Rhetoric and Incommensurability

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10

Measuring Incommensurability: Are Toxicology and Ecotoxicology Blind to What the Other Sees?

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In the account of incommensurability Thomas Kuhn introduced in *The Structure of Scientific Revolutions,* scientists who inhabit one theory-based perspective are unable to recognize, understand, or accept entities revealed through observations made from an alternative theoretical perspective.* The difference of ontologies stands as a fundamental roadblock to communication. Scientists can move from one perspective to the other only through a gestalt switch, which makes the accounts of nature from the previous theory incoherent and lacking reference to the world.[1] In the switch the old gestalt has evaporated. Later, when Kuhn reformulated the cognitive divide as a matter of a communal switch of a taxonomic lexicon rather than an individual psychological switch of gestalt, incommensurability remained. The terms in the old taxonomy do not exist in the same world of relations—of similitudes, contrasts, subordinations—as the terms in the new. The new and old terms are incoherent in each other's presence, and are only intelligible when each is viewed within its own taxonomic world. In his later formulations, Kuhn does think understanding across boundaries is possible, but only by a process akin to learning a new language. Translation is inevitably misleading (Kuhn 2000, 33–57).

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This difficulty of communication goes well beyond Norwood Hanson's recognition that all observations are theory-laden (Hanson 1958). Kuhn suggests it is impossible to adopt an alternative framework to see the entities and relationships posited by alternative theories while keeping one's initial entities and relationships in mind. Even the measurements made from one theoretical perspective would find little credibility in the other, for the methods of measurement and the entities measured from one framework would have little standing in the other, because the methods and the entities of interest are both warranted by the theory, "paradigm-determined" (Kuhn 1996, 126).[2] Even more suspect would be the theoretical or second-order entities that cannot be directly observed and measured, but are conceived only as the theoretical consequences of the observable and measurable phenomena—which would constitute higher order terms in a taxonomic hierarchy. Hanson's observation suggests a degree of generosity and empathy in cross-theory discussion, while Kuhn's anticipates mutual incomprehension, if not hostility.

This paper examines the comprehension and incomprehension between an existing field (toxicology) and a newer one (ecotoxicology), which appeared to engage in paradigmatic conflict with the prior field to establish its own meaning and value. Examination of the shifting relations between the two fields, along with an intermediary field of environmental toxicology, suggests that neither incomprehension nor generosity ruled the day. Rather the practical problems and interests that sponsored the fields prompted an accommodation that respected the value of the work of each. Each of the three fields needed the intellectual and evidentiary resources of the others.[3]

Habits of Thought in Pure, Bounded Science Versus Socially Saturated Sciences

Incommensurability gives philosophic warrant to a kind of intellectual stubbornness within a knowledge space wholly occupied by rational considerations.[4] One theory, one perspective on the world, in Kuhn's view, replaces another because anomalies become intellectually intolerable to a group of scientists, particularly newer ones, who are less fully habituated into the previous perspective. Scientists are not led to abandon the old theory because their problem changes or their interests shift to new concerns or they bring new resources and cultural dispositions. After a period of confusion, a new theory emerges that better matches the data and gains the adherence of scientists who find the theory solves their intellectual problem. The Kuhnian scientific world assumes a bounded rational world of science influenced only by its own internal logic, uninfluenced by what would be considered external to its investigative and reasoning procedures. Even as he moved from an individualist mental view of cognition to one of group cognition supported through a shared lexicon, the commitment remained to a science moving by its own logic, separate from worldly concerns and interests. Similarly, as he simultaneously shifted his focus from revolutionary scientific change to specialization, he continued to locate incommensurability at the boundaries of specialties (Kuhn 2000).

In a self-contained world of science, fundamental problems do not shift greatly; more adequate accounts of phenomena are just sought and gain ascendancy. To Kuhn the problems of Anaximander, Aristotle, Ptolemy, Copernicus, Kepler, Galileo, and Newton were all much the same (Kuhn 1957): explaining the motions of the heavenly bodies. The problem solved by phlogiston theory was not far from the problem solved by oxygen (Kuhn 1996). Stephen Toulmin (1972), in presenting a survival-of-the-fittest theory refinement of Kuhn's rationalist theory, says the continuity between generations of scientists and their theories (what he calls the *transmit*) is the problem formulation.

Much of the history and sociology of science dating back to Robert Merton's 1938 *Science, Technology, and Society in Seventeenth Century England* suggests that in many, if not all, instances science is not fully bounded from other socio-cultural domains, that the processes of investigation and adjudication are not purely or simply rational, and that problem choice changes substantially and sometimes rapidly, as people are motivated by different concerns and interests (in both the intellectual and self/group-seeking senses of the term). Further, even the notion of a bounded rational science is a new historical construction, maintained with considerable rhetorical energy (Gieryn 1999; Shapin 1994; Shapin and Schaffer 1985; Bazerman 1988). From a philosophy-of-science perspective, this would suggest there is no essential criterion demarcating a boundary between science and non-science, but only a contingent historical definition serving local practical purposes. This

position was suggested in a broad way by Feyerabend (1975) and was more fully articulated by Taylor (1996).

If there were a bounded space where scientific problems were held stable and action were simplified to a pure intellectual pursuit of best answers, theory change perhaps might be adequately described in Kuhnian terms of revolutionary gestalt shifts or new specializations with novel taxonomic lexicons. Within a world where there are no other forces beyond intellectual conviction to motivate change in concerns, problems and points of view, one can be stubborn in sticking by one's intellectual guns and can dismiss what is beyond one's vision as faulted, chimerical, unsubstantiated and unsubstantiatable. There is no exigency for change beyond what you and others think of your thought—and for those purposes it may be better to be a champion of a cause, even if it is losing, than to be a late convert to another's creed.

The case we examine in this paper does indeed in some respects resemble Kuhnian normal science replaced by a revolutionary paradigm shift. Even more it might be seen to resemble his later model of proliferation of specializations, each with different hierarchies and taxonomies of conceptual terms. Some actors in this case did resist and dismiss the new, particularly with respect to measurement outside the practices of the older normal science. Ultimately, however, there was little problem of incommensurability between the disciplinary perspectives of the two specializations. Further, while a number of pioneers of the new field describe the new endeavor in Kuhnian revolutionary terms, they never dismiss or displace the older discipline. That field continues going about its traditional business "normally." The new field never stops accepting the findings, measurements, or methods of the old, although placing them within a new framework, and the old gradually comes to recognize the findings, work, and methods of the new. The holders of alternative hierarchies and taxonomies find effective enough ways of communicating with each other to carry on their respective businesses, with the help of each other.

An "Impure" Case

But then, the case we will be looking at is not bounded in the pure space of rational science imagined by Kuhn—it is pervaded by the interests of industries, professions, politics, government regulations, the daily lives of people, and the health of the planet. One might think that those varieties of "nonscientific" interests might lead to an even greater intransigence and refusal to recognize the importance of alternative points of view, methods, measurements, and ontologies. One might expect that "rational science" might be more open-minded than applied sciences caught up in the ideological, economic, and political push and pull of life. But at least in this case, it is the complexity of nonscientific life that creates changing exigencies of concerns, changing definitions of problems and changing domains of interest, and complex multiple areas of engagement and activity. These complexities leave seemingly overlapping sciences and theoretical perspectives alive, side by side, each accomplishing their work and respecting the work of the other insofar as it fits their needs and interests. Each set of interests focuses empirical inquiries as well as provides boundaries around empirical attention. As interests change or divide, attention shifts. Loyalty to theory and theory-warranted methods evokes some defensive reaction, but as interests shift or expand attention, the need for empirical knowledge about new domains leads to acceptance of phenomena and methods, even if they are not fully within the toolkit of prior theory. As intellectual interests are so integrated by the interests of other domains of action, it is hardly possible to talk about these sciences as having hard boundaries dividing the internal and the external. The sciences here provide epistemic means for carrying out various human ends in as empirically grounded a way as current theory and methods will allow. The sciences we are looking at here are means of knowing the world so as to act effectively within this world while avoiding untoward effects of human action. What some might call "external factors" set the agenda for work and attention. It is then up to the applied fields to find and develop what they consider the most empirically grounded and intellectually justifiable way to carry out that work.

The case we are examining here is that of the relations of the recent field of toxicology to the even newer field of ecotoxicology, along with an intermediate field of environmental toxicology. Toxicology itself emerged as a distinct field from its parent, pharmacology, only in mid-twentieth century, but soon normalized in theory and practical method—even as both deepened with advances in biology, medicine, and chemistry. From its beginning it was a field that served a diverse set of needs—from the fields of medicine and pharmacology; from

drug, chemical, and cosmetic corporations; from government regulatory bodies; from the criminal justice system; and from various other political concerns. Those interests directly motivated toxicology's projects and methods: identifying the dosages at which chemical substances had toxic effects on humans and, secondarily, on economically valuable domesticated animals, describing and understanding those effects, uncovering the mechanisms of those effects, and detecting the presence and levels of toxicants in individuals. Its studies were conducted under laboratory conditions where individual organisms were exposed to controlled amounts of toxicants. In the 1960s, with increasing public awareness of environmental pollution, toxicologists had a new range of substances to examine and a new set of government regulations, industries, and public interest groups to motivate and or/sponsor their work.

Soon some scientists began arguing that environmental pollution problems could not be fully understood in the laboratories by studying dose effects on individual organisms nor on individual species. They argued for gathering data and studying effects in the field, for studying populations rather than individuals, and for studying dynamic and complex effects in the ecosystem overall rather than isolated effects on separate species regarded independently of each other. Further concern turned from protecting humans, and species economically valuable to humans, to protecting all species participating in ecosystems. Although borrowing some techniques and knowledge from toxicology, these new concerns required a fundamentally different form of knowledge, with a radically different theoretical perspective, one that expanded the scope of entities and systems of interest to the field, employed new theories to describe relations among the entities, and new ranges of measurement to gather data about these entities. These incipient ecotoxicologists measured things that were not part of the ontology of toxicology and they measured them in ways that were not accepted and had no standing within toxicology.

As ecotoxicology emerged just when Kuhn's work was becoming widely known, the founders of the field adopted Kuhnian terminology to describe the novelty of their enterprise and to assess its maturity. Yet when we look at this story in greater detail we do not find the hard-edged verbal battles of opponents with different worldviews—those who see the rabbit versus those who see the duck, Unitarians versus Trinitarians, small-enders versus big-enders. Nor do we see opponents refusing to talk. Over time we see a complex pattern of communication, an emerging division of labor, continuity and evolution of practices in both the traditional field and the revolutionary one, and a deepening accommodation between the two. Not only is mutual communication taken seriously, their respective entities and measures are taken seriously and used as needed by each other. Although there was some early dismissal of each other's approach, suspicion of the methodological clarity and direction of attention motivated by alternative approaches, over time there seems little that fits the Kuhnian profile of incommensurability, although foci of attention do remain largely distinctive. While the two disciplines for the most part look in different directions, when they need to, their eyes wander to the other side, and they each accept what the other finds.

We draw evidence for the degree of commensurability between specialties by looking at the historical development of publications that present and codify knowledge in the specialties. Our measure of commensurability is whether each field accepts the phenomena and results the other sees through its methods and theory. We examine field-defining statements of leading researchers of toxicology and ecotoxicology to see how they explicitly connect or divide fields and how they evaluate methods and evidence relevant to their field definitions. We also examine the leading journals of toxicology, environmental toxicology, and ecotoxicology, at their founding and in their current manifestations, in order to see the range of phenomena, methods, and references to journals of other fields. Finally, we examine textbooks and other compendia to see how the three specialties of toxicology, environmental toxicology, and ecotoxicology characterize their phenomena of interest and methods to newcomers, as well as how they position the value of the work and findings of the other fields to their own. While textbooks typically lag several years behind the research front, they represent widely held views and so can be taken to indicate consensus views. The historically grounded analysis we present here examines how texts form relations with particular ways of viewing the world, empirical practices, and observed phenomena, as well as with other bodies of texts and groups of practitioners. Such an analysis can be seen as rhetorical in its close attention to what texts do, even though our particular analytical concepts are not drawn from classical rhetoric and we examine patterns across large numbers of texts rather than closely examining extended passages from individual texts.[5]

Classic Toxicology

Toxicology has its roots in the earliest human selection of food, avoidance of poisonous animals, and use of poisons on weapons. The word *toxin* comes from the Greek word *toxon*, meaning 'bow.' Papyri dating from the second millennium BCE indicate Egyptians had extensive knowledge of poisons and curatives; Nicander of Colophon (204–138 BCE) wrote two early treatises on snake and plant poisons; medieval and renaissance herbal compendia and other documents attest to a wide knowledge of toxic substances. However, the principles of modern toxicology rest on the insight of the sixteenth century Swiss Physician Paracelsus who pointed to the importance of the dose. "Everything is a poison," he wrote, "it is only the dose that makes it not a poison." In the early nineteenth century the Spanish chemist Bonaventura Orfila, began the "systematic use of test animals" and developed "methods of chemical analysis to identify poisons in tissue and body fluids" (Niesink *et al.* 1996, 5).

Standard procedures for the investigation of toxic effects of substances soon emerged, and in the first half of the twentieth century development of the pharmacological, processed-food, and industrial-chemical industries increased the pressure for standardized toxicological tests, particularly in the wake of government regulation. In the United States the Food and Drugs Act of 1906 made mislabeling and adulteration crimes, but did not provide for prior regulation. The replacement Food, Drug and Cosmetic Act of 1938 mandated proof of the safety of drugs before their marketing, established safe tolerances of unavoidable poisons, and extended regulation to the cosmetics industry. World War II military needs created the influential Toxicity Laboratory at the University of Chicago (Doull 2001). In the United Kingdom the 1925 Therapeutic Substances Act had requirements for labeling and record keeping, but safety testing was not required until the 1960s, with the 1963 creation of the Committee on Safety of Drugs, and the Medicines Act of 1968. The first journal of experimental toxicology was *Archives fuer Toxikologie* (*Archives of Toxicology*) founded in 1930, and continuing until today.

In both the U.S. and the U.K., the primary disciplinary sponsor of toxicological studies has been and remains pharmacology. From 1961 to 1975, toxicological research was covered within the *Annual Review of Pharmacology*; in 1976 toxicology gained status but remained paired with pharmacology in the *Annual Review of Pharmacology and Toxicology.* This serial has an impact factor three to four times greater that of any other serial in the field (based on 1997 and 1998 Journal Citation Reports). The longest continuously published U.S. toxicological journal is entitled *Toxicology and Applied Pharmacology,* founded in 1959. The Society of Toxicology was formed in the U.S. in 1960 to distinguish itself from pharmacology, but many of the articles in the journal relate to pharmacological substances. According to the *Society of Toxicology Resource Guide to Careers in Toxicology* (1989) the Chemical, Pharmaceutical and Support Industries provided 37 percent of the jobs in the field, followed by academic institutions (33 percent)—mostly in schools of medicine or public health. The overwhelming majority of graduate programs listed in the guide are affiliated with schools of pharmacology or medicine. Government is next with 15 percent—mostly in federal regulatory agencies. Nowhere is environmental work mentioned in the *Resource Guide,* although it is likely that some of the regulation involves environmental related work.

As described in the standard textbook, *Essentials of Toxicology,* the field concerns "the study of quantitative effects of chemicals on biological tissues" with a particular focus on "harmful actions" (Loomis 1968, 2). Following Paracelsus, Loomis notes "the single factor that determines the degree of harmfulness of a compound is the dose of the compound." Thus the cornerstone method of toxicology is dose-response studies done under laboratory conditions by exposing organisms to measured amounts of toxicants by inhalation, oral ingestion, injection, or cutaneous administration and measuring the degree of uptake of the toxicant and effect in each organism. As the largest interest is on toxic effects on humans, studies typically use surrogate species. Test species are bred for laboratory uniformity. These are the principles and methods reviewed with little change in the four editions (1968, 1974, 1978 and 1996) of Loomis' *Essentials.* The major difference among the editions is the increasingly detailed treatment of laboratory principles and methods along with an increasing number of laboratory tests presented. The fourth edition also adds a new chapter on clinical toxicology.

Method and Ontology in Journals in Toxicology

These well-defined and reasonably stable principles, practices, and procedures are reflected in the articles appearing in the top-line journals of the field. The journal *Toxicology,* the official journal of the British Toxicological Society, defined its concerns in its first volume in 1973 as

> the biological effects on tissues arising from the administration of chemical compounds, principally to animals, but also to man. Such compounds include food additives, pesticides, drugs, additives to animal feed, chemical contaminants, industrial chemicals and residues consequent upon their use. (*Toxicology* 1973)

It notes however, "A section devoted to brief reports on toxicological evidence related to the environment will be included." Research articles were limited to reporting quantitative studies. Almost all the articles in volume one report or review laboratory studies, mostly of dose-response (with three exceptions, to be discussed shortly). Representative titles include "The Influence of Dichlorvos from Strips or Sprays on Cholinesterase Activity in Chickens" (Rauws and van Logten 1973), "Tryptophan Pyrrolase in Rat Liver after Phenobarbitol Administration" (Seifert 1973), and "Short-Term Peroral Toxicity of the Food Colour Orange RN in Pigs" (Olsen *et al.* 1973). There are three exceptions to this pattern. One looks for an "objective measure of environmental effects through use of plants" (Berge 1973, 79). A second reports on the regulatory limits for toxicants in water in the Soviet Union (Stofen 1973), a concern closely related to the concept of laboratory-established threshold levels of toxic dose. The third exception, the first article in the first volume, to be discussed shortly, strongly reflects commitment to the laboratory dose-effect model of toxicological science (Worden 1973).

The opening purpose statement of *Toxicology* remained in 2001 much the same as it did at its founding, with only some reordering of terms and some additions to the list of chemical compounds of "consumer products, metals, cosmetics" and as

> the biological effects arising from the administration of chemical compounds, principally to animals, tissues or cell, but also to man. Such compounds include industrial chemicals and residues, chemical contaminants, consumer products, drugs, metals,

> pesticides, food additives, cosmetics and additives to animal feeding stuffs. (*Toxicology* 2001)

Again there is a limitation to quantitative studies: "Preference will be given to investigations dealing with the mechanisms of action of toxic agents. Papers describing molecular interactions with cellular and genetic processes will be welcomed" (*Toxicology* 2001). All articles in volume 159 (2001), for example, were laboratory dose-response studies with titles such as "109 CD Accumulation in the Calcified Parts of Rat Bones" (Hunder *et al.* 2001) and "The Effect of Polychlorinated Biphenyls on the High Affinity Uptake of the Neurotransmitters, Dopamine, Serotonin, Glutamate and GABA into Rat Brain Synaptosomes" (Mariussen and Fonnum 2001).

The longest continuingly published toxicology journal in the United States (founded 1959) is *Toxicology and Applied Pharmacology*, and it remains a leading journal of the toxicological field. It is one of two journals published by the Society of Toxicology.[6] As its name suggests it is closely tied to the testing of pharmaceutical agents and other medical applications of toxicology. The work published from the beginning has been and currently remains entirely laboratory based, primarily of dose-response (and associated mechanisms) in live organisms and, increasingly, in vitro tissues. The official statement of the journal says

> *Toxicology and Applied Pharmacology* publishes original scientific research pertaining to action on tissue structure or function resulting from administration of chemicals, drugs, or natural products to animals or humans. Articles address mechanistic approaches to physiological, biochemical, cellular, or molecular understanding of toxicologic/pathologic lesions and to methods used to describe these responses. Papers concerned with alternatives to the use of experimental animals are encouraged. (*Toxicology and Applied Pharmacology* 2005)

The first sentence has barely changed from the purpose statement of the earliest years of the journal.[7] The second sentence (added in the 1980s) adds a particular interest in the mechanisms of the induced effect, and the last sentence, added in the last few years, reflects increasing sensitivities to the use of test animals.[8]

All sixty-one research reports in *Toxicology and Applied Pharmacology* in a representative early volume (Volume 8, January-June 1966), concerned laboratory dose-response studies on animals, with fifty involving pharmaceutical and medical-related substances. Typical titles include "Acute Toxicity of Cephaloridine, an Antibiotic Derived from Cephalorisporin C" (Atkinson, *et al.* 1966) and "On the Mechanism of Sulfide Inactivation by Methemoglobin" (Smith and Gosselin 1966). Of the research reports, five were directed towards food treatments and additives (e.g., "Feeding of Irradiated Beef to Rats"—Blood *et al.* 1966), and six were related to agricultural and industrial environmental pollutants. The environmentally polluting toxicants were studied in exactly the same manner as the pharmacological agents, and the articles are of the same genre and read similarly (e.g., "Foot Deformity in Ducks from Injection of EPN During Embryogenesis" —Khera *et al.* 1966). Two of the articles are particularly interesting in terms of bringing environmental issues into the normalized practice of toxicology. "Cholinesterase Inhibition and Toxicological Evaluation of Two Organophosphate Pesticides in Japanese Quail" (Schellenberger *et al.* 1966) has as its aim evaluating the usefulness of Japanese quail as a laboratory species to test toxicity of pollutants on all game birds. In order for efficient and normal toxicity studies to proceed a single species needs to be identified that will "provide representative data" and is suitable for laboratory breeding. The second article attempts to develop new laboratory measurement methods to record the effect of air pollution, and thereby make this environmental problem more amenable to study by laboratory toxicology: "Application of the Evoked Response Technique in Air Pollution Toxicology" (Xintaras *et al.* 1966).

Just a few years later, in 1969, volume fourteen reveals the effect of increased environmental concern with at least twenty research reports on the toxicity of various agricultural and industrial environmental pollutants, with the majority concerned with pesticides such as DDT, dieldrin, and parathion. We also see the effect of other changing social concerns, with four studies directed towards the effects of alcohol, another towards the effects of marijuana, and a sixth towards amphetamine. All articles follow the normalized practices of the field. One, however, again shows an interesting attempt to bring complex environmental problems into the normalized science: "An Exploration of Joint Toxic Action: Twenty-Seven Industrial Chemicals Intubated in Rats in all Possible Pairs" (Smyth *et al.* 1969). As the report explains

"In the occupational, domestic or ambient environments, encounters with mixtures of chemicals far outnumber encounters with individual chemicals" (Smyth *et al.* 1969, 340). The study develops laboratory methods for measuring and analyzing joint toxicity and points to instances where the effect of joint exposure was greater or lesser than one would expect by additive effects of the separate exposures. It then notes patterns in these variances.

Current issues of the journal continue with the laboratory studies, but with a particular focus on uncovering mechanisms of action, as suggested by the current statement. The selection of topics has tended to be more narrowly focused on substances of pharmaceutical and medical interest, perhaps because environmental issues now have a range of journals in which they may be pursued, as we will discuss below. However, when they are discussed they follow the current normalized laboratory practices of the field, as in "Induction and Inhibition of Aromatase (CYP19) Activity by Various Classes of Pesticides in H295R Human Adrenocortical Carcinoma Cells" (Sanderson, *et al.* 2001).

The Social and Political Birth of Ecotoxicology

During the 1960s and 1970s, as toxicology was settling into its modern "normal science" themes and practices, a new social concern was developing in the environment, catalyzed by Rachel Carson's 1962 *Silent Spring,* publicizing the dangers of DDT and other insecticides and herbicides.[9] In some of her chapters, Carson adopted an ecological perspective that cast the threat not just to individual organisms and species but to the entire balance of nature. And while she documents the direct toxic effects of insecticides on humans, as well as the cumulative effects as they pass up the food chain, she also considers the effect of ecosystem change on humans. A report of the President's Science Advisory Council on "The Use of Pesticides" soon followed, taking a much stronger stand on the dangers of pesticide use than it and other government agencies (such as the Department of Agriculture and the Food and Drug Administration) previously had (Wang 1997). One consequence of the heightened concern for the effect of chemical poisons was a 1972 strengthening of the Federal Insecticide, Fungicide, and Rodenticide Act. This law provided for registration, data submission, and approval of pesticides for particular uses, as well as monitoring of production facilities and seizure and criminal penalties for illegal distribution and use. Other regulatory legislation soon followed. But unlike most previous toxicological problems, the exposure was not direct (as through ingested food or medicine). Exposure was ambient and required field monitoring of toxicant levels, as well as complex estimates of exposures of individuals. Further, it was unclear whether the exposure within natural contingencies was adequately modeled by laboratory tests of controlled exposures under controlled conditions. Rather than being concerned about thresholds for a well-defined toxic effect, demographic studies of effects of lower level entered in, as did the concept of risk assessment. Nonetheless most regulation at least followed the notion of regulating the level of exposure or dose. Other scientists, however, saw the issues in ecological terms and called for ecological studies aimed at protecting the biosphere as a whole.

Truhaut's Revolutionary Vision

René Truhaut in 1969 coined the term *ecotoxicology* for this new approach in a speech before the International Council of Scientific Unions, and he is generally recognized internationally as the founder of the field.[10] In 1977 the first journal of this new field appeared, *Ecotoxicology and Environmental Safety.* The editors' foreword to the first issue of this flagship journal of ecotoxicology draws a sharp distinction between the new field of ecotoxicology and classical toxicology:

> Ecotoxicology can be defined. [. . .] as the study of the adverse effects of chemicals, natural products, and physical agents on populations and communities of species of plants, animals, and microorganisms as they occur and are organized in nature. In contrast to classical toxicology, which deals predominantly with the toxic effects of chemicals on individual organisms, Ecotoxicology is essentially the study of the toxic effects of environmental chemicals on naturally occurring populations in various ecosystems, including Man. (Foreword 1977, iii.)

Although there is no overt opposition here, the statement by clear implication ("In contrast to classical toxicology ... ") draws dividing lines on a major conceptual issue and a major methodological issue. Conceptually, the units of analysis are populations and communities within ecosystems rather than individual organisms or isolated species. This position further implies that ecological systems theory is to play an important role, and not just organic chemistry, biochemistry, pharmacology and other studies that isolate mechanisms within individual organisms. Methodologically effects are to be studied *in situ*—in the field, as organized in nature rather than under the controlled and abstracted conditions of the laboratory. The guide-for-authors statement in 2005 goes significantly further in making ecosystems the unit of analysis, rather than organisms or populations in ecosystems:

> [. . .] Novel technologies, techniques and methods such as the biomedical photonic technologies, biomarkers, biosensors and bioanalytical systems, QSARs and QSPRs, advanced high-performance computational methods, models and storage systems, and their applications in the obtaining and processing of interdisciplinary ecotoxicological information, are [...] addressed in the journal. We welcome the applied outcome of the complex ecotoxicological research such as developing the science-based Environmental Quality Criteria (EQC), standard toxicity tests, techniques and methods for ecotoxicological evaluation of the environment, as well as developing ecotoxicologically proven methods and technologies for prevention, interception and remediation of human-induced damage to ecosystems. (Guide for authors 2005)

Qualitative studies are now welcomed, as are papers using the techniques of a wide range of disciplines.

Truhaut, in an article in the premier issue, takes on Paracelsus's founding principle of toxicology, cited by almost every overview of toxicology, that the dose makes the poison. In "Can Permissible Levels of Carcinogenic Compounds in the Environment be Envisaged? Critical Remarks" Truhaut argues that some substances being released in the environment are toxic at any level. He frames the challenge to classical toxicology baldly in the opening sentence and a single-sentence contrasting third paragraph.

> The golden rule in toxicological evaluations of environmental pollutants is to establish dose-effect (exposure-effect) relationships in order to be able to set toxicity threshholds and, consequently, permissible limits. [. . .]
>
> But in the case of carcinogens, a current view is that it is impossible to establish safe levels, because there are no thresholds for action. (Truhaut 1977a, 31)

After reviewing the evidence and arguments on both sides, he supports a World Health Organization conclusion that while thresholds might be envisioned, they have not been determined and are exceedingly hard if not impossible to determine. Thus rather than seeking no-effect thresholds we must calculate risks and adopt "socially acceptable risk" levels (Truhaut 1977a, 31).

In the second issue of this journal, a long article by Truhaut spells out "Ecotoxicology: Objectives, Principles, and Perspectives." In this article, which is often cited as the founding document of ecotoxicology, he associates the development of toxicology with the chemical age and the consequent need to study the effect of the industrial chemicals upon organisms, particularly man. However, he points out that man is part of an ecosystem and that chemicals affect the entire biosphere. It is, therefore, important to study toxic effects "in the context of biologic equilibria, the study of the harmful effects on the various constituents of ecosystems of chemical pollution of the environment, for which man is to a large extent responsible"(Truhaut 1977b, 152). An earlier 1974 definition of the field talked of the effect of pollutants "to the constituents of ecosystems, animal (including humans), vegetable and microbial, in an integrated context" (Truhaut 1974). But already the distinction was being reframed as the impact not on organisms but on "populations of living organisms [. . .] constituting ecosystems" (Truhaut 1977b, 152). In light of this redefinition, Truhaut identifies three principal sequences of ecotoxicological studies.

1. Study of the emission and entry of pollutants into the abiotic environment, with their distribution and fate.

2. Study of the entry into and fate of pollutants in the biosphere, with the very important problem of contami-

nation of biological chains, in the first place of food chains.

3. Study, qualitative and quantitative, of the toxic effects of chemical pollutants, at a certain level, to ecosystems, with investigation of the impact on man. (Truhaut 1977b, 153)

Even though he casts ecotoxicology as a subfield of toxicology, he clearly marks the field as different in object of analysis—the ecosystem and populations within ecosystems. He also marks the field as different in conceptual frame and different in method. Ecotoxicology is not limited to quantitative studies in the laboratory; it studies effects on populations and ecosytems in the field, as they are organized in nature. In his detailed comments on these three areas he follows disciplinary orientations that are outside the normalized world of toxicology. He does incorporate traditional toxicological work in talking about the importance of establishing quantitative dose-effect relationships in order to determine toxicity thresholds and allowable limits—for which laboratory studies are useful. But then he talks about the limitations of laboratory studies and surrogate animal studies for humans, pointing out the necessity of qualitatively comparing laboratory effects to populations of actually exposed humans, and calls attention to species differences and selective toxicity (Truhaut 1977b, 165- 166), stage of life, and interactions within complex ecosystems.

It is in the final section on "Perspectives and Prospectives in Ecotoxicology" that Truhaut takes the most transformative stand in calling for the multidisciplinary collaboration of ecology and toxicology. Ecology is anchored in the field-based study of systems over time, requiring statistical studies as well as qualitative observation. Toxicology is anchored in the laboratory-based study of individual organisms demonstrating specific concrete effects. While Truhaut retains a central place for dose-effect studies and what he calls the routine tests of toxicology, they need to be reassessed in light of the actual life, habitat, conditions of exposure and other field-based considerations:

> Joining efforts, toxicologists and ecologists should not forget to pay attention to the possible consequences for an ecosystem in its totality. To this end, *models with predictive value* should be established (Metcalf 1974), and laboratory studies should be complemented as much as possible by field studies on a much larger scale, using data from chemical analysis in a *continuous surveillance* of the environment in adequately programmed "monitoring." (Truhaut 1977b, 171)

Truhaut takes the stance, common at the beginning of widespread environmental concern, that we do not know enough to act and we need new studies. This was indeed the political attitude and stance that led to National Environmental Policy Act of 1969, which mandated Environmental Impact Statements for projects involving federal lands. The EIS, which soon became widely imitated, was a mechanism for increasing information to lead to wiser decisions rather than directly regulating behavior. The need for more knowledge about the environment was central to the rhetoric of the Impact statement's great advocate, Lynton Keith Caldwell, as well as the congressional discussion preceding the passage of NEPA (see Bazerman *et al.* 2002). Just as Caldwell felt that new governmental mechanisms were needed to generate the needed knowledge, which led to NEPA and the EIS, so Truhaut finds a new discipline necessary.

In Kuhnian terms, this is revolutionary science, despite Truhaut's meliorative language. While the work of toxicology is embedded in ecotoxicology as a contributing element, it is clearly cast as limited and inadequate in theory and method to deal with the full scope of problems. Specifically, in terms of incommensurability, one must measure and take into theoretical account entities that are outside of the scope or vision of classical toxicology, using methods and devices that are not recognized within the traditional field.

First issues of the journal *Ecotoxicology and Environmental Safety* included some articles in the dose-response laboratory paradigm, but concerning environmentally important chemicals, such as the first article of volume one, issue one, "Studies on the Interactions of Dieldrin with Mammalial Liver Cells at the Subcellular Level" (Wright *et al.* 1977). However, it includes a number of broad ranging essays, some of which use field, demographic, economic, and public health data, as in "The Importance of Chlorinated Hydrocarbons in World Agriculture" (Snelson 1977), and "Organicochlorine Pesticides and Liver Cancer Deaths in the United States, 1930–1972" (Deichmann and

MacDonald 1977). Other articles propose and evaluate methods for monitoring environment, such as "Assessment of the Trace Organic Molecular Composition of Industrial and Municipal Wastewater Effluents by Capillary Gas Chromatography/Real-Time High-Resolution Mass Spectrometry: A Preliminary Report" (Burlingame 1977).

Contrasting Disciplinary Visions

While the two flagship articles in the 1977 first volume of *Ecotoxicology and Environmental Safety* by the founder of the field of ecotoxicology call for new methods and new ways of thinking, the flagship article of the journal *Toxicology*, the first one in the first volume ("Toxicology and the Environment" by Alistair Worden) shows methodological caution and skepticism about non-traditional evidence suggesting environmental damage, as well as potentially risky products. The article is the text of the "Annual Lecture at the Royal College of Physicians, London, Sponsored by Merck, Sharp and Dohme Research Laboratories." As he reviews the state of evidence on a number of high-profile issues concerning pharmaceuticals, industrial chemicals and the environment, his attention is as much on those raising concerns as on the science. The spirit of his talk is captured by his introductory statement:

> It is possible to speak from experience of some of the approaches that are being made to tackle toxicological and environmental problems, but an evaluation of these problems is complicated beyond the comprehension of most of us by the genetic make-up, the innate or early-acquired behavioural patterns and the varying social and political motivation of our own species. [. . .]
>
> It is not surprising that the reaction among so many of us is alarmist, or that the allegiance of the cranks, the do-gooders or the somewhat unkindly designated lunatic fringe is so frequently transferred to an anti-pollution campaign or to stressing the potential dangers of new therapeutic agents. (Worden 1977, 4)

Worden does grant some grudging respect to Rachel Carson for making the public aware of toxic issues "whatever the special pleading or

the technical shortcomings of [*Silent Spring* . . .] its intended message was a stimulus to research and thought that will not, in the long run, have proved damaging either to the general public or to the agricultural and chemical industries" (Worden 1977, 5). He, however, consistently shows skepticism about research outside laboratory dose-effect studies on animals, which remains his gold standard. He argues for maintaining animal laboratory studies as central even if satisfactory tissue culture methods are developed. Methods and calculations that go beyond the lab are dismissed by him, such as the systems models used for the Club of Rome's *The Limits to Growth* (Meadows *et al.* 1972). He does allow some measures of environmental contamination but he is also ready to state that evidence of higher concentration of mercury in fish and humans in contiguous coastal areas can be traced to the eating of canned tuna, and that higher concentrations apparent in England in comparison to other countries appears "no cause for alarm" (Worden 1977, 13). Similarly, he discounts heavy concentrations of chemicals and fish mortality in Hungary as being confounded by river flooding. Real-world measures seem for him to be too multicausal and situationally complex to draw conclusions from. He does express concern for pollutants in industrial waste discharged into sea water, and does guardedly note that manufacturers are not fully forthcoming. "I have tried to pay tributes to industry and to its co-operative attitude," he says, "but it is difficult to escape the conclusion that not all the information that could, and should, be provided on the subject of the industrial effluents discharged into rivers, estuaries and the sea has been forthcoming" (Worden 1977, 19). This guarded criticism is immediately cushioned by praise of industrial cooperation in decreasing PCBs. He ends with some jokes implying environmental criticism is the moral equivalent of adultery (tempted to be faithless to true principles) that suggest he misses the point of toxicological science by a rather wide margin. He then reaffirms his methodological faith: "We are facing quantitative problems and should try to quantify the help we try to give to their solution" (Worden 1977, 24). Given his clear distrust of numbers gathered in the field, this can only mean laboratory measured quantities under controlled conditions.

The division between the stances of Truhaut and Worden is sharp. One argues that since we do not know enough about the effect of human activity on the environment we need new theories and new methods which gather data widely from the complex world where effects take place, in order to be able to understand and model the total picture and understand the risks we are putting ourselves in. The other argues that we should be cautious in identifying toxic effects, holding ourselves to the highest standards of scientific data, with controlled laboratory conditions and precision of measurement of dose and response defining that standard. If we restrict industry and economic growth without that level of certainty we do more harm to human development than good. It is not just their theoretical and epistemic commitments that differ. Truhaut ascribes no overt commitment to those who stand on the opposite side from him, but he is clearly an advocate of environmental protection who believes that we are in great difficulty and must know more so we can act. Worden clearly sees human development and interests advanced through industrial growth, particularly through the introduction of agricultural chemicals and new pharmaceuticals, but unlike Truhaut he is willing to ascribe unscientific political, social and psychological motives to those who take the position opposite from him, representing his own motives, and those of traditional toxicologists generally, as simply pursuing the interests of true science.

This case in many ways appears to be a sharply drawn example of the Kuhnian conflict between normal science and revolutionary science, with a strong dose of incommensurability thrown in. The themes and practices are clearly at odds, and the incommensurability has most clearly to do with the willingness to take the other side's measurements and phenomena seriously. In this particular case incommensurability appears to be asymmetrical, even unilaterial. For Truhaut's ecotoxicology, toxicological methods of laboratory study of dose-response are accepted as valid and important, although they must be viewed in relation to the complicating factors of real, complex, *in situ* processes, and then are recontextualized in an ecologically based account of the systemic effects. For Worden's toxicology, field data are questionable because of confounding effects and multicausality. Models, similarly, are necessarily incomplete, so that it is very difficult to talk with confidence about anything outside the laboratory—the numbers are uncertain and the phenomena those numbers are supposed to indicate are hazy. So for Truhaut the real object of knowledge is *in situ* systematic processes—lab studies are useful but simplified contributors to unpacking the complex big picture. For Worden the complex big picture

is too messy to be seriously knowable, so only lab studies provide true, warrantable knowledge. The laboratory is where the action is.

Textbooks and Disciplinary Definition

The views presented by these two leaders were reflected in the words and actions of many in their field during the seventies, and later. While all were cognizant of the fact that toxicants in the environment were an issue, traditional toxicology at first treated this contamination just as it treated other toxicological problems. The mid-seventies textbook *Toxicology: The Basic Science of Poisons* (Casarett and Doull 1975), while it has chapters on Clinical Toxicology, Forensic Toxicology, Industrial Toxicology, and Veterinary Toxicology, has no chapter on environmental toxicology (or ecotoxiology). Among its various chapters on pollutants it does, however, have chapters on air pollutants and pesticides. Thus it treats environmental toxicants as nothing special—simply substances needing to undergo standard toxicological measurement of toxicity.

The first edition of Loomis's *Elements of Toxicology* includes two pages in the introduction defining environmental toxicology as "that branch of toxicology which deals with incidental exposure of biologic tissue, and more specifically in man, to chemicals that are basically contaminants of his environment, food, or water" (Loomis 1968, 7). The section describes the various sources and substances that comprise toxic pollution, with no indication that different methods or theories are needed for the problem. The substance of the book provides no mention of any theories or methods that are specifically aimed at environmental issues. No field methods are discussed. The section remained essentially unchanged in the second (1974) and third (1978) editions. This is particularly interesting as in those same three editions Loomis includes a chart indicating the resource disciplines and the areas of specialization within Toxicology. It lists environmental as equal to economic and forensic. Thus it subsumes environmental issues into normal toxicological practice, based in methods developed largely for pharmaceutical and secondarily for medical, industrial and agricultural purposes.

The ecotoxicology textbooks (all of a more recent vintage), on the other hand, treat ecotoxicology as making a substantial break from toxicology and adopting a new "broad conceptual framework for evaluating chemicals in the environment," as it is phrased in *Introduction to Ecotoxicology* by Connell, Lam, Richardson, and Wu (Connell *et al.* 1999, v). It identifies ecotoxicology as having its roots in both the sciences of ecology and toxicology, and drawing on chemistry, pharmacology, and epidemiology as well. In this respect it is much like Loomis's and other toxicologists' view of toxicology as multidisciplinary—except that ecology is more a field-and-systems science than a lab-and-organism one. The authors make one further addition: "a managerial aspect, resulting from the increasing need to regulate industrial and human activities" (Connell *et al.* 1999, 1). This managerial aspect serves as the warrant for adding "risk assessment and risk management into the ecotoxicological equation." Toxicologists viewed themselves as scientists meeting social needs set by others, but did not view themselves engaged in management and regulation. The book cites Truhaut's invention of the term *ecotoxicology*, and defines the goal of the field (following Moriarty 1988) as "to assess, monitor and predict the fate of foreign substances in the environment" (Connell *et al.* 1999, 1). Note how this definition shifts attention from the effect on humans and other organisms to chemicals and to the environment. Also it includes all substances foreign to the environment under its purview and not just toxicants. Although citing the Paracelsian principle that all substances are potentially poisons, depending on the dose, the authors invert its use to identify potential harm at all dosages rather than to suggest safety at lower dosages. Since ecotoxicology is concerned with persistent chemicals that may accumulate, all substances have the potential of being toxic, even if the immediate exposure is low.

Rombke and Moltmann's *Applied Toxicology* defines its field as "concerned with the toxic effects of chemical and physical agents on living organisms, especially on populations and communities within defined ecosystems" and as "the science which seeks to predict the impacts of chemicals on ecosystems" (Rombke and Moltmann 1996, 3). Consequently, the textbook identifies several ways ecotoxicology is distinct from toxicology. In contrast to toxicology's attempt to identify the dose which determines toxic effect, in ecotoxicology "no single measurement of the concentration of a substance in the environment is sufficient in itself to evaluate the stress on the ecosystem" (Rombke and Moltmann 1996, 5). Ecosystems are more complex in their operations than even the most complex single organism. And the environmental impact of various foreign substances is not always measurable

in terms of acute responses. Ecosystems need to be studied through ecological theory.

Similarly, *Fundamentals of Ecotoxicology* defines the field as "the science of contaminants in the biosphere and their effects on constituents of the biosphere, including humans" (Newman 1998, 130). In seeing the field as synthetic and multidisciplinary, the author sees effects of concern occurring at every level of a hierarchy "from the molecular (e.g., enzyme inactivation by a contaminant) to the population (e.g., local extinction) to the biosphere (e.g., global worming) levels of biological organization" (Newman 1998, 14). However, he also sees "questions dealing with the lower levels of the conceptual hierachy, e.g., biochemical effects of toxicants, are more tractable and have more potential for linkage to a specific cause than effects at higher levels such as the biosphere" (Newman 1998, 14–15). A bit later he describes the field in the explicitly Kuhnian terms of *paradigm* and *normal science*, the latter in partial contrast with "innovative science"(Newman 1998, 19). He suggests that while some parts of this synthetic field are appropriately mature to proceed in normal ways, others still require innovation and should not be saddled by a "preoccupation with details [. . .] or measurement" (Newman 1998, 19–20). The study of the lower levels of hierarchy of biological systems (those that are encompassed within traditional toxicology) is mature and normalized with specific expectations for detailed measurement. The study of higher orders of biological organization (those added by the ecological sciences) needs to be taken seriously, but is pre-paradigmatic. It needs license to innovate before it can produce mature, normal science.

While the tables of contents of toxicology textbooks and other overview works are organized by kinds of toxicants, kinds of effects, domains of practice, and methods of laboratory measurement (see Loomis 1968, 1974, 1978; Loomis and Hayes 1996; Cassarett and Doull 1975; Kent 1995; and Niesink, deVries and Hollinger 1996), the ecotoxicology books have very different chapter organizations, including chapters on ecological theory, on processes of chemical transformations in the environment, on populations, communities and ecosystems, and other topics. There is no fixed set of organizing principles, suggesting that the field is, in Kuhnian terms, pre-paradigmatic. However, each of the ecotoxicology books does have chapters on laboratory dose-response studies, indicating that the work of toxicology has a respected, though limited, place within the work of ecotoxicology to establish the biological risk of specific levels of exposure to toxicants.

Symposium volumes, and other overview statements of ecotoxicology reveal the same sense of a creative, innovative science that has not yet reached maturity or a normalization of practices, theories, and methods. Smeets, in a late-seventies article, "New Challenges to Ecotoxicology," states that ecotoxicology has yet "to develop adequate and representative test methodology techniques [...] to simplify test procedures" and thus to define "standard methods" (Smeets 1979, 120). Public concern and regulatory interest now made it imperative that the field mature into more normalized practices. In the first chapter of *Ecotoxicology: A Hierarchical Treatment,* Newman similarly represents ecotoxicology as a creative field not yet developed into a mature science, specifically citing Kuhn. It is not yet ready to be normalized despite strong practical and technological pressures that necessitate standard methods and immediate guidelines for specific actions (Newman 1998, 3). But he does urge the development of theoretical and methodological tools to soon make "the transition into a mature science" (Newman 1998, 7) where there is a balance between normal and innovative work (Newman 1998, 5). These views are echoed by a number of the authors of other chapters in the volume. *Ecotoxicology in Theory and Practice* (Forbes and Forbes 1994) also sees the struggle of ecotoxicology in becoming a fully independent science, with a key site of definition being a deeper engagement with ecological theory.

But the most radical statements of a deep division between ecotoxicology and toxicology accompanied by limited communication and lack of cooperation appear in the volume *Ecological Toxicity Testing* (Cairns and Niederlehner 1995). Cairns in his opening chapter on the genesis of ecotoxicology sees a deep division in the field between toxicological testing and an ecosystem approach, which is an aspiration of ecotoxicology (Cairns 1995, 7). A follow-up chapter by the sociologist Halffman documents and examines the tall boundary that exists between ecology and toxicology. He finds the boundary realized in discontinuities in organizational structure, funding agencies, journals, theories, and research programs (Halffman 1995, 16). He supports his observations with evidence from the citation structure of international journals through 1988, an analysis of Dutch scientific funding agencies, the testimony of practitioners, and an historical analysis of the theories and research programs in both the U.S. and Europe.

But when we look further into the histories and analyses documented by Cairns and Halffman, we find a more complex story about the relationship of toxicology and ecotoxicology, intertwined with their relations to industry, government regulation, university disciplines, and academic research. While the face of their stories is very much like the previously recounted story about an older normalized field with institutional infrastructure and a new revolutionary field attempting to displace the older as authoritative, the complexities expose more dynamics at play than just intellectual commitments. These complexities provide a way of approaching another level of materials that do not fit so easily into the dichotomous Kuhnian story adopted by the founders of ecotoxicology.

Cairns casts his own professional position in the dichotomy in a curious way. Cairns adheres to an ecological view, has criticized the limitations of normal toxicological studies for understanding environmental problems, has numerous publications in ecotoxicological journals, and is viewed as a leader in the field; but he does not yet consider himself to deserve the name of ecotoxicologist.

> I have stated that I do not yet feel that I deserve to call myself an ecotoxicologist although I had been involved for two decades in multispecies and community–level testing. The reason that this remains an aspiration rather than an accomplished fact is that attributes recognized as fundamentally important to ecologists are not yet routine endpoints in the field of environmental toxicology. My assumption is that people label themselves ecotoxicologists to indicate that they reject the sole use of single species laboratory toxicity tests low in environmental realism as the primary means of estimating the effects of toxicants on ecosystems. A concomitant intent in the use of the term is almost always certainly to relate toxicological testing more closely to ecosystem responses even though it is more of an aspiration than a reality at this time. If this is the case, then the term ecotoxicologist is used to indicate an expansion of the toxicity testing array now available without denigrating either single species tests or the events leading to the present

> evolutionary stage of the development of the field. Without doubt, there will be the usual lag of two or three decades before regulatory agencies embrace the new position. (Cairns 1995, 7–8)

Ecotoxicology seeks to realize ecological theory in toxicological tests, according to Cairns. Importantly, he operationalizes the maturity of the discipline in its ability to develop tests that match its theoretical ambitions. Further he notes the relationship between those tests and government regulation. Also even as he seeks the maturity of a new field he respects the well-established measures and methods of toxicology and its evolving specialty of environmental toxicology. Each of these elements points us to a more complicated and enriched story of disciplinary evolution in a complex social, political and scientific environment.

Halffman's follow-up essay places the development of toxicological studies of environmental pollution and ecotoxicology in the context of governmental need to legitimate decisions in an emerging arena of policy and politics. Part of that story involves the support of the American Chemical Society in the late 1960s while seeking a place in the monitoring of pollution called for more ecological research within chemistry. But when regulation was established in the 1970s the monitoring tasks went largely to the well-established procedures of toxicology and its new subspecialty environmental toxicology, which adapted traditional toxicological procedures by finding critical species for testing chemical pollutants in the laboratory. Ecotoxicology, then, did not develop within the context of government regulation. To some extent it was a university-based endeavor, although disciplinary differences in the location of ecological and toxicological sciences created some barriers to integration.

Because of the political charisma of the term *ecology*, people doing conventional toxicological and chemical work at times attempted to adopt the term, but few people at the time of Halffman's study had been able to develop new techniques to study and monitor an ecological system as their primary object of analysis. Government regulatory measures—particularly as administered by the EPA in the U.S., which set the terms for approvals of listed chemicals to be released in the environment—remained tied to traditional toxicity testing, despite the ecologists' argument that such tests lacked consonance with the

complexity of real ecosystems. Without factoring in the complexities, judgments of chemical toxicity would not reflect the actual toxicity in real situations. One attempt to establish microecosystems as an experimental standard for regulation failed in the mid 1980s, which left single species testing as the dominant force at the end of the 1980s where Halffmann's study ends. Significantly, though, Halffman does note that just at the end of his study period toxicological and ecological journals began to be more tightly linked through citations. We will examine this change more closely when we look at recent publications in toxicology.

The story Halffman tells is of the important role of institutional sponsorship, and the necessity of producing regularizable tests that would meet the needs of sponsors. The contention over methods is in part a debate for control of regulatory regimes, but without a commodifiable procedure that can win arguments for regulatory use, ecotoxicology is left only with an unfulfilled moral ambition and a marginal institutional role. The argument over alternative measures and thus the commensurability or incommensurability of alternative views is an interested argument. Indeed, recounting the changing political and regulatory environment is a standard introductory move in most textbooks and other overviews of the field, even if they typically do not continue to keep the economics and politics at the forefront of their presentations. This is equally true of presentations of toxicology (for examples, see Loomis 1968; 1974; 1978, 4–9; Loomis and Hayes 1996, 4–12; Cassarett and Doull 1975, 9; Kent 1998, 3–4), environmental toxicology (Cockerham and Shane 1994, 5–7; Yu 2001, 1–5; Landis and Yu 1995, 4–5; Zakrzewski 1997, 1–14; Hughes 1996, 10), and ecotoxicology (Rombke and Moltmann 1996, 5–6; Forbes and Forbes 1994, viii, 185–6; Newman 1998, 1–7; Levin *et al.* 1989, 497–540). These are scientific specialties that grew directly in response to industrial developments, perceived public harm and political reaction, and government regulatory regimes. These fields aim to provide the knowledge and measurement practices that meet the public concern and government need for scientifically warranted decisions and regulation. And as fields their continued prosperity and research agendas depend on the sponsorship that comes with being percieved as delivering the goods on public regulation, corporate liability, public concern, and the many other sites where toxicity and pollution are adjudicated and negotiated.

Environmental Toxicology in the Shifting Middle

This changing view of what must be studied in order to regulate the environment can be traced in the changing definition of the specialty of environmental toxicology, which was originally very closely linked to toxicology, as a means of expanding its traditional methods to the new market of environmental concern. As mentioned earlier, the first edition of Ted Loomis' standard *Essentials of Toxicology* had two pages describing environmental toxicology in terms entirely normalized into toxicological procedures with no environmentally specific discussion in the remainder of the book. This was unchanged across the first three editions (1968, 1974, 1978.) However, the fourth edition, co-written with A. Wallace Hayes (who is employed in the office of Corporate Product Integrity of the Gillette Company) entirely revises the introductory material on environmental toxicology. The new discussion describes the complexities in understanding pollution in the environment, including issues of biological, solar, and mechanical transformations, interactions within the environment, transformations, dilution and accumulation and fates of populations rather than individuals. The discussion takes something of a systems perspective, even including a diagram that approximates an ecological system, though never using the word *ecology.* And at the end of the volume is a new chapter on Risk Assessment.

Environmental toxicology undergoes an even more major redefinition in other publications. In 1975, a 750-page reference on *Toxicology: The Basic Science of Poisons* mentions ecological terms in only two paragraphs on DDT affecting ecological balance (431). Such a mention would be hard to ignore in any discussion of DDT in the wake of Carson's explicitly ecological discussion. In comparison, a 1996 compendium of similar genre, the 1,250-page *Toxicology Principles and Applications,* has a 28-page chapter on ecotoxicology (and not environmental toxicology), plus another chapter on biotransformations.

The transformation of environmental toxicology into the equivalent of ecotoxicology can be traced in the various textbook definitions of the field. One 1980 textbook *Environmental Toxicology* (Duffus 1980) defines the field as "the study of the effects of toxic substances occurring in both natural and man-made environments." This definition does not move far from traditional toxicology doing dose-effect lab studies of pollutants that appear in the environment. Another textbook from the period, *Introduction to Environmental Toxicology* (Guthrie and Perry 1980), however, while maintaining a strong grounding in traditional toxicology moves further into the field and considers ecosystem issues. While the first four chapters consider a range of toxicants, measurable in classical toxicological ways, chapters five and six consider the social and economic processes that generate pollutants in the actual world, and chapters seven through ten consider the impact of pollution on various organisms as they exist in the world. Chapters eleven and twelve develop a dynamic view of the movement of toxicants and the role of behavior; chapters thirteen and fourteen begin to develop an ecosystem approach to aquatic and estuarine ecologies; and chapters fifteen and sixteen consider the effects of oil and pulp industries in ecological terms (localizing the social and economic themes of chapters five and six to specific industries). Chapters seventeen through twenty-one are a series of case studies of pollutants in ecosystems, and twenty-two examines "Pesticide Effects on the Agroecosystem." Beginning with traditional toxicological tools, then, the book gradually leads into complex problems as they are found in the field, and thus moves to an ecological perspective.

The mid-1990s collection, *Basic Environmental Toxicology* (Cockerham and Shane 1994), opens with two chapters introducing ecotoxicology and its principles. While the chapters in section two cover the laboratory treatment of toxicity of environmentally sensitive materials, section three gives a systems treatment of air, soils, aquatics, estuarine ecosystems and wildlife based on field studies. Section four on methods and areas of work includes ecological risk assessment.

The 1995 *Introduction to Environmental Toxicology: Impacts of Chemicals upon Ecological Systems* redefines environmental toxicology to be virtually equivalent to ecotoxicology. The book's opening sentence states "Environmental toxicology is the study of pollutants upon the structure and function of ecosystems. For the purpose of this text, the emphasis will be on ecological systems, at every level of organization, from molecular to ecosystem" (Landis and Yu 1995, 1). The substance of the book follows suit. While it includes chapters on "Typical Toxicity Test Methods," it also includes chapters on field measures and risk assessment as well as on routes of exposure and modes of action, and the factors that effect toxicity in field. Yu's 2001 textbook *Environmental Toxicology: Impacts of Environmental Toxicants on Living Systems* also takes a largely systems approach.

By the late 1990s, Newman could state that the definitions of environmental toxicology and ecotoxicology "are rapidly converging" (Newman 1998, 12). What this history of convergence reflects is the inability of traditional toxicology to adequately speak to public and scientific concerns about changes to the environment. In order to maintain a central role in providing service to the various sponsors of toxicology, the field had to recognize the kinds of phenomena and problems manifest in the ecology, even if measures and tests had not yet developed that could be administered in a normal, commodified way.

While a number of environmental toxicology books of recent vintage maintain a more traditional toxicological orientation, they all make a nod towards ecology, such as *Essentials of Environmental Toxicology: The Effects of Environmentally Hazardous Substances on Human Health,* which stays methodologically quite close to traditional toxicology lab dose-response studies (Hughes 1996). But it does have a couple introductory pages on ecological concepts. Interesting is Sigmund Zakrzewski's 1997 second edition of his 1991 *Principles of Environmental Toxicology.* In the preface to the second edition he comments that in response to criticism of the first edition he now adds "a section on wetlands and estuaries" and includes a description of the fate of one ecosystem. He then explains,

> Despite these changes, this book is primarily a toxicology, and not an ecology, text. Thus, certain important areas of interest to environmentalists have been omitted. To remedy these shortcomings, a list of subjects for student research and seminars have been included. (Zakrzewski 1997)

Thus while he bounds his area of presentation, he also legitimates the value of ecological study.

So Who Recognizes Whose Work?

There seems to have developed a division of labor that leaves the core field of toxicology with only limited attention to environmental issues and ecological theory. This leaves toxicology largely free to serve its primary clients of medicine, pharmacology, cosmetics, and other industries—and the regulation of them. Core toxicological journals

such as the two sponsored by the Society of Toxicology (*Toxicology and Applied Pharmacology* and *Toxicological Sciences*) currently carry little that directly speaks to environmental or ecological issues. However, when they do run articles in that area, those articles cite appropriate ecologically based literature.

Toxicology and Applied Pharmacology has particularly devoted itself to mechanisms by which toxicants have effect within organisms, a focus well suited to laboratory organism-based studies. An inspection of the contents in volumes 170 to 183, covering the period from January, 2001, to September, 2002, reveals that only a handful of articles concern environmentally related toxicants. The journal currently appears twice monthly, with each volume constituted of three issues for a total of 42 issues in the covered period, containing 343 articles. Of those 343 articles, only eight appear to treat environmentally related toxicants. Those few articles treat the toxicant primarily within the organism, and thus cite primarily health, medical, biochemical, and toxicological literature. However, the first few sentences or paragraphs typically gesture towards the environmental presence and/or the epidemiological consequences of the toxicant, and may cite field studies of contamination levels or population studies of effects. Thus they use environmental and ecological literatures and data to identify the importance of the problem to be studied through the laboratory, organism-based methods of toxicology. The first paragraph, for example of "Percutaneous Absorption of Explosives and Related Compounds: An Empirical Model of Bioavailability of Organic Nitro Compounds from Soil" (Reifenrath *et al.* 2002, 160) details the history of military use of TNT and other explosives, and the mechanisms of soil contamination. The second paragraph then identifies contamination levels, citing *in situ* studies, and establishes research problems concerning uptake. Then the article moves into laboratory experimental studies for its remainder. In these introductory comments, such articles show respect for the findings and methods of field, demographic, and even ecologically-based studies, even though the laboratory accounts withdraw into laboratory-based literature. One article, however, enters more fully into field ecological studies: "Evidence for Endocrine Disruption in Perch (*Perca fluviatilis*) and Roach (*Rutilus rutilus*) in a Remote Swedish Lake in the Vicinity of a Public Refuse Dump" (Noakson *et al.* 2001). This *in situ* study of entire populations of fish uses many kinds of field data, including statistical samples, and cites several articles from journals in aquatic science, environmental science, marine environmental science, and ecotoxicology. Thus, while publications in this journal currently raise issues far from ecotoxicology, when the study enters into problems or issues that intersect with the interests of ecotoxicology there is no difficulty in accepting the findings and methods of environmental science, ecology, or ecotoxicology.

A similar pattern holds for *Toxicological Sciences*, the other journal of the Society of Toxicology, but because the journal is not restricted to studies of mechanisms of effect on organisms, it is freer to range into the field and into environmental problems. This monthly journal categorizes articles by topic and lists environmental toxicology as a topic of interest. However, only nine of the 225 articles appearing in calendar year 2001 were under this heading with perhaps an equal number of environmentally related articles appearing under the categories of Risk Assessment and Forums. Most of the articles, in contrast, appeared under topics such as carcinogenicity, neurotoxicology, respiratory toxicology, biotransformation, and toxikinetics. While the articles focusing on environmental issues are few, there seems no stricture against citing ecotoxicological findings and even using ecological theory and ecotoxicological measures.

An example of the acceptance of ecotoxicology within this toxicological forum is "Fitness Paramaters and DNA Effects Are Sensitive Indicators of Copper-Induced Toxicity in Daphnia Magna" (Atienzar 2001). This article compares effects occurring at the molecular and the population levels. While the population studies of water fleas here are within the laboratory, the article situates the work within literatures from aquatic science, aquatic toxicology, environmental science, ecology, environmental toxicology and ecotoxicology. Another study, "Acquired Resistance to Ah Receptor Agonists in a Population of Atlantic Killifish (*Fundulus heteroclitus*) Inhabiting a Marine Superfund Site: *In Vivo* and *In Vitro* Studies of Inducibility of Xenobiotic Metabolizing Enzymes" (Bello *et al.* 2001), rather than using laboratory-bred specimens, takes the experimental species directly from a contaminated superfund site, in order to study the particular adaptations of the fish that have allowed them to survive in a polluted environment. Again the article includes in its citations and intellectual context multiple articles from environmental, ecological, marine, and ecotoxicological sciences. "Masculinization of Female Mosquitofish in Kraft Mill Effluent-Contaminated Fenholloway River Water is Associated with Androgen Receptor Agonist Activity" (Parks *et al.* 2001) similarly collects both specimens and water samples from the field to be studied further in the laboratory. This article includes environmental, ecological and ecotoxicological literature in its discussion.

The journal *Toxicology* seems to have an even broader mandate, but except for the special articles described below, only ten of the almost 230 articles appearing in 2001 were on environmental toxicants. In seven studies the toxicant (in several cases diesel exhaust particulates) was brought into the laboratory for study on test animals. Another article was a longitudinal public health study of chromosome damage in Croatian workers producing pesticides (Garaj-Vhrovac and Zeljezic). Two articles, however, demonstrated significant respect for the measures and methods of ecotoxicology. The first, "Pesticide Use in Developing Countries" (Echobichon 2001) is a wide-ranging review article that includes considerations of economics, politics, regulation, ecological and environmental transmission and transformations, complexities of real-life exposures, and the value of long-term population studies to determine chronic exposure effects. The second, "Toxicological Profile of Pollutants in Surface Water from an Area in Taihu Lake, Yangtze Delta" describes findings from "monitoring the toxicological profile of aquatic ecosystems" (Shen *et al.* 2001). The study revealed "significant mutagenic activity" (71) and identified aspects of the hormones that were affecting the ecosystem. Among the very interdisciplinary resources cited were several articles from ecological and environmental journals. So we do again have a pattern of division of labor so that toxicology largely takes up industrial, pharmacological and medical issues and leaves most environmental issues to other specialties. When however, the subject warrants ecological theory and complex field measures, these are accepted as appropriate, intelligible and commensurable, revealing valuable and reliable data.

Most revealing about the respectful division of labor that now exists between toxicology and ecotoxicology is the special 2001 double issue of *Toxicology* (Volume 157: 1–2) devoted to "digital information and tools" (1). In this double issue, eleven articles catalog and describe the various information sources that have appeared on the internet, particularly the Web. While some articles predominantly focus on medical and pharmaceutical toxicological databases containing largely laboratory based information, the majority of the articles cover some environmental issues using field-based data and information about ecosystems. The report on "Toxicology information from US government agencies," for example, describes a wide range of agencies making toxicological data of various sorts available to the public—including environmentally focused agencies gathering field data from an ecological perspective (Brinkhuis 2001).

Several of the articles are focused particularly on environmental and ecological issues. "Toxicology Information Resources at the Environmental Protection Agency" (Poore *et al.* 2001) describes the EPA website, which contains basic public education and more professional data on environmental management and ecosystems, as well as pesticides and other pollutants. The article particularly mentions the Office of Research and Development's National Health and Environmental Effects Research Laboratory, which is concerned with "the effects of contaminants and environmental stressors on human health and ecosystem integrity" (Poore *et al.* 2001, 17).[11]

"Toxicology and Environmental Digital Resources from and for Citizen Groups" gives a rationale for attending to data from groups usually not considered scientifically significant by toxicologists: citizen groups "have provided an 'early warning' network" for "emerging problems" and "have initiated and advocated public policy initiatives" (Montague and Pellerano 2001, 77). The article reviews this history of citizens' movements in bringing attention to and regulation of environmental issues. Many of the databases described take an ecological perspective and provide field data and reports on the state of ecosystems, particularly as they have been affected by toxicants. "Online Resources for News about Toxicology and other Environmental Topics" lists in detail the sites devoted to environmental news (South 2001). Overall this special issue makes evident the many environmental information sources that toxicology needs to attend to if it is to contribute to environmental issues, even if toxicology's contribution is to be made primarily through traditional methods and theories.

Incommensurability Lost and Complex Practice Found

This catholic representation of the data resources available to toxicologists suggests that toxicologists must pay attention to a wide range of data and dynamics that reach far beyond the kinds of laboratory studies they focus their work on. It makes visible and legitimizes the work of colleagues taking ecological perspectives and gathering population and system data from field sites. The economic, political, and regulatory clients of environmental knowledge and the complexity of toxicants in the environment do not leave toxicologists the luxury of ignoring areas where their traditional methods fail to look, if they are to maintain authority within environmental spheres. This is especially true once the internet distributed widely the information generated by many organizations of different sorts. Because toxicology does have increasing amounts of work in areas that do not challenge the traditional laboratory methods and organism orientation, such as pharmacology, medicine, and consumer products, the field did have the option of simply withdrawing from environmental issues. Since, however, ecotoxicology has reserved a substantial though limited role for traditional toxicology, it seems in the field's interests to maintain a working synthetic alliance. Holding by methodological purity and ontological narrowness—in short acting as though ecological and field-based work were not commensurable with toxicology's ideals—seems to run counter to the field's practical goals, social responsibilities, and economic sponsorship.

Unlike Kuhn's vision of science, where practitioners seem free to follow the theoretical and practical commitments of their paradigms, fields like toxicology and ecotoxicology must be responsive to the complexity of applied problems, and changing economic, political, and regulatory climates. They do not have the insulation from practical concerns that would allow the luxury of incommensurability with the accompanying methodological intolerance and ontological blinders. The pressures are great to attend to all data and phenemoena that might be construed as relevant by the social, economic, and political sponsors. Although a science insulated from practical concerns is often thought to be more creative, flexible, and truth seeking because it claims not to be driven by interests, in this case we find the opposite: practical concerns of applications and interests *foster* the creativity and flexibility. Here application broadens the vision and mitigates methodological obstinacy of a field to allow a fuller understanding of the issues, acceptance of a greater range of data and phenomena, and tolerance of more methodological tools.

Even in the late 1980s when Halffman notices a great divide between toxicology and ecotoxicology, the Society of Toxicology's 1989 *Resource Guide to Careers inToxicology* lists over twenty-three programs with an environmental focus, even though the majority of the almost ninety programs listed have a traditional medical and pharmacological focus. The environmentally focused programs often include faculty with ecological and field-study orientations, according to faculty biographies that are part of the program descriptions.[12] When it comes to preparing students for jobs, providing students with relevant and useful perspectives may trump disciplinary purity.

Here continuity and difference within research programs is driven by the needs, interests and perceptions of varying sponsors that are more concerned with policy, politics, profits, and life-styles than with pure knowledge for its own sake. Perhaps incommensurability requires a purer science, driven only by its internal intellectual dynamics, with theory change being a response to anomalies. Kuhn's sociology is limited to recruitment and induction into paradigmatic camps. But as Fuller (2000) and others have noticed this ideology of a pure science driven only by its internal dynamics had its heyday in the post World War II period (when, in fact, physics and other sciences were heavily sponsored by governmental interest). It may be that all of science is more responsive to the complex exigencies of practical problems and interests of various human communities than the believers in pure science would have it. If that is the case the exigencies and complexities of the world militate against the motivated blindness of those who are strongly attached and ingrained to an insulated way of viewing the science. New specialties and new theories arise not just because anomalies make former accounts increasingly untenable, but because there are new problems to address in the world, and new groups bringing new interests to bear on scientific inquiry. It may be the problems of living in the world lead one to keep opening one's eyes wider, to counteract the psychic ease and sociological comfort that comes from the paradigmatic security of communally held gestalts or tightly structured taxonomic lexicons. Such would be at least the pragmatist hope for increasing knowledge in a world without foreordained correct ways of knowing it.[13]

Such a form of pragmatic relativism—roughly, the inverse rhetorical stance to what Harris diagnoses as pragmatic incommensurability in the introduction—rather than being a threat to the epistemic grounds of science, may be the means of holding accountable our intellectually proud ways of knowing to the world that we are trying to live in. The practicality and multiplicity of interests of science may help keep its spirit of open inquiry alive. At moments of change, the readjustment to be made, the tensions of alternative views, may seem to create great divides between different worldviews. The exigencies of coming to knowledgeable solutions for practical problems experienced by people in all walks of life, however, constantly humble our certitudes and keep us seeking better, more comprehensive, and more practically successful truths. For that, we can keep our eyes narrowed for only so long, no matter how much we are committed to our favored ideas and habituated perspectives.

Notes

[1] See, for instance, Kuhn (1996, 122–125); in the introduction to this volume, Randy Harris discusses these elements of Kuhn's conception under the label *cosmic incommensurability*. In "Second Thoughts on Paradigms" (Kuhn 1977, 293–319), Kuhn explicitly recognizes that the cognitive commitments are embedded with the complex of practices he calls the "disciplinary matrix." The embedding in practice makes the cognitive commitments even more resistant to change, as a cognitive change would disrupt an entire way of life. In an even later formulation, "The Road since *Structure*," he sees disciplinary practices rather than individual cognition maintaining the disciplinary way of thought and perception. As Alan Gross takes up in his contribution to this volume, Kuhn here particularly points to the role of the taxonomically structured lexicon as the vehicle that structures disciplinary thought (Kuhn 2000, 90–104). Gross explicitly disagrees in that essay with our characterization of Kuhnian incommensurability here, but, as we see it, while he moved from an individualist model of cognition to a group model, based in the publicly displayed thought of communal vocabulary, Kuhn's model remains one of cognition, with incommensurability across cognitive boundaries. A switch of taxonomies is the group equivalent of an individual's switch of gestalt.

[2] Further: "operations and measurements that a scientist undertakes in the laboratory are not 'the given' of experience but rather 'the collected with difficulty.' [. . .] they are selected for the close scrutiny of normal research only because they promise opportunity for the fruitful elaboration of an accepted paradigm" (Kuhn 1996, 126).

[3] Carolyn R. Miller's essay on a controversy over non-thermal EMF effects, which follows ours in this volume, also looks at incommensurability through an interdisciplinary case study. The developments she explores are quite different, however, in that the two parties are steadfastly recalcitrant.

[4] For the depth of paradigmatic commitment based on solved problems, see Kuhn (1996, 169).

[5] The methods and theoretical approach of this analysis are an extension of an approach presented by one of us in Bazerman (1988) and elaborated most recently in Bazerman and Prior (2004).

[6] The second journal of the Society of Toxicology, *Toxicological Sciences,* has a somewhat broader mandate, but also stays close to laboratory dose-effect studies on organisms or tissues, as its current purpose statement indicates:

> *Toxicological Sciences* publishes research articles 12 times a year that are broadly relevant to assessing the potential adverse health effects resulting from exposure of human or animals to chemicals, drugs, natural products, or synthetic materials. Manuscripts are published in all areas of toxicology, both descriptive and mechanistic, as well as interpretive or theoretical investigations that elucidate the risk assessment implications of exposure to toxic agents alone or in combination. Studies may involve experimental animals or human subjects, or they may focus on *in vitro* methods or alternatives to the use of experimental animals. Other articles include historical topics, contemporary issues in toxicology, scientific and regulatory reviews, and international perspectives. (Society of Toxicology 2005)

[7] See, for example, January 1969 14:1 p. 205, Information for Authors: "*The Journal of Toxicology and Applied Pharmacology* publishes original scientific research pertaining to effects on tissue structure or functions resulting from administration of chemicals, drugs or natural products to animals or man." The title of the journal has changed, *effects* has become *action, function* shows up as a mass noun, rather than a pluralized count noun, and *man* has become *human.*

[8] We can't date the sentence exactly, but it showed up between 2002 when we first accessed the description, on the Society for Toxicology site, and 2005, when we accessed it from the Elsevier Science site, which publishes the journal.

[9] See Waddell (2000) for several rhetorical analyses of *Silent Spring.* These analyses, as do most other analyses of environmental rhetoric, examine strategies of arguing environmental issues in various public spheres, and are based on rhetorical readings of texts or recounting particular episodes of controversy or advocacy. These studies differ in character from this current study, which considers the rhetorical organization of knowledge fields arising in the wake of environmental concerns.

[10] Although French, he is widely cited by Americans as the founder and first theorist of ecotoxicology. Thus his statements have importance for the development of ecotoxicology in the United States.

[11] Also mentioned and described are the databases of the mid-continent ecology division AQUIRE, Phytotox, and TERRETOX (which has field data on the toxicity of exposures on wildlife). These three databases are gathered in the ECOTOX database. Also described is the ENVIROFATE database that has data on "the environmental fate or behavior of chemicals released in the environment" (Poore *et al.* 2001, 20).

[12] See, for example, in the *Resource Guide,* the program profiles on Clemson 18–19; Duke 22–23, Iowa State University. 30–31, University of Illinois Urbana-Champaign 112–113; University of Wisconsin-Madison 172–173.

[13] For related historically grounded philosophic accounts of the hybridity of scientific practice and communication see Pickering (1995) and Galison (1997), whose results are highly consonant with ours. The first author of this paper, however, grounds his view of hybridity and contingency in an utterance-based view of language in the tradition of Volosinov, a sociocultural, interpersonalist view of psychological development in the traditions of Vygotsky and Sullivan, and a pragmatist historical account of social relations in the tradition of G. H. Mead. See, for examples, Bazerman (2000, 2001, 2004); Bazerman and Prior (2004).