The Multidimensionality of Environmental Problems: The GMO Controversy and the Limits of Scientific Materialism[1]

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ABSTRACT

This paper argues for a broader understanding of complexity; an understanding that speaks to the multidimensionality of environmental problems. As argued, environmental problems rest upon ontological, epistemological, and moral claims; they rest, in other words, upon statements about *what is*, *knowledge*, and what *ought* to be, respectively. To develop and illustrate this argument, the GMO (genetically modified organism) controversy is broken down according to these three dimensions. Dissecting environmental problems in this manner reveals why we cannot look solely toward the natural sciences for resolution: because these problems beg questions that cannot be answered with references to materiality alone.

KEYWORDS

Complexity, science, values, ethics, biotechnology, risk, uncertainty

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INTRODUCTION

Much has been written of late about the complexity of environmental problems. Disciplines (e.g., ecology), theories (e.g., complexity theory) and journals (e.g., *Ecological Complexity*) are now devoted to the subject. Complexity is often evoked in environmental discourse to argue in favour of a 'bigger picture' view of reality; the 'everything is connected to everything else' type of materialist philosophy that underpins the ecological sciences. Yet, for a term used to express an anti-reductionist approach to the study of reality it is often applied in a surprisingly myopic manner. That is because 'ecological complexity', as it is often called, is exclusively materialist in its orientation. To put it simply, complexity, as it is conventionally understood, speaks to questions about *what is*. Yet, this begs the question: can environmental problems be reduced merely to their material components?

In this paper, I argue for a broader understanding of complexity, which speaks to the various dimensions of environmental problems. As argued, environmental problems rest upon ontological, epistemological, and moral claims – which is to say, they rest upon statements about *what is*, *knowledge*, and what *ought* to be, respectively. To develop and illustrate this argument, the GMO (genetically modified organism) controversy is analytically dissected by way of these three dimensions. In the case of GMOs, looking toward these three dimensions helps explain, at least in part, why these artefacts remain so hotly contested the world over. More generally, however, this analysis highlights a more fundamental issue. It points to why we cannot look toward the ecological sciences alone to resolve today's environmental problems: because environmental problems are in fact more complex than the complexity sciences would lead us to believe.

THE ONTOLOGICAL DIMENSION

The ontological dimension of environmental problems speaks to those questions of *what is* that drive so much of today's environmental debates. *What is* the affect of glacial melt on global air flows? *What is* the level of radiological contamination in the area surrounding Chernobyl? *What is* the population of species X? When studying and debating environmental problems – and solutions to those problems – knowledge is sought to better understand the materiality of the issue at hand. And why shouldn't it be? We need to understand the material reality (the *what is*) of environmental problems if we ever wish to resolve them. Right? It is naive to think scientific materialism does not serve an important role in all of this. The question, however, is not whether material reductionism should play a role in guiding environmental policy. Rather, as will be clear by the paper's end, the real issue is determining *just how big a role* that ought to be.

Turning to the GMO debate: The ontological questions underlying this controversy involve, at least in part, understanding the processes by which genetic information is exchanged across functional levels of organisms. Having jettisoned the highly reductionist dogma that was prevalent in the mid-twentieth century, the new view among molecular biologists is that an organism is not solely derived from its genes (that is, from the 'bottom-up'). Rather, organisms are the outcome of an ontogenetic process that is contingent upon interactions between various scales – between genes, organisms and the broader environment within which organisms are embedded (Fox Keller 2000; Lewontin 2000).

For an example of *what is* language used by scientists to explain the biological world, specifically in terms of understanding how genetic information is expressed, take the term 'epigenesis'. E. O. Wilson (1998: 193) describes epigenesis as 'the development of an organism under the joint influence of heredity and environment'. To highlight the role of the environment in gene expression, Wilson gives the example of the arrowleaf plant. As described by Wilson (1998: 137), while its leaves resemble arrowheads on dry land, when grown 'in shallow water, the leaves at the surface are shaped like lily pads; and when submerged in deep water, the leaves develop as eelgrass-like ribbons that sway back and forth in the surrounding current'. Importantly, however, '*no known genetic differences* among the plants underlie this extraordinary variation' (my emphasis) (Wilson 1998: 137).

Yet, even this example does not fully capture the embeddedness of biological systems, which involves such processes as cell-signalling and mutual-regulatory interactions. Not encapsulated in this example, for instance, is how organisms themselves shape the very environment that helps to give form to the ontogenetic process. The concept of 'alteration' speaks to ways that organisms mould their immediate local conditions, and these local conditions, in turn, mould the organism, which, in turn, further mould local conditions, and so on (Levins and Lewontin 1985).

Richard Lewontin (2000: 57) gives the following example of a consequence of this interrelationship as it relates to the science of plant engineering:

> In an attempt to increase the productivity of crops, plant engineers make detailed measurements of microclimate around the plant and then redesign the pattern of leaves to increase the light falling on the photosynthetic surfaces and the available carbon dioxides. But when these redesigned plants, produced by selective breeding, are tested it turns out that the microclimatic conditions for which they were designed have now changed as a consequence of the new design. So the process must be carried out again, and again the redesign changes the conditions. The plant engineers are chasing not only a moving target but a target whose motion is impelled by their own activities.

Further evidence of the ecological embeddedness of biological systems comes from research on 'gene knockouts'. This method involves the targeted disruption of particular genes and noting their effects. It has been well documented – to the initial surprise of many molecular biologists – that 'knocking out' a normal gene and replacing it with an abnormal copy often has no discernable effect, even in many cases when the gene in question was believed to be essential to the functioning of the organism (Angier 1993; Fox Keller 2000; Sterelny and Griffiths 1999). Such research is pointed to by critics to problematise GM technology (McAfee 2003; Wynne 2001, 2002). Specifically, critics argue that if extensive redundancy is built into the genomes of organisms this would further complicate attempts by the biotech industry to produce desired phenotypic effects by the mere insertion of genes into a plant.

What is questions seem to command the most attention by politicians, scientists and the media when attention turns to GMOs. What are the signal pathways of biological systems? How open to technological manipulation are biological systems and to what extent is redundancy built into these systems? And can gene transfer between species occur resulting in so-called 'super' pests and weeds? Not surprisingly, such ontological questions surrounding biotechnology remain the intellectual property of the natural sciences – of molecular biology, ecology and the life sciences more generally. And such disciplines are well-suited for such 'is' questions.

Yet, there is a problem when questions of *what is* are all that are being asked. That is because debates over GMOs do not only concern ontological matters, which is to say they cannot be framed (and understood) in purely materialist terms. Indeed, as later detailed, such *what is* statements often rest upon epistemological and moral questions – such as (respectively) 'How is 'the system' to be defined when calculating the risks of GMOs?' and '*Should* we be genetically engineering organisms in the first place?' And these questions *cannot* be answered through scientific methods alone. So while an understanding of environmental problems needs to include the natural sciences *it must go beyond them as well*.

Most are likely familiar with the ontological dimension of environmental problems, particularly given how scientific materialism lies at the centre of today's environmental debates. This point is evidenced, for example, by the recent introduction of 'sound science' bills into political structures around the world; bills that codify scientific materialism's influence by emphasising the need for 'more' and/or 'better' science when making decisions (Carolan 2008). Because of this, I wish to reserve the remaining space of this paper to discuss the epistemological and moral dimensions of environmental problems and GMOs in particular.

THE EPISTEMOLOGICAL DIMENSION

Environmental problems are an effect of more than just materialist claims about *what is*. They are also a consequence of competing knowledge claims of not only what the relevant facts *are* but also of what those facts, once established, *say* in terms of guiding public policy. This brings us to the epistemological dimension of environmental controversies.

The social sciences in particular are no stranger to examining the processes by which environmental issues or problems are framed. From critical realism (e.g., Carolan 2005a, 2005b; Murphy 2002) to political ecology (e.g., Bates and Rudel 2000 and Belsky 2002), actor network theory (Goodman 1999; Murdoch 2003) and social constructivism (e.g., Burningham and Copper 1999; Hannigan 1995; Yearley 2002); a wide array of theoretical frameworks speak to how knowledge is, to a degree at least, socially situated. (To some degree, then, participants of the social constructivist/realist debates of the 1990s [e.g., Buttel et al. 1990; Dunlap and Catton 1994] were speaking past each other. That is, the former were concerned primarily with making epistemological statements – e.g., 'Our knowledge of environmental problem is socially mediated!' – while the latter tended to emphasise ontological claims – e.g., 'Environmental problems are real!'.) As indicated in the previous section, environmental problems are ontologically multifaceted, involving the interpenetration of socio-cultural, economic and ecological systems; each of which are individually complex, but when taken together the emergent complexity far exceeds the sum of its parts. Consequently, being the finite creatures we are, it is difficult for us to arrange 'the facts' of a particular controversy in such a manner to reveal a picture of reality in its totality. Thus, even if knowledge was not to a degree socially mediated (which it is) and Truths were objectively given (which they are not), we would still not have the ability to take it all in through one God-like gaze.

Turning to the debate surrounding GMOs, we find a wealth of examples of where 'the facts' are not objectively given and are thus subject to certain social filters. Take, for example, the following analysis by Daniel Sarewitz. Sarewitz (2004) points out how the scholarly debate over the publication of a paper in *Nature* involving the occurrence of transgenic corn in Mexico (Quist and Chapela 2001) disproportionately saw ecologists on the side critical of GMOs and molecular biologists on the side that was more positive. According to Sarewitz, these divergent conclusions rested largely on the different views of reality that come out of each discipline. In his own words,

> The two sides of the debate represented two contrasting scientific views of nature – one concerned about complexity, interconnectedness and lack of predictability, the other concerned with controlling the attributes of specific organisms for human benefit. In disciplinary terms, these competing views map onto two distinctive intellectual schools in life science – ecology and molecular genetics. (Sarewitz 2004: 391)

For further understanding of what might be going on here, let us look at the study by Mansfield and Haas (2006) of the Steller Sea Lion debate (involving a population off Alaska's coast). In this study, Mansfield and Haas (2006: 81) detail how uncertainty is less a statement about objective reality and more about the social relations that give shape to what we perceive when we look at that reality: 'People produce uncertainty when they agree on what is not known [...], but also when they disagree on what is known [...], or even when they agree on what is known but interpret that knowledge in different ways.' The authors demonstrate how powerful interests were able to shift the scale at which the Steller Sea Lion debate was framed to introduce further uncertainty into scientific models. Specifically, the fishing industry successfully framed the scale of the debate at the level of macro-regional drivers, such as climate change (versus another group who wanted to focus on local interactions between individual fisheries and the Steller Sea Lion). In doing this, understandings of 'the system' were expanded to include a larger scale. And with this, so too expanded the assumptions and unknowns that were included in the scientific models used to 'see' the Steller Sea Lion problem. Applying this insight to the case described earlier by Sarewitz, we can begin to understand why methodological standpoints can have a significant affect on what scientists perceive when they look at biotechnology: because all views are 'situated' (Haraway 1988).

Through this, we can begin to understand why scientists themselves often disagree when answering seemingly well defined scientific questions. Bruno Latour provides a useful metaphor for highlighting this point. As he explains, 'Scientific facts are like trains, they do not work off their rails. You can extend the rails and connect them but you cannot drive a locomotive through a field' (Latour 1992: 266). In light of the above discussion, I would extend this metaphor to include the scientific disciplines, where each discipline rests upon certain 'rails' – that is, partial views of reality – that both open up and constrict our epistemic access to the world around us.

Extending this point, it may therefore be in one's interest to support one epistemic outlook (or 'rail') over another. Take how commercial interests are supported through the particular epistemic lens offered by biological reductionism; a lens that perceives determinism, predictability and control when looking at genes (see also Tesh 2000; Wales and Mythen 2002). As Brain Wynne (2005: 77) argues,

> [This] determinist commitment can instead be seen to reflect the instrumentalist epistemology of modern scientific culture overall, but is also a function of the wider commercial exploitation assumptions which have increasingly shaped the practical culture of such science – its take-for-granted context and worlds of potential wider meaning and use.

As others have argued, this commitment to determinism and predictability has been essential for building public support of biotechnology (Davison et al. 1997; Dietrich and Schibeci 2003; Jasanoff 2005a). This can be witnessed, for example, in the repeated use of such terms as 'predictability' and 'control' by GMO proponents to rebuff critics of this technology (see, e.g., Bradford et al.

2005: 440), while, conversely, critics of GMOs continually challenge such arguments (see, e.g., Jasanoff 2000: 279). Even discussions of complexity, which risk problematising these commercially essential beliefs of predictability and control, are frequently tempered by calls for the predictive modelling of such systems (see, e.g., Stephanopoulos et al. 2004: 1264). Thus, whereas traditional definitions of complexity presumed a degree of uncertainty (see, e.g., Joergensen 1990; Merry 1995), newer uses of the term have been stripped of this ambiguous epistemic component. This, again, is necessary so as to not challenge those beliefs of predictably and control, which are necessary if biotechnology is to be viable in the eyes of the public and thus commercially successful (McAfee 2003).

Yet the multidimensionality of the matter does not end here. As if the GMO debate was not complex enough, involving up to this point not only questions of *what is* but also competing answers to those questions given how understandings of the world are fundamentally situated. Now add to this the numerous moral questions that are implicit in the GMO debate and we can begin to appreciate the full complexity of the issue.

THE MORAL DIMENSION

The third component of environmental problems is perhaps the most ill-understood and least recognised of the lot, at least among the social and natural sciences. This component centers on the normative assumptions that underlie *all* environmental problems and debates. And the GMO debate is no different in this regard; it too rests upon a seemingly endless array of moral questions, which in part explains why we appear to be no closer to a resolution today to this debate than a decade ago. In an attempt to provide some analytic order to this section, I speak to five specific normative areas embedded within the GMO controversy. I refer to these areas as 1) the front-end problem, 2) the definitional problem, 3) the temporal problem, 4) the participatory problem, and 5) the objective knowledge problem. Each area begs a host of moral questions; questions that are typically black-boxed and unexamined but that lie at the heart of this debate.

The Front-End Problem

Front-end moral problems, as they relate to the GMO debate, speak to questions that were (tacitly) answered *before* these artefacts were created. Often, these questions address the essential 'goodness' or 'rightness' of the technology or practice in question. In the GMO debate, such front-end queries might ask, for instance, 'Are these technologies even necessary?' or 'Should we be crossing the species barrier, as is sometimes done in biotechnology?' Yet these questions have had little public airing; certainly they were not publicly asked prior to these technologies being released onto the world. For instance, in those rare instances where public participation is sought to speak to the normative underbelly of GMO technology, participation is typically directed at such 'back-end' questions as 'What constitutes an acceptable risk?' Rarely has public input been sought to determine whether these technologies even *should* exist or to what end they *ought* to be directed.

This is most unfortunate. For, ultimately, much of the public's dissatisfaction toward GMOs has been shown to lie not in irrationality or unwarranted fear but in a fundamental disagreement over these important front-end questions (Wynne 2005). As Brian Wynne (2002: 463) argues, attempts to improve public participation in risk assessments, while admirable, have served to 'perversely reinforce attention on only back-end science questions about consequences or risks' instead of looking at why such widespread public dissatisfaction exists toward modern technologies.

Admittedly, the front-end problem is particularly difficult to overcome. It is unlikely that a consensus will ever be reached on the subject of these front-end questions. Fortunately, all is not lost. While recognising there is no such thing as a panacea, one potential strategy to resolve such front-end disagreements is to 'open' every stage of production up for deliberation, from research, to development, to assessing threats. Thus, rather than solely focusing on the back-end of the production process, *after* a technology has been developed, participatory energies should also be directed at the front-end, to allow the public to provide direction to research trajectories.

Monsanto, for example, has been chided for making most of these front-end decisions behind closed doors (Hart and Sharma 2004). This has produced a research and development trajectory that meets the needs of only a few individuals, which in part explains why many in the world view Monsanto unfavourably (Hart and Sharma 2004). Yet, if these front-end decisions would have been made with input from a majority of their global stakeholders (and if Monsanto had taken this input seriously), things would likely be different. In doing this, Monsanto would quite possibly not have spent the last decade focusing so intensively on increasing the productivity of industrial-scale corn, soybeans and the like. Instead, they would have placed greater emphasis on the product development of crops that are important to a majority of the world's farmers (and not just the most industrialised few), such as cassava, sweet potatoes, etc. Developing technologies for the public and their needs, versus trying to make the public conform to these novel artifacts by locking them into a type of dependency (as is currently the case [Gomez and Torres 2001]), would do much to reduce public dissatisfaction toward GMOs and biotech companies (recognising also that GMOs would probably look considerably different than they do today if this strategy were adopted).

In short, public dissatisfaction toward GMOs need not be due to inaccurate answers to questions of *what is*. The public may in fact well understand the materialist workings of these artifacts and still reject the technology (Wynne

2002). That is because public dissatisfaction, at least at times, resides in moral questions that lie 'in front' of these artefacts, which ask whether we even *should* be engaging in such activities (or if the ends of biotechnology *ought* to be directed more toward putting food on the tables of the poor than cash in the coffers of large biotech firms). The take home message: meaningfully involve stakeholders in the creation (front-end) of these technological artefacts and they will likely be less suspicious of them at the back-end.

The Definitional Problem

The definitional problem stems from this simple point: when talking about, for instance, 'nature', 'risk', 'harm', 'society' and 'the common good' we are ultimately making subtle value statements. These moral assertions are everywhere. They can be seen in the very words the environmental sciences often unproblematically employ, in terms like 'seasonal *disturbances*', '*alien*' or '*invasive*' species, and ecological '*health*' or '*integrity*'. They are embedded in all conservation policies, where competing views of what nature *ought* to look like are reduced to the one implied in the policy implemented. And they underlie discussions of the common good, recognising that this concept is not objectively given. Thus, whether debating, for example, if GM food *ought* to be labelled or if GMOs harm the environment (given that 'harm to the environment' is not a self-evident scientific concept), we are ultimately engaging in discussions with normative underpinnings.

It should quickly become clear why the definitional problem is a *problem* when energies are directed at easing controversies surrounding GMOs: because if people are defining the very terms of the debate differently then consensus on the matter suddenly becomes considerably more difficult. Admittedly, we can never be sure that everyone is on the same definitional page when debating environmental problems/solutions. Yet, discussions that allow these terms to be opened up, with the goal of arriving at some consensus as to what these terms *ought* to mean, would at least help increase awareness of the subtle value judgments that underlie each.

The Temporal Problem

When talking about risks to the environment and humans posed by GMOs, what space/time are we implying? In such analyses, does the environment only mean the-environment-at-the-present-time or are we speaking about something more temporal, which exists within history rather than outside of it? What about humans: do only those alive today 'count' or should we include future generations in risk analyses? And how should we value these beings – for example, do we give the unborn as much value as currently living loved ones?

The temporal problem speaks to how time creates both disparities between potential stakeholders as well as barriers in our valuation of future beings. For example, to highlight the latter, time lies at the root of temporal fragmentation (which is fundamentally different from spatial fragmentation), which speaks to the problem agency as it relates to actors across time. As Gardiner (2006: 404) explains, while 'spatially fragmented agents may actually become unified and so able really to act as a single agent [...] temporally fragmented agents cannot actually become unified, and so may at best only act *as if* they were a single agent' (emphasis in original). In other words, even if we recognise future generations as being in possession of moral worth, those individuals will never be able to act with one collective voice, *as if* they were in possession of consensus on the subject. At best, this voice would be ours *imposing our beliefs* about what future generations would say on the issue.

Then there is the issue of how time creates disparities between potential stakeholders. This is most obvious in the incentive problems that exist due to the nearsightedness of our political institutions. Democratic political institutions have a difficult time 'seeing' more than a couple years into the future (Gardiner 2006). Recognising that the 'voting public' is composed of living, breathing beings, politicians have a tendency to place the needs of the living ahead of the non-living who cannot vote. Although politicians love to talk about protecting the rights of the unborn, what they really care about is being elected back into office. So unless those 'rights of the unborn' find a receptive audience among a large voting block of the (living) public, future generations appear to matter little to politicians who cannot see past the next election cycle.

Related to this is the disproportional relationship that often exists between the benefits and (potential/unknown) costs linked to contemporary technologies, activities and processes (Manson 2002). While many of today's environmentally questionable activities have negative effects that tend to fall disproportionately on future generations – such as with nuclear power, CO_2 emissions and natural resource extraction practices – the present generation is most likely to reap their benefits (Gardiner 2006; Pearce et al. 2003). Take the case of GMOs. While actors in the present (e.g., states, heavily capitalised farms, biotechnology firms, etc.) accumulate most of the benefits of biotechnology the potential risks are largely left for future generations to deal with – such as future losses of biodiversity (brought on by monocropping), 'super' weeds and insects/pests, and those 'unknown unknowns' that we cannot predict.

The Participatory Problem

The participatory problem speaks to an issue that emerges when the rubber of an abstract principle hits the pavement of reality. In recent years, public input has been sought to help inform environmental policy in general and GMO related matters in particular – through, for example, consensus conferences, public forums and Congressional hearings (Fuller 2006; Gregory 2002). Yet the principle of 'democratisation' – conceived as giving stakeholders a voice in issues that matter to them – inevitably bumps up against a number of brute facts. For instance, given that the category of 'stakeholders' is not self-evident (Wynne 2002), who is to be included in this group (and who decides this)? If rights are to be given to future generations, who speaks for them (and who decides this)? Or the environment: who speaks for it (and who decides this)? Nor can deliberation go on forever; otherwise decisions would never be made and actions never taken. So what constitutes 'sufficient' deliberation (and who decides this)? Indeed, the very principle of democratising decision making structures breaks down when put into practice, collapsing under its own logic. Although this principle argues that we *ought* to make decisions in a democratic matter it is itself *not* a product of its own prescriptive process – which is to say, this principle was not arrived at democratically.

My point in highlighting all of this is not to minimise the significance of these participatory structures. We just need to be realistic in our expectations of what they can accomplish. Even when participatory spaces are created to get at some of the moral questions that underlie environmental problems, there will always be people, things and spaces/times that are excluded from this process. It has to be this way: e.g., 1) for action to occur; 2) because not all can speak for themselves (e.g., future generations, the environment, etc.) and a representative is not self evident; 3) not everyone many choose to (or can) participate; etc.

We can see this playing out in the GMO debate. When assessing the costs, benefits and risks of these technologies, whom should we include in our understanding of a 'stakeholder' – e.g., farmers, consumers, future generations, environment, etc? And even if by some miracle we one day reach consensus on the terms included in this list we still have to arrive at a common understanding of what each term *ought* to mean (which brings us to the aforementioned definitional problem): e.g., what *should* be included in definitions of 'the environment', how far into the future *should* future generations be given a voice, and so forth.

This is not to suggest that such participatory structures have no value. Deliberation is an important means through which to open many of the normative black-boxes discussed in this section. Indeed, it is hard to image how conflicts tied to divergent normative underpinnings could be lessoned without some type of public airing of these moral (*ought*) questions.

The Objective Knowledge Problem

Not all knowledge is equal in the eyes of the courts, scientists, politicians and policy makers when it comes to understanding environmental problems (Haack 2005; Jasanoff 2005b). This brings us to the objective knowledge problem, which speaks to the obsession our political and regulatory institutions have toward so-called objective knowledge. While this could have been discussed in the aforementioned epistemological section, the objective knowledge problem ultimately rests upon a normative position: that objective, quantifiable knowledge *ought* to be of greater value than knowledge that does not conform to these particular parameters (this position is normative because the reasons supporting it are not self evident nor are they derived by logic alone [see e.g., Carolan 2008; Knorr-Cetina 1999; Latour 1987]).

Take, for example, risk assessment. An important point about so-called scientific risk assessment is that it can only 'see' those phenomena that can be objectified (Feldman 2004). As a result, risk assessment has a tendency to value *quantity* over *quality*. How many more bushels are produced annually using biotechnologies? What are the economic impacts of such artifacts? What is the probability for cross-pollination with a non-GM species? These are the questions asked in risk assessments. And each seeks answers that are reduced to a numerically standardised form, so as to allow for an 'objective' cost-benefit analysis to be performed. This is not to diminish the value of these important questions. Yet are these questions of quantity any more important than questions of quality, which speaks to issues that cannot be as easily reduced to a standardised numerical form? A question of quality as it applies to the GMO debate could be, for example, 'How do these technologies disrupt traditional systems of production, cultural roles and social networks?' Should the fact that such a question cannot be unproblematically reduced to a series of numbers make it any less important than those questions that can? Yet, alas: even this question cannot be answered without taking a normative – which is say, nonscientific – stance.

All of which begs the following question: *whose* interests are being recognised as a result of this asymmetrical valuation of questions of quantity over quality? Risk assessments have a tendency to overvalue the interests of those stakeholders whose values can be easily quantified. Note how the main interests of corporations revolve around issues of profitability. Yet this interest is undoubtedly more easily quantified than, say, the interests of aboriginal farmers in developing countries, whose concerns may include, for example, the preservation of tradition, culture and informal exchange networks (phenomena that are not easily reduced to a standardised, numerical form). It is therefore not surprising why debates over these technologies continue to rage the world over: because certain interests are implicitly being valued over – or at least acknowledge at the expense of – others.

Yet the implicit normative biases built into objective, scientific risk assessments are difficult to illuminate precisely because objective, scientific knowledge is, by definition, *not supposed to be that*. We are taught from a young age that objective knowledge is, well, objective, which to say it is value free, unbiased and amoral. Yet, while objective knowledge may *itself* be value free, how we get to the position that says this type of knowledge *ought* to be valued over others involves the making of value judgments.

CONCLUSION: COVERING ALL DIMENSIONS

The previous sections point to the need for a broader understanding of complexity; one that the looks beyond the materialist conceptions offered by the ecological sciences to include epistemological and moral questions (questions that are best answered by the social sciences and humanities). Ultimately, however, these three dimensions – the ontological, epistemological and moral – represent analytic heuristics. As mentioned earlier, they are independent, in that they each ask different questions. Yet they are also interdependent, in that each dimension subtly shapes, and is shaped by, the other two. Thus, while we can (and regularly do) analytically bracket off one realm from the others when studying environmental controversies (which is often a function of the disciplinary location of the analyst), we must not forget this interconnectivity.

The limitations of traditional materialistic conceptions of complexity as they apply to understandings of environmental problems should now be clear. A resolution to environmental problems cannot be found within the natural sciences alone. In fact, gleaning insights from the earlier sections, we can begin to understand why environmental problems and controversies are best addressed within the context of interdisciplinary frameworks. Of course, interdisciplinarity has never been easy; communication, methodological and theoretical differences and resource imbalances between disciplines are just some of the barriers to successful interdisciplination (Bauer 1990; Heemskerk et al. 2003; Lele and Norgaard 2005; Pohl 2005). Yet the importance and value of this strategy is clear.

In sum, my goal has not been to prescribe any one way to study environmental problems. Rather, my intention is just the opposite: to provide justification for an intentionally broad conceptual and empirical unpacking of such phenomena. While many still position the natural sciences, and the voice of natural scientists, at the front and centre of today's environmental controversies, increasing calls are being made for greater analytic diversity. In other words, answers are being sought for more than just the *what is* questions underlying environmental problems. This represents a step toward a fuller understanding of these matters; an understanding that reveals the true complexity of today's environmental problems and the interdisciplinary steps that need to be taken if we ever hope to resolve them.

NOTE

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