? How long and on what spatial scale should scientists carry out observations until they can be reasonably confident that specific technologies have no harmful effects: six weeks, six months, three years, or two decades? The synthetic hormone diethylstilboestrol (DES), for instance, turned out to be the cause of cancer in young women whose mothers had taken it during pregnancy fifteen to twenty years before (Ibarreta and Swan 2001).

4 For the interrelation of social and scientific regimes, see Jasanoff (2004).

5 Whether a fourth dimension referring to the situatedness of non-knowledge within a community or society (*collective* versus *local/individual non-knowledge*) adds further analytical power to the model, remains open for discussion.

TABLE 1: Dimensions of non-knowledge.

1st dimension	**knowledge (or awareness) of non-knowledge** fully recognised ⟷ completely unrecognised
2nd dimension	**intentionality of non-knowledge** unintended ⟷ consciously refused
3rd dimension	**temporal stability (or reducibility) of non-knowledge** not yet known ⟷ entirely unknowable

2. How are unforeseen events and unexpected results dealt with? Are they merely negligible "disturbances" and temporary aberrations from the "true" processes of knowledge generation? Or should they be taken seriously, perhaps even searched for deliberately, as sufficient reasons for critically evaluating and possibly modifying the underlying assumptions?
3. How are complexity, diversity, uncertainty, ambiguity, indeterminacy, and limits of knowledge addressed?
4. What are the ways and routines of coping with de- and re-contextualisation of knowledge (Bonss et al. 1993 a and 1993 b)? Strand (2000) in regard to the life sciences has termed it the *in vivo-in vitro* problem: Do scientists tacitly assume that their research objects (genetically modified organisms, nanoparticles, chemicals, etc.) behave in the natural environment exactly as they do in the controlled and artificial setting of the laboratory? Or do researchers take into account the probability or even unavoidability of hitherto unknown effects resulting from the non-transparent multiplicity of influencing factors under real-world conditions? Strand criticises the former attitude as "epistemological optimism" or "naivety" and pleads for a more reliable and self-critical "epistemological disillusion".
5. How pronounced is the disciplinary, interdisciplinary, and transdisciplinary (self-)reflexivity of a scientific culture?

Cultures of Non-Knowledge in Agro-Biotechnology

The controversy, both scientific and political, over the release of genetically modified plants offers a good example for studying different cultures of non-knowledge. Firstly, because a wide range of scientific disciplines is involved in the ongoing debates. Secondly, because the "politicisation of ignorance" (Stocking and Holstein 1993) apparently plays an important role in the conflict (e.g., Wynne 2001). Thirdly, because a closure of the debate over appropriate modes of political intervention is not in sight, and the elaboration of innovative analytical tools for democratic deliberation seems overdue.

In the field of agro-biotechnology, we consider four scientific (sub-)disciplines to be particularly important and influential: molecular biology (including genetics), ecology (especially ecosystem research), agricultural sciences (including plant breeding and cultivation), and medical sciences (including veterinary and human medicine). Within these fields, molecular biology and ecology play central roles in shaping and advancing scientific practices and bodies of knowledge. They possess specific ways to generate and handle non-knowledge. However, molecular biology and ecology are rarely linked by interdisciplinary cooperation. When asked for an explanation of this situation, one interviewed molecular biologist referred to their divergent interests, belief systems, and ideologies, resulting in a gap between their proponents and disabling exchange and joint research. The two approaches of molecular biology and ecology to knowledge production and non-knowledge are described in the following, drawing on interviews with molecular biologists and ecologists (see box).

Molecular Biology: Controlled Conditions

In the field of agro-biotechnology, applied molecular biology merges two influential positions: the scientific interest and laboratory research practices of *genetics* in identifying chromosomes, genes, and their respective functions, and the traditions of *plant breeding,* providing plant varieties with certain desired traits and/or high yields under field conditions. The latter is currently being implemented through the techniques of molecular farming and metabolic engineering. Both positions are characterised by laboratory-bench research (as context of discovery and validation), by traditional plant breeding (as context of comparison and explanation), and by a specific (variable) link to agricultural production and industry (as context of funding and as context of application and social legitimisation). Consequently, the temporal and spa- >

BOX: Methodology

The comparative reconstruction of scientific cultures of non-knowledge is designed to clarify the ways in which their everyday practices, their prevalent styles of thought (including their affinities to certain attitudes and concerns), and their heuristic and perceptive horizons (including their blind spots) result in distinct assumptions concerning non-knowledge and the best ways of dealing with it under conditions of social and ecological risk.

The methodology applied in our research project consists of an analysis of the research situation in Germany, based on preliminary talks with experts and on literature research in relevant journals. This was followed by in-depth structured interviews with German scientists in the field of agro-biotechnology. We conducted 36 interviews that included fifteen active scientists, whose anonymity was guaranteed.

As all interviews were conducted in Germany, the interviewees refer to the German debate and research context. Although all interviewed scientists are in close contact with their international scientific communities and refer to international research methods and standards, we have to keep in mind that public debate, GMO regulation, and agro-biotechnological industry differ significantly between the USA and the EU (e.g., Gaskell et al. 1999, Joly and Marris 2001)[a] as well as within Europe. The GMO debate is admittedly more complex than can be shown in this article, for instance, concerning the different international regulation strategies and practices (e.g., Borrás 2006), or concerning shifts in the underlying debate on risk management procedures (Klinke and Renn 2002, IRGC 2005).

a For similarities, see Marris et al. (2001).

tial awareness of molecular biologists is to a great extent determined by de-contextualised laboratory experiments aiming at the production of stable organismic constructs under controlled conditions (table 2):

What we are actually doing here is introducing genes into plants and observing at a molecular-biological level what happens: That is, how does the plant react to the new gene? What aspect of the gene does the plant recognise? Why does it recognise this aspect? What mechanisms are involved in the recognition process? What does the plant do with these mechanisms and how can we control them?
a molecular biologist (interview no. 13a, p. 131)[6]

In contrast to agricultural plant breeding, in molecular biology the total life cycle of an organism and the statistical evaluation of crop output versus crop loss are of secondary importance in scientific publications. Unforeseen or unintended results, such as instability, deformation, or death of living objects during the time span of the research process, pose crucial questions to the scientists. They must decide whether such results are due to a lack of experimental control or to unknown characteristics of the objects themselves, and whether the results should be ignored or analysed and converted into a new research hypothesis.[7] Under conditions of time pressure, financial constraints, and the need to produce reliable results, practical conduct may diverge from theory:

The system itself forces us, so to speak, to consider only those questions which are answerable.
a molecular biologist (interview no. 13a, p. 144)[6]

One molecular biologist recalled a research project on herbicide-resistant plants, during which the search for a scientific explanation for the death of the plant population led to a major scientific breakthrough and completely new information about the organisms studied. But one of his colleagues remarked that such a thorough exploration is rather unusual:

In general things work differently. We have a set topic, such as vaccine production in transgenic plants, and naturally we have to see that we achieve something worth presenting. Finding out why something went wrong and what exactly is going on in the plant can only be of secondary importance.
a molecular biologist (interview no. 13b, p. 471)[6]

Molecular biologists develop a certain expertise in controlling their experimental conditions (such as molecular object characteristics, diurnal temperature changes, chemical instabilities of the culture medium) to avoid the unforeseen and unintended:

I have to define my system very precisely to get answers. If I have too many variables which aren't under my control, I usually can't interpret the results.
a molecular biologist (interview no. 19, p. 249)[6]

Consequently, research in a specific and controlled context is usually highly developed and the epistemic systems are closely analysed. However, it seems to be uncommon to take other possible contexts into consideration – whether they be biological, ecological, or social. A paradoxical result of this is that the controlled research setting in the laboratory appears to be a source of both reliable knowledge and non-knowledge. The better the system is defined, the more variables tend to remain out of focus.

Within the scientific culture of molecular biology, the perception of non-knowledge and possible risks of GMO is mainly guided by the comparison of biotechnological methods with modern plant breeding. Agro-biotechnology is described as relatively well controlled and therefore well understood. A *per se* difference between biotechnological interference and conventional breeding, between (supposedly) substantially equivalent products of different technological origins, is rejected. Non-knowledge is treated as specific, temporary, and reducible, although the existence of unavoidable uncertainties is admitted in theory. The attitude of molecular biologists regarding impacts of GMO can be called "semi-blind confidence" (in reference to "semi-blind variation"): Their experience in everyday research is that living objects highly resist their attempts to transform them. Why, then, should other organisms be transformed by mere contact with GMO? In addition, the discovery of molecular repair systems that ensure stable genetic conditions during evolution appears to lead researchers into trusting in effective self-regulation mechanisms which eliminate unintended and undesired results:

I would say that the biological mechanisms of an organism are trained to eliminate malfunctions. Biochemically speaking, a gene will survive only when something really functions. Through experience I have learnt that many insertions are lost again during transformation.
a molecular biologist (interview no. 12, p. 299)[6]

This attitude of "semi-blind confidence" tends to be assigned to all natural systems such as agro-ecosystems where genetically modified corn is released. It is supported by the claim of an overall absence of contradictory evidence.

Ecology: Anticipating the Unexpected

Ecologists, as proponents of a so-called weak discipline, face greater difficulties in producing reliable, reproducible results as compared to molecular biology researchers. They often have a wide range of interdisciplinary and transdisciplinary connections. In transdisciplinary projects aiming at nature preservation and ecosystem management, the scientific interest lies in the object world afield, captured by observation, idiographic description, comparative analysis, and field experimentation. This is complemented by laboratory research and computer modelling. Invasive techniques of investigation are only introduced in a second step. An attentive and unrestricted view is a valued skill, adopted to avoid the unintentional reduction of unrecognised key details. Complex-

6 The unpublished interviews are archived as part of the project *Cultures of Non-Knowledge* at the Environmental Science Center of the University of Augsburg.
7 For further methodological differentiation between technical objects and epistemic things, see Rheinberger (1997).

ity, diversity, vitality, and contextuality (or interconnectedness) are acknowledged characteristics of the object world (table 2).

> *The typical methodological procedure within my research project was to go afield and to look after rape and possible hybrid partners in every accessible corner. Not only did we scan sites where we would expect them, we searched for them area-wide. We also looked at places where one would think it wasn't worth it (...). We did find that the actual hybrid partners were quite numerous in the city. Indeed, the city district X turned out to be a rich source. We really hadn't expected to find such a diversity centre of rape and hybrid partner plants in* this *of all places.*
> an ecologist (interview no. 6, p. 83–86)[6]

In contrast to molecular biology, ecology seems to intend to open and broaden its perceptual horizons beyond what could be "rationally" expected. Temporal and spatial scales are far-reaching. Ecologists attempt to describe different and distinctly characterised entities (genes versus organisms, inter-species differences, geographic specificities, living versus non-living systems, etc.) by *in situ* observations and idiographic descriptions:

> *We often go out relatively unencumbered and just look: What is actually happening outside? And then we allow ourselves to be surprised by what we find: We observe this and then try to evaluate our findings without looking for a specific systematic condition that has to be achieved. Thus, quite different objects are perceived at the same time, and we see how many unexpected developments there are. You come to realise how often what you observe differs from what you actually expected to find. It is our recurrent finding that self-organised natural systems are highly resistant to our planning. This aspect of self-organisation is perceived less as a disturbing factor that has to be eliminated, but rather as an actual characteristic of the systems.*
> an ecologist (interview no. 4, p. 202)[6]

In ecology, non-knowledge is seen as the result of the contingent experimental research strategy and the problematic (re-)transfer of experimental results to open, complex, and dynamic natural systems. This attitude is underlined by recurrent failures in forecasting the behaviour of natural entities. Particularly in ecosystem ecology, major epistemic strategies appear to consist of maintaining an unprejudiced openness towards surprise and of a paradoxical effort "to expect the unexpected" in order to test and modify prevalent theoretical assumptions:

... while ecologists expect the unexpected.

> *Thus we often find in fieldwork that we observe phenomena which we had not expected at the outset; but afterwards, during the analysis, we realise that we actually could have anticipated them.*
> an ecologist (interview no. 4, p. 217)[6]

As the same ecologist explains, this orientation towards the unexpected is difficult to realise, since observation in absence of any expectation and focus of attention is impossible:

> *There is also, so to speak, an attempt to operationalise the area of non-knowledge and to say that we are looking for unexpected effects. This leads to an antinomic situation: How can we observe something which we don't know is relevant, whilst taking into consideration that we are unable to observe everything that could be observed, but have to make a suitable selection for study?*
> an ecologist (interview no. 4, p. 217)[6]

To overcome this dilemma – the inadequacy of reducing the object world to its anticipated, observable traits, and the impossibility of observing the unanticipated – ecologists have developed strategies of coping with conditions of restricted knowledge in risk >

TABLE 2: Cultures of non-knowledge within molecular biology and ecology. The epistemic strategy of openness for the unanticipated and handling of the unknown within ecology contrasts with that of drawing the attention to controlled experimental conditions within molecular biology.

cultural traits	molecular biology: control-oriented scientific culture	ecology: uncertainty-oriented scientific culture
1 temporal and spatial scale and specification of the knowledge produced	small; irrespective of time and space	small to large; relating to temporal and spatial contexts
2 dealing with unforeseen events and unexpected results	avoidance of uncontrolled situations	methodological sensitivity
3 dealing with complexity, diversity, uncertainty, ambiguity, indeterminacy, and limits of knowledge	reduction of complexity to allow for the production of "hard facts"	acknowledgement of complexity; acceptance of idiographic and preliminary data
4 de- and re-contextualisation of scientific knowledge	de-contextualisation *in vitro*	observation *in situ*
5 disciplinary, interdisciplinary, and transdisciplinary (self-)reflexivity	focussed on product marketability	focussed on ecosystem conservation

situations. They adopt a precautionary attitude and try to specify different forms of non-knowledge requiring different forms of precaution. An example is the categorisation of genetically modified plant species according to the uncertainty and risk associated with their release in a certain ecosystem, resulting in suggestions for different strategies of precautionary measurement (Breckling and Verhoefen 2004, Menzel et al. 2005).

Integrating Non-Knowledge into Democratic Deliberation and Policy

We started our argument referring to cases in which knowledge was ignored by society and non-knowledge was not recognised, resulting in harmful effects. This led to the political demand to take possibly harmful unknown unknowns into account. In our so-called knowledge society, epistemic cultures develop specific expertise not only in the production of knowledge, but also in the handling of non-knowledge. Our comparison of molecular biology and ecology in the field of agro-biotechnology exposed the existence of two different scientific cultures of non-knowledge – one that is based on the reliability and regularity of causal interrelations established in the controlled setting of the laboratory, the other focussing on the ubiquity of unanticipated, unforeseeable, or even unrecognisable effects under varying real-world conditions. We conclude that the specific traits of the epistemic cultures help to characterise science-based non-knowledge in detail. Moreover, our analysis provides a source to critically discuss and broaden our societal capability to handle situations of non-knowledge. As in science, societies can, in principle, choose between a control-oriented and an uncertainty-oriented approach (table 2) in situations of unknown risks. Experts from specific scientific disciplines may advocate those options that are more familiar or more consistent with their own epistemic style. Each culture of non-knowledge is associated with specific (implicit/explicit) motives and based on specific (known/unknown) implications and limitations. At the same time, they are equally "scientific", "rational", and potentially helpful. This has far-reaching consequences, not only for science studies but also for political deliberation and decision making in various fields. It seems of major importance

- to acknowledge non-knowledge in the sciences as well as in the public debate;[8]
- to elaborate and preserve a variety of cultures of non-knowledge as a basis of intercultural critique and as a rich source of future action;
- to think of different societal options of precautionary political actions, referring to different cultures of (non-)knowledge;
- to societally reflect upon and discuss the world views and implicit value systems inherent in different cultures of non-knowledge and actions of precautionary politics.

The fact that we can discern different scientific cultures of non-knowledge raises several questions which are likely to be of fundamental importance for future socio-ecological developments:

- What can modern societies and their institutions learn from control-oriented and from uncertainty-oriented scientific cultures of non-knowledge?
- Is it realistic to think we can completely avoid non-knowledge – and risks based on non-knowledge – by controlling real-world situations? To what extent is this socially desirable?
- What are the alternatives to "first-order knowledge" via controlled experiments and to precautionary strategies based on the enhancement of system control? How can first- and second-order approaches in science and policy be integrated in a sensible way?

The present societal and political reactions towards emerging risk technologies such as biotechnology suggest that we are currently extending the range of uncertainty-oriented approaches in order to avoid negative socio-ecological (side-)effects in the present and future (Böschen 2005). The following examples can be interpreted as first steps in this direction: the post-market monitoring of GMO and their general environmental surveillance; the step-by-step and case-by-case procedures regarding the permission to release and market GMO (e. g., Tiedje et al. 1989)[9]; the development of "second-order indicators" (second-order knowledge) to evaluate the specific risk associated with the release of specific chemicals[10] (Scheringer 2004, p. 94) or genetically modified plants[11] (Menzel et al. 2005) even before they are released. With the recent turn toward precautionary politics within the EU, a broader discussion and a more detailed conceptualisation seem adequate.

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8 For scientists' reluctance to communicate non-knowledge, see Frewer et al. (2003).

9 For a critical view, see Jasanoff (2005, p. 12).

10 Indicators such as environmental persistence and spatial range.

11 Indicators such as spatial dispersal, potential partners for cross-breeding, and environmental persistence.

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Submitted January 30, 2006; revised version accepted October 2, 2006.

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