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Perspective

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Perspectives on Communicating Risks of Chemicals

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ABSTRACT: The Agrochemicals Division symposium "Perfecting Communication of Chemical Risk", held at the 244th National Meeting and Exposition of the American Chemical Society in Philadelphia, PA, August 19−23, 2012, is summarized. The symposium, organized by James Seiber, Kevin Armbrust, John Johnston, Ivan Kennedy, Thomas Potter, and Keith Solomon, included discussion of better techniques for communicating risks, lessons from past experiences, and case studies, together with proposals to improve these techniques and their communication to the public as effective information. The case studies included risks of agricultural biotechnology, an organoarsenical (Roxarsone) in animal feed, petroleum spill-derived contamination of seafood, role of biomonitoring and other exposure assessment techniques, soil fumigants, implications of listing endosulfan as a persistant organic pollutant (POP), and diuron herbicide in runoff, including use of catchment basins to limit runoff to coastal ecozones and the Great Barrier Reef. The symposium attracted chemical risk managers including ecotoxicologists, environmental chemists, agrochemists, ecosystem managers, and regulators needing better techniques that could feed into better communication of chemical risks. Policy issues related to regulation of chemical safety as well as the role of international conventions were also presented. The symposium was broadcast via webinar to an audience outside the ACS Meeting venue.

KEYWORDS: *risk assessment, risk communication, risk management, biomonitoring, runoff, ecotoxicology, biotechnology, petroleum, organoarsenical, fumigants, endosulfan, persistent organic pollutants (POPs), diuron, 2,4-D, polynuclear aromatic hydrocarbon (PAH)*

INTRODUCTION

Fear of chemicals is a common response, in part for good reason. Yet use of chemicals properly managed brings many benefits, and overcoming fear would help to ensure continued use of beneficial chemicals. As risk communicators we need to reassure the community that rational means of managing environmental risk are becoming available and that safety is one of the main reasons for regulation.

In his letter addressed to chemists in the International Year of Chemistry (2011), Ropeik[1] pointed out that neuroscience shows that the brain's hard-wiring guarantees instinct and feelings take precedence as reactions to external threats, with cognitive reasoning only coming second. As a result of this he claimed that

- human-made risks are more feared than natural risks;
- risks we cannot detect or measure are more feared;
- risks that lead to painful or irreversible results, such as cancer, are more feared;
- imposed risks are more feared than those taken by choice; and
- risks from structured industries whose behaviors have taught us not to trust them are scarier.

The blame for poor communication of risks lies at many levels, from large government agencies to the individual scientist at the bench or computer. The following sections include examples of risks from chemicals that were well communicated and also of those done poorly or confusingly. As informed communicators, we offer suggestions on improving the process of informing the general public in an open and transparent way.

COMMUNICATING SCIENCE-BASED ASSESSMENT OF RISKS AND BENEFITS OF AGRICULTURAL BIOTECHNOLOGY (FISCHHOFF)

Agricultural biotechnology has played a role in improving the sustainability of agriculture to date by enabling farmers to employ conservation tillage practices that minimize erosion and promote soil health and by helping reduce the amount of chemical pesticides applied on-farm. In addition, agricultural biotechnology

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combined with modern breeding technologies has led to increased and sustainable crop yields.

Biotechnology can provide alternative biological solutions to the challenges farmers face by providing beneficial and environmentally friendly products such as the Roundup Ready trait for herbicide tolerance in soybeans and other crops, and Genuity SmartStax corn, which has multiple genes for in-plant protection against insects.

To ensure the quality and safety of foods from genetically modified crops, rigorous testing must demonstrate that the genetically modified food is safe to consume and that the crops are safe for the environment.[2] Products are evaluated for safety on the basis of strict principles established by leading international organizations, such as "CODEX" data requirements for crops improved with biotech traits—standards for food put in place by the World Health Organization and the Food and Agriculture Organization of the United Nations.

Studies are conducted that look at changes in potential allergenicity, toxicity, nutrient composition and level, unintended effects, and the safety of proteins produced by the introduced transgenes. In addition, researchers conduct comprehensive tests to assess agronomic performance and environmental safety. The data generated from all of these studies is then submitted to regulatory agencies worldwide for review.

Today, 40 agencies in 23 countries evaluate biotech products prior to commercialization. On average, regulatory studies to final approval can take 5−6 years and cost more than U.S. $35 million.[3,4] The agricultural biotechnology sector is one of the most heavily and carefully regulated industries today; new varieties improved by biotechnology must meet exhaustive regulatory requirements (approvals) before commercialization, and many countries have established regulatory systems and policies on plant biotechnology.

Some comments resulting from these agency reviews and the more than 15 year history of use of biotechnology in crops are

- ***"There is no substantiated case of any adverse impact on human health, animal health or environmental health, ...and I would be confident in saying that there is no more risk in eating GMO food than eating conventionally farmed food."***
  - Anne Glover, Chief Scientific Advisor, European Commission, July 24, 2012
- ***No more risk to people than any other food.***
  - U.S. National Academy of Sciences (NAS) National Research Council
  - European Union Joint Research Centre
  - U.N. Food and Agriculture Organization (FAO)
  - World Health Organization
  - American Medical Association
  - American Dietetic Association

Therefore, if these products are rigorously tested for safety and reviewed with science-based principles by multiple regulatory agencies, and there are well-documented benefits to agriculture and to society, why are there very different viewpoints in today's discussions about food and agriculture? Some advocacy groups such as GreenPeace and the Union of Concerned Scientists as a matter of policy believe that our agricultural system is broken and that sustainability and modern farming practices including the use of biotechnology are not compatible. These groups and others identify biotechnology in agriculture as key issues.

Experience at Monsanto with agricultural biotechnology shows that, although it is vitally important to communicate the safety and benefits of agricultural biotechnology products, this alone is not sufficient. Taking a "he said, she said" approach by communicating positive messages about the science, safety, and benefits to counteract the messages of opponents of agricultural biotechnology does not always resonate with the public. Opponents of biotechnology are able to continue to sow doubt and uncertainty even when public sector scientists and regulatory agencies provide positive messages regarding safety and benefits. There are also other motivating factors that drive opposition to agricultural biotechnology, such as anticorporate views of business practices and agriculture, etc. The technology becomes the flag-bearer for all of these.

Key messages from an NAS Sackler Colloquium on "The Science of Science Communication" (Washington, DC, May 21−22, 2012)[5] that are relevant to the situation with agricultural biotechnology include

1. Your audience determines your source of credibility, not you. Credibility in communication is a combination of
   - perceived interest proximity: Does the audience think you care about the things they care about? Do you share common values?
   - perceived relative expertise: Do they think your knowledge is valuable to them on the given topic? Will people question your "angle" on the information you provide?

   If you do not begin conversations by demonstrating that you share in the core values of your stakeholders, your expertise will have less impact. This might sometimes sound as if you are stating the obvious.
2. As media begin to talk more about a subject and elevate its presence in the public, beliefs about that subject can become increasingly polarized.

   Good examples of groups working on communications about agriculture and biotech include
   - Physicians Offer Expert Advice on Food Biotechnology, from the International Food Information Council (IFIC)[6]
   - Food Dialogues, from U.S. Farmers and Ranchers Alliance (USFRA)[7]

   In a recent survey conducted by the USFRA,[8] of 1400 individuals including food communicators (200), opinion leaders (600), and general consumers (600)
   - 58% think about how the food they eat is grown or raised frequently
   - 71% say they have "serious or some concerns" about the methods used by conventional, nonorganic agriculture
   - 27% said their attitude toward the way food is grown and raised was "very or somewhat unfavorable"
   - 75% viewed farmers as very or somewhat favorable

   Communication efforts made by the Ag industry and scientists should seek to engage consumers in venues where they are already comfortable today (reality TV, social media, online gaming, etc.) and build common ground from the core values both groups share to sustainably feed, clothe, and power our planet.

■ INTERAGENCY RISK ASSESSMENT AND COMMUNICATION: ARSENIC IN POULTRY (JOHNSTON)

Food safety is a responsibility shared among multiple federal departments and agencies including (but not limited to) the U.S. Department of Agriculture (USDA), the Department of Health and Human Services (DHHS), the Department of Homeland Security (DHS), and the U.S. Environmental Protection Agency (EPA). Although each federal food safety entity has its own area of responsibility, food safety issues may affect the domain of multiple agencies and often require a coordinated interagency response.

The USDA Food Safety and Inspection Service (FSIS) is responsible for ensuring that the nation's commercial supply of meat, poultry, and egg products is safe, wholesome, and correctly labeled and packaged.

The DHHS Food and Drug Administration (FDA) is responsible for the safety of virtually all other food and beverages sold in the United States. Its mission is to protect consumers and enhance public health by maximizing compliance with FDA regulated products and minimizing risk associated with those products.

The EPA's purpose is to ensure protection from significant risks to human health and the environment. As environmental contaminants can find their way into human foods, the EPA is an integral part of the federal food safety continuum. EPA's determination of maximum acceptable exposure limits and/or oral cancer slope factors are often used by other agencies to determine acceptable concentrations for chemical contaminants in foods. For the case study described here, which involved the assessment of arsenic residues in poultry, the oral cancer slope factor for inorganic arsenic (iAs) was used by both the FDA Center for Veterinary Medicine (CVM) and the USDA.

Roxarsone (4-hydroxy-3-nitrobenzenearsonic acid) was widely used as a coccidiostat chicken-feed additive in the United States. Approximately 1 million kilograms of this compound was produced annually since 2000. Roxarsone has attracted attention as a source of potential arsenic contamination of food. When first approved for use, the available data indicated that Roxarsone resulted in organic arsenic residues in poultry. In 2002, the EPA presented research suggesting that Roxarsone metabolism in poultry may also result in inorganic arsenic residues.[9,10] This is significant because inorganic arsenic is a human carcinogen. The As-containing transformation products detected in the chicken manure are depicted in Figure 1.

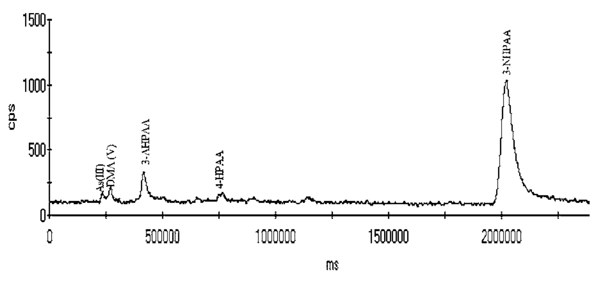

Figure 1. HPLC ICP-MS chromatogram of chicken manure extract showing Roxarsone (3-NHPAA) as the major arsenic compound followed by 3-amino-4-hydroxyphenylarsonic acid (3-AHPAA), 4-hydroxyphenylarsonic acid (4-HPAA), dimethylarsinic acid (DMA(V)), and arsenite (AS(III)).[9]

Because inorganic arsenic (iAs, as arsenite) was detected in manure by the EPA, it seemed plausible to the FDA that iAs residues may be present in poultry tissues. Therefore, the FDA conducted a chicken feeding study to follow up on the possibility of iAs in poultry tissues.[11] The FDA also attempted to quantify iAs in chicken muscle, but the residues were below the limit of detection.

In evaluating the safety of the inorganic arsenic residues in chicken, the FDA applied the protective approach typically used to evaluate new animal drugs. Deterministic "worst case" exposure was employed to account for uncertainty in future use of this product and consumption of chicken. FDA estimated the safe concentrations of iAs in chicken (liver, muscle, kidney, and fat). These estimates were based on an allowable level of protection of 1-in-1 million (10^{-6}) excess cancer risk and the oral cancer slope factor of 25.7 per mg/kg bw/day. The concentration of concern (COC) was estimated using "default" consumption metrics for each edible tissue.

Comparison of the COC with observed iAs concentrations suggests that the risk associated with consumption of Roxarsone-fed poultry exceeds 1 in a million (Table 1). **This indicates that the magnitude of iAs residues contributed by Roxarsone represents a potential public health concern.** These findings and the fact that chickens can be produced without Roxarsone led the FDA and Roxarsone producer Pfizer to voluntarily suspend the sale of Roxarsone in the United States with a phase-out period of 30 days. The FDA advised the USDA of the pending press release related to the discontinuation of Roxarsone in the United States. As Roxarsone had been used in U.S. poultry production for more than 50 years, the USDA anticipated queries based on the public health impact of historic Roxarsone use and continued use for the next 30 days of phase-out.

Table 1. Observed Inorganic Arsenic Liver Residues versus Concentration of Concern (COC)

withdrawal (days)	mean (ppb)	LOQ (ppb)	corrected mean (ppb)	COC (ppb)	corr mean/ COC
0	7.8	0.6	7.2	0.023	313
3	1.8	0.6	1.2	0.023	52
5	1.4	0.6	0.8	0.023	35

For historic estimates of iAs consumption and risk, the USDA conducted a probabilistic assessment rather than a worst-case deterministic assessment. The probabilistic approach provided an assessment of risk for the entire population of chicken consumers. This permitted estimation of the fraction of chicken consumers (if any) that likely exceeded acceptable risk metrics.

Curve-fitting techniques were used to estimate the distribution of iAs liver residues. Gender-specific chicken consumption data were obtained from the National Health and Nutrition Examination Survey (NHANES).[12] Multiplying consumption by iAs residue concentrations generated gender-specific iAs exposure estimates. Monte Carlo sampling from entire distributions of chicken consumption and iAs residue concentrations produced gender-specific distribution for chicken consumption-associated iAs exposure. Multiplying exposure by gender-specific cancer potency factor (dose−response slope) produced the range of estimated lifetime cancer risks associated with historic chicken consumption.

Historic mean lifetime cancer risk for consumption of chicken meat is approximately 1 in 10 million, which is less than the 1 in a million allowable level of protection (acceptable risk) (Figure 2). Consumption of chicken meat contributed more than 1 in a million additional cancer risk for <0.15% of the population of chicken meat consumers (Figure 2). The mean iAs associated cancer risk due to consumption of chicken livers also was <1 in a million, but consumption of chicken livers contributed more than 1 in a million additional cancer risk for approximately 17% of the population of chicken liver consumers.

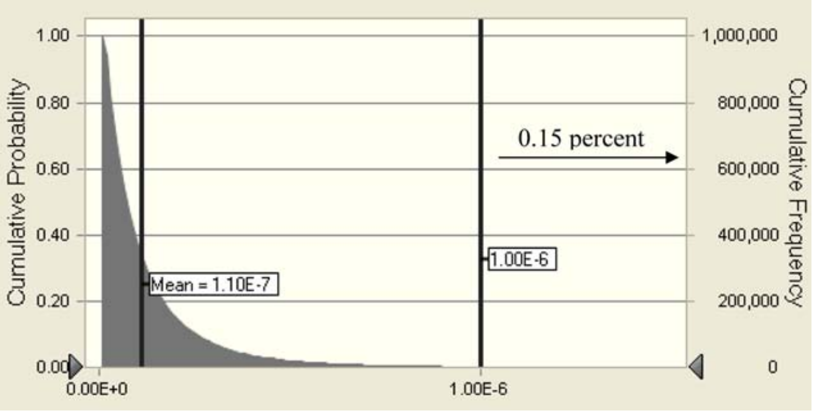

Figure 2. Reverse cumulative cancer risk distribution for consumption of chicken meat.

To communicate these risk estimates to the public, interagency brain-storming suggested that the agencies communicate the quantity of chicken meat and liver that could be safely consumed on a regular basis. The weekly consumption of chicken meat and liver that would contribute a cancer risk of 1×10^{-6} was estimated. For chicken meat, this equated to >10 pounds per week (for a 60 kg adult). For chicken liver, this equated to about 4.5 oz of liver per week over one's entire lifetime.

The manufacturer voluntarily suspended sale of Roxarsone and facilitated an orderly process for suspending use of Roxarsone. Allowing sales for 30 days provided time for animal producers to transition to other treatment strategies and helped ensure that animal health and welfare needs were met. The FDA stressed that the levels of inorganic arsenic detected were very low and that continuing to eat chicken as Roxarsone was suspended from the market did not pose a human health risk.[13]

This case provides a wonderful example of interagency cooperation to ensure the continued safety of the U.S. food supply. It also provides examples of transparency in risk communication, both interagency and with the public, based on sound science and its analysis.

PAHS MEASURED IN SEAFOOD IN MISSISSIPPI FOLLOWING THE GULF OIL SPILL (ARMBRUST)

The Deepwater Horizon oil spill in the Gulf of Mexico is the largest offshore spill in U.S. history. Hundreds of millions of gallons have spilled since the explosion of the rig on April 20, 2010.[14] The spill caused extensive damage to marine and wildlife habitats as well as the Gulf's fishing and tourism industries. Precautionary fishery closures were implemented in an area when significant visible oil was observed on the surface. These closure areas included the immediate vicinity of the observed oil as well as a designated buffer zone.

The seafood industry contributes U.S. $450 million dollars annually to the Mississippi Gulf Coast economy, supporting an estimated 1600 shrimp workers and 1200 employees in seafood processing. Shrimp accounts for about half of the seafood market, followed by oysters, menhaden, and crabs. Thirty-eight seafood processing plants are situated along the Gulf Coast, with 11 in Biloxi.[15]

To aid in the environmental and economic recovery that ensued, fixed sampling of seafood representing five distinct zones was conducted to aid in making fisheries reopening decisions (Figure 3). These cover the three coastal counties of Mississippi out to the state territorial limit. Analysis was conducted in cooperation with Agilent Technologies, Inc., using an Agilent model 7000B triple-quadrupole GC-MS/MS system.

Concentrations of polycylic aromatic hydrocarbons (PAHs) observed over the course of sampling were <10 ppb for >90% of the seafood samples tested. The levels of PAHs were below the FDA's Levels of Concern (LOC) for all seafood samples. Levels of PAHs in oysters following the spill were similar to those observed before the spill and also in shellfish collected from the same locations as a part of NOAA's mussel watch program in prior years. Additionally, levels of PAHs in oysters along the MS coast were at levels similar to or below those found at these locations in national monitoring programs. These data suggest the oil spill had very little impact on PAH concentrations in oysters collected on the coast. The levels observed were likely related to background levels of PAHs from urban runoff or natural seeps in the gulf region.[16] Maximum levels of PAHs (including alkylated homologues) were far below the LOC for any PAH, typically by ≥3 orders of magnitude.

All samples analyzed to date fell below LOC for PAHs (Table 2). However, people were still concerned about these detectable (albeit trace) levels of PAHs, so officials in the state felt it important to put these numbers into perspective with the levels of PAHs that people are exposed to in food they eat on a regular basis. PAHs are produced by combustion or heating and are present in many different commodities. Samples were obtained from local eating establishments of barbecued and smoked food items. Additional items were collected at grocery stores. The levels of PAHs observed in these food items were similar to and in some cases higher than those observed in seafood samples collected from the Gulf Coast.[16] All were far below the LOCs for any PAH. The information provided in newsletters distributed for seafood safety contained the summary data in Table 2. It conveyed a very simple easy to understand message.

NOAA and British Petroleum funding was secured to promote the marketing of Gulf of Mexico seafood and designed to change the public perception across the nation that Gulf seafood is tainted. The "Gulf Safe" campaign is intended to reverse negative perceptions about Gulf seafood. The Gulf Safe seafood message was that Gulf seafood is harvested only from open, regulated waters and is tested extensively to ensure consumers' safety. This message continues to be transmitted through a variety of media venues. The data from monitoring programs are summarized in various food magazines and presented through television advertising as well as on shows through public broadcasting networks. Additionally, Mississippi representatives attend national seafood shows and culinary conferences meeting one-on-one with culinary experts and purchasers who have any concerns about the safety of Gulf seafood.

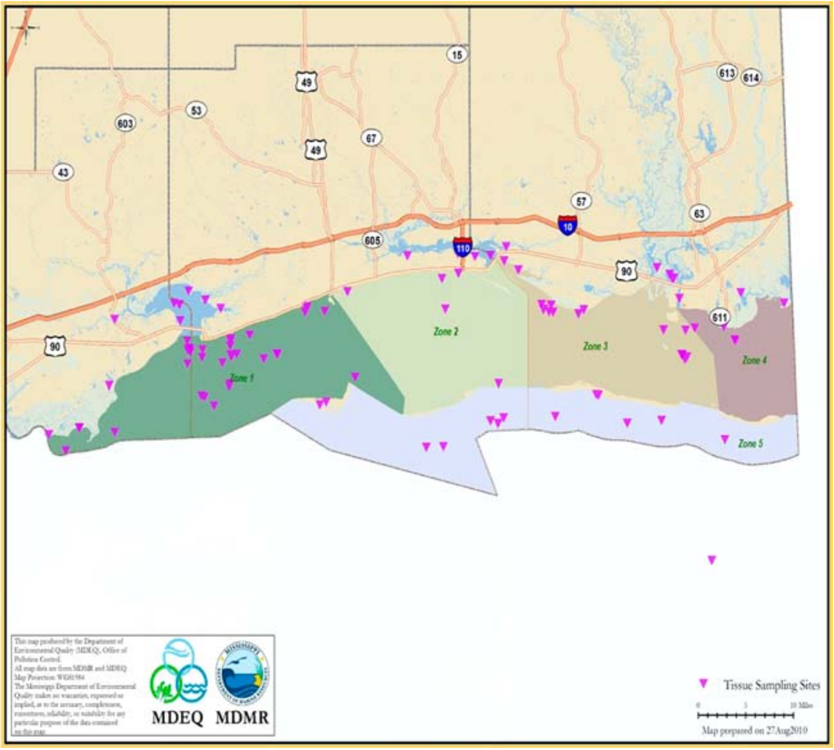

Figure 3. Sampling locations for shrimp, fish, crabs and oysters collected along the Mississippi Gulf Coast. See ref. 16 for a detailed description of samples collected by location.

Table 2. Summary of Mississippi Seafood Results for PAHs[a]

sample dates: May 28, 2010–Jan 1, 2013	total analyzed	above LOC[b]
shrimp	105	0
crab	87	0
finfish	167	0
oyster	109	0
all seafood	468	0

[a]Polycyclic aromatic hydrocarbons (PAHs) monitored include naphthalene, fluorene, anthracene/phenanthrene, pyrene, fluoranthene, chrysene, benzo(*k*)fluoranthene, benzofluoranthenes (*a*,*b*,*k*), indeno(1,2,3-*cd*)pyrene, dibenzo(*a*,*h*)anthracene, and benzo(*a*)pyrene as well as their alkylated homologues. [b]Levels of concern (LOC) vary according to seafood type (wet weight) and PAH. Specific LOCs were taken from the FDA's July 29, 2010, document: "Protocol for interpretation and use of sensory testing and analytical chemistry results for re-opening oil-impacted areas closed to seafood harvesting due to the Deepwater Horizon oil spill" (http://www.fda.gov/downloads/Food/FoodSafety/Product-SpecificInformation/Seafood/UCM233818.pdf).

At the time of the symposium (August 2012) public concerns over the safety of Gulf seafood had largely dissipated. The use of extensive sampling after the spill provided a scientific basis to support an effective risk communication campaign.

REAL WORLD EXPOSURE AND BIOMONITORING (HAMMOND)

To the alarmist, exposure to pesticides means harm, adverse health effects, and possible poison. Any detection raises concern. This is illustrated in recent public opinion surveys.

Q: If you are exposed to a toxic chemical substance, then you are likely to suffer adverse health effects.

A: 85% of the public agreed with this statement versus 30% of toxicologists who agreed.

Q: For pesticides, it is not how much of the chemical you are exposed to that should worry you, but whether or not you are exposed at all.

A: 35% of the public agreed versus <5% of toxicologists.[17]

Scientific views appear to have little impact. Activists use 60-year-old DDT or Agent Orange information to scare the public and often cherry-pick publications and studies that show high toxicity results. They have gained significant support from the professional medical community and effective use of the social media.

The swords of the pressure groups include billboards/fliers/protests with messages such as "Is your lawn giving you cancer?" "Pesticides kill weeds and bugs—who's next?"

Biomonitoring studies may provide information regarding risks needed to counter alarmist views regarding the ill effects of pesticides. The Centers for Disease Control's definition for biomonitoring is the direct measuring of environmental chemicals or metabolites in human specimens (such as blood or urine or breast milk).[18] The value measures "internal dose" rather than the less toxicological relevant "external" or potential sources of exposure.

Examples of studies that use biomonitoring include the following:

Agricultural Health Study[19]

- The goal was to investigate and measure exposure from applied pesticides using a prospective cohort study of 4,916 commercial applicators, 52,395 private applicators, mostly farmers, and over 32,000 spouses from Iowa and North Carolina.

Farm Family Exposure Study[20]

- A prospective cohort study of 95 families enrolled from Minnesota and South Carolina, applying glyphosate, chlorpyrifos, or 2,4-D.

A biomonitoring equivalent (BE) is defined as the concentration of a chemical in blood or urine that corresponds/parallels to an allowable exposure guidance value, such as a reference dose (RfD) considered to be safe by regulatory agencies. BEs provide a tool for placing population-based biomonitoring results in a public health risk context. CDC urinary biomonitoring found general U.S. population mean exposure to 2,4-D to be 1.27 μg/L (ppb), 95th percentile. Compared to the most recent 2,4-D animal study, the male no observed adverse effect level (NOAEL) is ∼13,000-fold higher than the CDC biomonitoring study (Table 3).[18,21]

Table 3. CDC Urinary Biomonitoring 2,4-D Data U.S. Population[a18]

study (n)	age group (years) population	percentile μg/L (ppb) 50th	95th
546	6−11	<LOD[b]	1.55
797	12−19	<LOD	1.24
1070	20−59	<LOD	1.27
2413	all, 6−59	<LOD	1.27

[a]Compared to the extended one-generation animal study, the male NOAEL is ∼13000-fold higher than 2,4-D exposure from biomonitoring studies. NHANES, 2001−2002 (CDC 2005). [b]LOD, limit of detection was 0.2 μg/L.

In summary

- Inaccurate interpretation and selective reporting of studies challenges risk managers in conducting their jobs.
- A risk manager makes a determination of a reasonable certainty of no harm if label directions are followed.
- It is imperative that industry, producers, academics, and regulators educate the public on these aspects of risk assessment. Biomonitoring represents a potential tool for informing and communicating risks more effectively, because it measures internal or absorbed exposure dose rather than external potential exposure dose.

RISKS FROM CHEMICALS IN THE ENVIRONMENT: FUMIGANTS (SEIBER)

Fumigants are important tools for food production, particularly in states with high-value specialty crop production on a large scale, such as California and Florida. In the areas of heaviest uses, fumigants often walk the fine line between risk and benefit. California is the leading U.S. state in terms of farm gate value and numbers of commercial food varieties produced. Not surprisingly, it is a leading user of fumigants to control soil pests (Table 4).[22,23]

Fumigants are volatile and can present inhalation exposures to applicators and downwind workers and residents. Often a plastic tarp barrier is used to cover the fumigated soil to reduce losses to the air and increase efficacy. For metam, and a few other fumigants, soil treatment is often made through the drip irrigation system. Center pivot sprinklers are used in Washington state to dispense metam, a soluble salt, which converts to the volatile methyl isothiocyanate (MITC) in the moistened soil. Chloropicrin is the most acutely toxic of the fumigants in common use in California, measured by LC_{50} in inhalation studies with rats, followed by methyl bromide, MITC, and 1,3-dichloropropene (Telone). However, a major concern is with chronic toxicity—chloropicrin produces pulmonary edema, whereas methyl iodide and methyl bromide are central nervous system (CNS) depressants and neurotoxic.[24] According to the EPA Integrated Risk Information System, propylene oxide has been classified as a probable human carcinogen, and 1,3-dichloropropene is considered likely to be a human carcinogen;[25] earlier classification efforts by EPA's Office of Pesticide Programs designated metam sodium and metam potassium as probable human carcinogens and methyl bromide and methyl iodide as unlikely to be carcinogenic to humans.[26] Chloropicrin is not classifiable, due to a lack of data.[27]

Manufacturers, transporters, emergency responders, laboratory personnel, and applicators constitute a group that may be exposed as part of their occupation. This group is presumably instructed on fumigant risks and safety procedures by their employers. A second group includes farmworkers and residents, who are exposed incidentally. This group constitutes a target for improved risk communication, including such topics as exposure (how much and for how long), risk mitigation measures, alternatives to chemical fumigants, and the uncertainty in our knowledge of exposures and effects. This second group may include pregnant females and mothers of children who are concerned about effects of fumigant exposure in infants and children.

Farmworkers working in nearby fields need better communication of risk, including the reasons for reentry intervals and buffer zones intended to be health protective. The general residents in the valleys, such as the Salinas Valley of California, are also targets for risk communication. Residents of the valley may be exposed to vapors of several types of fumigants as well as those emanating from several source fields undergoing fumigation. The valley has a majority Hispanic population; environmental justice programs may be underway and coordinated on community-wide bases. An example is the

Table 4. Soil Fumigants in Use in California[a]

active ingredient	principal uses, 2010	pounds used, 1980	pounds used, 2010
methyl bromide	strawberries, preplant soil fumigation, container plants and transplants, raspberries, commodity fumigation	6,065,000	3,868,000
metam sodium/MITC	carrots, processing tomatoes, potatoes, peppers, strawberries	16,700	11,000,000
potassium n-methyldithiocarbamate (metam-potassium)	processing tomatoes, preplant soil fumigation, sweet potatoes, carrots	0	4,830,000
telone or related (1,3-dichloropropene)	strawberries, almonds, preplant soil fumigation, sweet potato	799,000	8,771,000
chloropicrin	strawberries, almonds, preplant soil fumigation, sweet potato	1,444,000	5,825,000
propylene oxide	structural pest control, commodity fumigation, pistachios	0	300,000
methyl iodide	registered in CaliforniaDec 20, 2010; canceled at request of registrant March 21, 2012; never used significantly in CA	0	0

[a]Data approximated from refs 22 and 23.

"C.H.A.M.A.C.O.S." program (Center for the Health Assessment of Mothers and Children of Salinas), in which community groups partner with the Center for Environmental Research and Children's Health at the University of California, Berkeley, to investigate and reduce exposures of children and families, primarily from the Hispanic population of the Salinas Valley.[28] These programs help to communicate the risks of fumigant use to an often overlooked societal group.

Risk communication should include a discussion of benefits to the use of fumigants. Many who work in jobs ancillary to strawberries and other fumigated crops benefit as well from a vibrant agriculture. In 2010, more than 2.5 billion pounds of strawberries was produced in California, with a value of U.S. $1.7 billion.[29]

Methyl bromide (MeBr) is in some respects a "poster child" of the fumigants. In use since the 1940s, it enjoyed steadily increasing use after the banning of ethylene dibromide (EDB), dibromochloropropane (DBCP), and other chemicals. It is effective as a preplant sterilant against nematodes, plant pathogens, fungi, and weed seeds, plus it leaves no significant residues in the subsequent crop. MeBr is also used (in fact, may be required) for postharvest fumigation of some commodities destined for interstate or foreign markets. But MeBr is a stratospheric ozone depleter, to be phased out according to the Montreal Protocol agreements.[30] Methyl bromide phase-out began in 1999. In 2005 there was to be 100% phase-out except for allowable critical use exemptions agreed to by the Montreal Protocol parties. These exemptions allowed the permitting and use of about 3,868,000 pounds of MeBr in California in 2010.[23]

Methyl iodide (MeI) was registered as a potential replacement for methyl bromide, but attracted risk communication messages that were predominately anti-MeI. The messages that played in the newspaper reports, and reverberated in the social media, included

"A particularly toxic chemical has been approved for use on strawberries",[31] "If it weren't toxic, it wouldn't do the job that it does on microorganisms",[32] and "This is without question one of the most toxic chemicals on earth".[33]

Partly as a result of this publicity and an ensuing legal injunction, methyl iodide's registration was withdrawn in California by the registrant.[34]

Most major soil fumigants are also listed as Toxic Air Contaminants (TAC) under the California Air Toxics program, which identifies chemicals that may cause or contribute to increases in serious illness or death or pose a present or potential hazard to human health. Methyl bromide, chloropicrin, and MITC are TACs under California law and also Hazardous Air Pollutants (HAPs) under the federal Clean Air Act. These classifications further heightened public concern over the use of fumigants.

For all of these reasons, fumigants continue to be a contentious issue. Nonfumigant chemicals show promise as alternatives to chemical fumigants, as well as incorporation in the soil of *Brassica* cover crops that release isothiocyanate chemicals when they decompose. Naturally occurring nematicides provide leads to new chemicals under development for soil nematode control.[35] Crop rotation, including leaving a fallow year between planting of strawberries, is a promising method but economically disadvantageous. Soil solarization and steam injection also show promise, and there is ongoing research into nonfumigant chemicals that can be used to control nematodes and other soilborne pests.

The establishment of buffer zones surrounding fumigant use areas using models that can react to changing weather and topographic conditions have been of great value in estimating exposures to fumigants and communicating risk. These models are used by regulatory authorities when deciding whether a given application to use a fumigant will pose a hazard to residents and workers in the vicinity. Inputs to the model include physicochemical properties of the fumigant in question, type of surface, meteorological conditions, amount of chemical applied and depth, and surface topography. The model output is flux or emission rate to air and downwind concentration isopleths (Figure 4).[36−38]

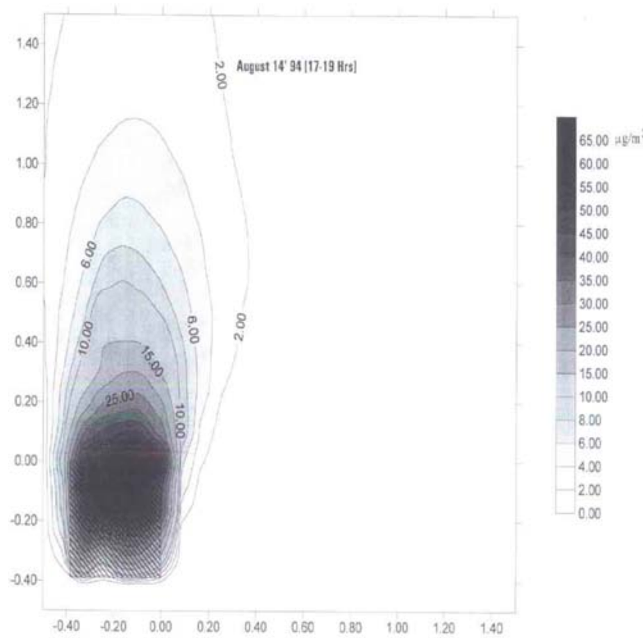

Figure 4. Dispersion modeling of downwind air concentrations of methyl bromide showing isopleths, may be used for setting buffer zones, other restrictions limiting exposure to MeBr, other fumigants. Reproduced from ref 37.

Traditional methods of communicating risk, including warning signs, brochures, and in-person instruction, are important as well. All methods for communicating risks should be employed, including those that can reach all sectors of the relevant population.

In summary, lessons from communication of risks associated with soil fumigants include

- know your audience so that the message communicated will fit their concerns
- communicate more than risks and toxicity; include mitigation, alternatives, and uncertainty and emphasize margins of safety
- individual fumigants have their own characteristics, that is, one size does not fit all
- keep benefits and risks in perspective
- understand and communicate side issues, for example, ozone depletion, transportation accidents
- methyl iodide became a "lightning rod" for opponents to fumigation but ultimately helped in putting risks into perspective
- understand and communicate regulatory/legal issues, for example, Toxic Air Contaminants Act, Proposition 65, and the federal Clean Air Act
- be an advocate for exploration of alternatives to fumigants even when involved in implementing fumigant technologies
- use the media, social and traditional, in communicating risk and benefit information

Table 5. Selection Criteria for POPs[48]

criteria for persistence (P)	criteria for bioaccumulative (B)	criteria for toxicity (T)	potential for long-range transport (LRT)
water: DT_{50} > 60 days sediment: DT_{50} > 180 days soil: DT_{50} > 180 days	BCF > 5000 or log K_{ow} > 5 other, e.g., very toxic or bioaccumulation in nontarget species	no specific criteria other than "significant adverse effects"	air: DT_{50} > 2 days or modeling or monitoring data which shows long-range transport

Communicating risks associated with soil fumigants is a continuing challenge as society becomes more risk adverse. Open dialogue, and use of Web-based media, as well as traditional means of communication, and continuing refinement of the tools for setting and assessing buffer zones, are needed to continue the use of fumigants for pest control. However, agriculture should also communicate the efforts toward safer chemicals and alternative methods that pose fewer risks for the communities that it serves.

■ PERSISTENT ORGANIC POLLUTANTS (POPS) ON THE CUSP: ENDOSULFAN (SOLOMON)

POPs were brought to the attention of the world by Rachel Carson in 1962 in her book *Silent Spring*.[39] Criteria for the classification of the POPs were developed in the late 1990s by the Criteria Expert Group for Persistent Organic Pollutants. Criteria were based on the properties of a number of compounds (the "dirty dozen"), which were subsequently classified as POPs under the Stockholm convention. These criteria are shown in Table 5, and the intersection of the four most important criteria is illustrated in Figure 5.

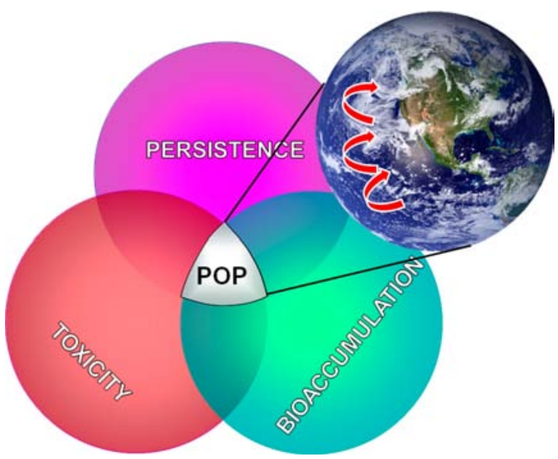

Figure 5. Graphical illustration demonstrating the four criteria used to classify POPs.

Endosulfan is an organochlorine (OC) insecticide with some features in common with chlordane and other OC pesticides classified as POPs, but with significantly higher polarity. The name "endosulfan" includes three distinct chemicals, α- and β-endosulfan and the environmental conversion product endosulfan sulfate. Reported findings of residues of endosulfan from long-range transport were summarized by Weber et al. in 2010,[40] but endosulfan classification as a POP is "on the cusp" in that

- the log K_{ow} is <5, but not by much;
- the bioconcentration factor (BCF) has a range of values, some below and some above 5000;
- trophic magnification, the gold standard for bioaccumulation, is inconsistent.[41]

Residue data from samples of organisms collected at Resolute (Nunavut 74° 41′ 51″ N, 94° 49′ 56″ W) do not show a trend toward biomagnification.[42] Endosulfan is present in environmental media and in biota, but these residues are likely on the cusp of maximum concentrations. Endosulfan has been used for many years and may have reached "quasi-equilibrium", and although endosulfan is found in remote locations, does it cause "significant adverse effects"; that is, are aquatic organisms at risk, are humans in remote locations at risk, or is wildlife at risk? This information has not been assessed by weight of evidence and communicated properly.

Endosulfan residues in Beluga whales from Baffin Island show an increase from 4 to 14 μg/g lipid weight from 1982 to 2002.[40] By most measures the dose people and wildlife might be exposed to would not present a significant hazard to them, given the infrequent nature of exposures and the inherent toxicity profile of endosulfan.[43] Concentrations of endosulfan in snow are <0.01 μg/L,[44] indicating toxicologically insignificant long-range transport. Likewise, concentrations of endosulfan residues in wildlife-derived foods from Greenland (fish, game, seal, walrus, and whale) are <100 ng/g w/w.[45] By contrast, average food intake in Greenland is heavily skewed toward imported foods, and this contributes the greater risk from residues and contaminants relative to the chronic reference dose (RfD) for Greenland's human population. Risks for carnivorous wildlife (narwhale, harp seal, etc.) show margins of exposure well below the no observed adverse effect concentration (NOAEC) in 2-year rat feeding studies. All of these facts point to small risks.

In considering whether endosulfan qualifies as a POP, account needs to be made of what the protection goals are for POPs and whether these are aimed at humans or wildlife. Also, where is the protection needed? Locally, close to use areas, remotely as for other POPs, or based on national jurisdictions? It is an open question whether these aspects have been communicated consistently.

Selection criteria for persistent, bioaccumulative, toxic (PBT) chemicals (Table 6),[46] which are similar to POPs criteria, are the subject of new legislation in the European Union (EU). Reach (EU 253/2011)[47] uses simple numerical criteria but also allows for weight of the evidence as well. By contrast, regulations for pesticides (EC1107/2009)[46] use only simple criteria as the final step in the decision, despite the wealth of data available for these compounds.

Table 6. Selection Criteria for PBTs (from Reference 46)

criteria for persistence (P) $t_{1/2}$	criteria for bioaccumulative (B)	criteria for toxicity (T)
marine water: >60 days fresh water >40 days marine sediment: >180 days freshwater sediment: > 120 days soil: >120 days	BCF > 2000 in aquatic species	chronic NOEC < 001. or is a carcinogen, mutagen, or toxic for reproduction, or other evidence of toxicity

In regard to assessment and transparency, the POP Convention[48] recommended that decisions be made "after rigorous scientific assessment". Environment Canada (1995) stated "Expert opinion and a weight-of-evidence approach must play important roles in the interpretation of scientific data and in

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the application of the criteria presented here. This is particularly the case where persistence and bioaccumulation data identified for a substance are close to the critical values recommended".[49] And all of this should be done in a transparent way.

The "real" POPs were easy to identify and largely have been dealt with. Many existing substances with a propensity for persistence, bioaccumulation, toxicity and/or long-range transport are "on the cusp" and will require a more detailed and rigorous assessment. Endosulfan falls into this category.

The simple criteria developed for identification of POPs and potential for long-range transport (LRT) do not consider other properties of the substance, which may mitigate their identification as POPs or LRTs. Weight of evidence needs to be applied as more substances are proposed as POP, PBT, or LRT, and this must be transparent. Similar arguments will apply to substances identified as potential PBTs in new legislation in the EU, Unites States, Canada, etc.

POPS AND ENDOSULFAN: LESSONS LEARNED (KENNEDY, ROSE, AND CROSSAN)

It is an open question whether the United Nation's Environment Program Stockholm Convention classified endosulfan correctly on the most significant factor for a POP, persistence.

In 2007 environmental scientists from France and Spain proposed listing endosulfan as a POP. This listing could lead to elimination in agriculture. The listing was primarily opposed by warmer countries where endosulfan is intensively used to control insect pressure and by manufacturing countries (principally India and China). A 2010 letter submitted to the POP Review Committee (POPRC) pointed out that ample field evidence existed demonstrating endosulfan did not meet the screening criteria for environmental persistence.[50] However, POPRC proceeded to recommend listing to the politically oriented Conference of Parties (COP5) Geneva, April 21, 2011, at the urging of nongovernment activist organizations (NGOs). Preceding that recommendation, July 7, 2009, Catherine Jacob, environment correspondent from SKYNEWS, reported that British celebrities and Bollywood stars were demanding a ban on a harmful pesticide in cotton production. Partly as a result, Bayer then ceased production.

As indicated in Table 5, the POPS Screening Criteria include ranking for persistence, bioaccumulation, potential for long-range environmental transport, and evidence of adverse environmental effect. It is instructive to examine these in detail and then compare the criteria with scientific data. The criteria as given in Stockholm Convention documents are as follows:

Persistence. Evidence must show that the half-life (DT_{50}) of a chemical in water is >2 months or that its half-life in soil is >6 six months or that its half-life in sediments is >6 months or that the chemical is otherwise sufficiently persistent to justify its consideration within the scope of the convention. As Table 7 shows, the DT_{50} for endosulfan is expected to be much less than 2 months in soil and water in countries where it is in use. For endosulfan sulfate, persistence is closer to criteria values, but still less in soil and water.

Bioaccumulation. Evidence must show that the bioaccumulation factor in aquatic species for the chemical is >5000 or that the log K_{ow} is >5 or that the chemical presents other reasons for concern, such as high bioaccumulation in other species, high toxicity, or ecotoxicity, or monitoring data in biota must indicate that the bioaccumulation potential of the chemical justifies its consideration as a POP. Neither endosulfan nor its more polar sulfate conversion product have BCF values >5000 or log K_{ow} > 5 from the peer-reviewed literature.

Table 7. Summary of DT_{50} Values for Endosulfan as ΣEndosulfan[a]

endosulfan sum of isomers	soil	water	plants
arithmetic mean	44.7 days (n = 42)	19.8 days (n = 40)	7.3 days (n = 20)
geometric mean	21.3 days	4.3 days	2.8 days
median	17.0 days	7.2 days	4.0 days
range	2.9−169 (280) days	0.03−93 days	0.1−34 days
POP criterion	**182 days**	**60 days**	
+ sulfate			
arithmetic mean	164.9 days (n = 10)	23.6 days (n = 8)	7.0 days (n = 10)
geometric mean	118.6 days	15.5 days	4.3 days
median	107.5 days	15.0 days	4.3 days
range	30−391 (1800) days	3−68 days	0.9−20 days

[a]Data were taken from peer-reviewed papers with the number of values (n) indicated for each mean. A full account will be published separately (Kennedy et al., in preparation); a preprint circulated to COP5 in Geneva in 2011 is available on request to I. R. Kennedy.

Potential for Long-Range Environmental Transport. Evidence that levels of the chemical in locations distant from the sources of its release is of potential concern. Such evidence might include monitoring data showing long-range environmental transport of the chemical, with the potential for transfer to a receiving environment via air, water, or migratory species, or the potential for long-range transport through air or in water or migratory species, with the potential for transfer to a receiving environment in locations distant from the sources of its release. For a chemical that migrates significantly through the air, its half-life in air should be >2 days. Published values for endosulfan indicate its half-life in air would be about 2 days,[51] although more research is needed.

Adverse Effects. Evidence of adverse effects to human health or to the environment justify consideration of the chemical within the scope of this Convention as do toxicity or ecotoxicity data that indicate the potential for damage to human health or the environment. There is much accumulated evidence that endosulfan does not pose a risk to humans or wildlife, but again this criticism should be addressed by outside experts with no stake in the outcome of the listing.

POPRC's risk profile for endosulfan involved a qualitative and noncritical review (no tables, with few statistics), lacking evidence for quality control of the data reported, which was highly selected, leading to conclusions given as a series of assertions. It was not peer reviewed. None of the screening criteria produced clear evidence that endosulfan was eligible for listing as a POP, and POPRC's decision to recommend listing would likely not have survived peer review. Despite substantial objections from several of the delegations, the listing proceeded without clear evidence of persistence. In fact, the field evidence (Table 7) for degradation clearly showed that, even using mean values, endosulfan did not meet the persistence criterion. For regulatory purposes, geometric means are preferable, and these were <10% of the screening criteria. Even by including half-life values for endosulfan sulfate (which is almost 2 orders of magnitude less volatile than endosulfan), the criteria were not met.

Only by choosing outliers for degradation rates and by including the much less volatile product endosulfan sulfate, which is not subject to aerial transport as vapor given its low vapor pressure, was the case for the listing supportable. Furthermore, no significant input was sought from experts in insect control or food security. This case raises important issues related to the regulation of agrochemicals and how stewardship is best achieved. A case is now being made that a reversal of its decision may be justified for some uses.

The aftermath of the listing of endosulfan as a POP includes the following:

- Endosulfan was listed by COP5 with exemptions for India and China. Stockholm Convention rules would have allowed a maximum 11 year phase-out period.
- NGO-supported groups in Kerala lobbied the Indian Supreme Court using a questionable case regarding adverse effects on human health. Pensions were instituted for "endosulfan victims", which are now being paid to applicants.
- The Indian Supreme Court instituted a stay on endosulfan manufacture.
- Indian farmers continue to use endosulfan, and it is freely available.
- Export of endosulfan stocks is allowed by the Indian Supreme Court.
- China will continue to use endosulfan, with eventual phase-out in mind.

Clearly the communication of endosulfan's risk lacked scientifically backed clarity. Ecological risk assessment could have been used effectively to clarify the status of endosulfan. Any further assessment of endosulfan should be quantitative, based on a ratio of single deterministic values, for example, hazard quotients, and with assessment of risk based upon likelihood of exposure and/or toxicity (i.e., probabilistic risk assessment) similar to that referred to by Keith Solomon (see above).

Hypotheses should be properly tested using the weight of the evidence, that is, making use of all validated scientific research data. Despite Weber at al.[40] reporting residue data that could suggest long range transport to the Arctic region, their evidence actually indicates these endosulfan residues were mainly derived from local applications, since significant levels of both endosulfan isomers were reported, as well as endosulfan sulfate. The β-isomer and endosulfan sulfate are progressively less volatile than the α-isomer and not subject to long range transport as vapour. The rather constant levels in Arctic air of about 4 pg/cm^3 are consistent with a quasi-equilibrium, too low to have toxic effects as discussed earlier in this paper. Indeed, endosulfan's toxic effects appear to be short or medium range, not long range. Thus, the criteria for POP or PBT listing themselves are not clear-cut for compounds such as endosulfan, which are "on the cusp" of criteria values. Use of ranges might be considered rather than discrete, somewhat arbitrary, values.

Countries like India should have adequate time to adapt to more complex integrated pest management lest food security be threatened. India's successful adoption of genetically modified cotton in recent years, reducing the need for endosulfan, shows they have the technological capability required, but time and good management are needed to phase out the use of endosulfan.

Organizations such as the Stockholm Convention and UNEP should be required to adopt peer review for the conventions to have a legitimate role. Accurate conclusions are essential to guarantee best use of scarce resources for remediation or development of alternatives and instill public confidence in both the process and its results.

CONTINUED DIURON USE IN AUSTRALIA (BURNS)

Australian studies often characterize the "risk" from pesticides but generally lack a consistent method for communicating risk to all stakeholders. Without effective communication, there can be no rational discourse or consensus for using results to achieve management solutions. An alternative is discussed here based on the use of catchment basins to provide residue data for assessing risk. This is done in three steps: first, a context is given using the catchment as a management unit through an Australian case study; second, the important aspects to be considered in catchment-based ecological risk assessment (ERA) are emphasized using results from the application of a spatial modeling approach; and third, a perspective is provided for communicating results of an ERA based on the catchment approach.

An example of a catchment-based ERA approach for the herbicide diuron is provided for the Gwydir River catchment, Australia.[52] This approach followed PA guidelines for conducting ERAs that include problem formulation, analysis, and risk characterization.[53]

In the problem formulation phase, readily accessible information was collated to establish the ecologically significant areas of the catchment, human activities involving the use of diuron, possible sources of diuron loading in streams, identification of susceptible organisms, and end points. Specifically, the assessment end points were chosen to reflect local catchment management goals, one of which focused on protection of the abundance and diversity of the ecological groups within the ecoregions of the Gwydir River catchment.[54] Protected wetlands, such as the Gwydir wetlands, were assigned an end point with the highest level of protection, where 95% of the number of species was required to be protected for 95% of the time. For other environments that had more significant human influences and were not considered to be of high ecological importance, an end point at which 90% of the number of species was required to be protected for 95% of the time was chosen.

The analysis phase involved collating and characterizing aquatic toxicity data and the range of concentrations of diuron occurring in streamwater at various monitoring sites of the Gwydir River catchment. Aquatic toxicity values for diuron were obtained from the EPA ECOTOX database.[55] Water concentration data were obtained upon request from the New South Wales Office of Water. These data sets were summarized into continuous probabilistic distributions of species sensitivity (SSD) and exposure. To support the assessment end points, hazardous concentrations (HC) that represent 5% (HC_5) and 10% (HC_{10}) of species being affected in the SSD for diuron were estimated to respectively correspond to the protection goals of 95 and 90% of species. These exposure distributions and SSD formed the basis of the risk characterization phase.

The characterization of the risk from diuron occurring in the reaches of the Gwydir River catchment involved using the probabilistic approach of Solomon et al.[56,57] The probability that the concentrations of diuron occurring in the reaches of the Gwydir River catchment exceed the thresholds defined in the end points for the different ecoregions was quantified for all data available for each site and monitoring year (1991−2007). Using all of the exposure data collected over the monitoring years, the probability that the end point thresholds were exceeded are summarized in a map (Figure 6). Examples of the annual risk observed at four of the monitoring sites are given in a series of graphs (Figure 7). Both the map (Figure 6) and the graphs (Figure 7) show that risk varies between monitoring locations and temporally. This variability in the risk is the outcome of different pest

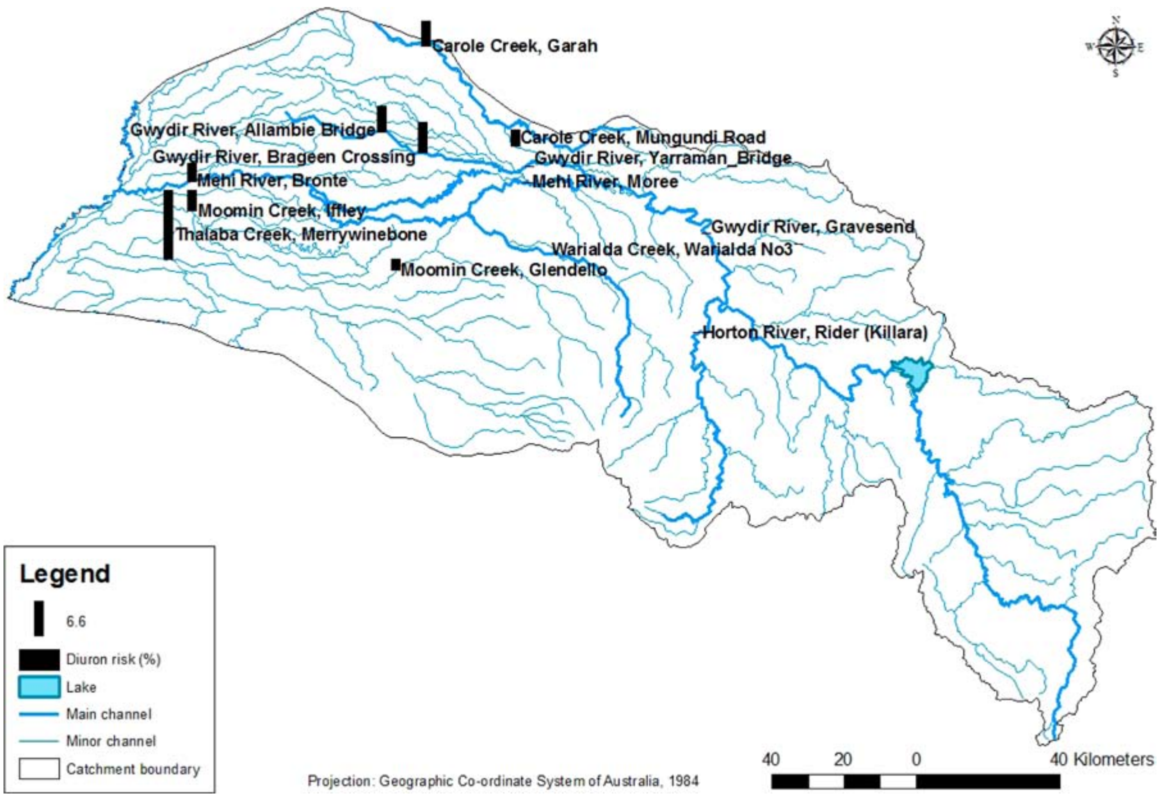

Figure 6. Results of the diuron probabilistic risk assessment for each monitoring site in the Gwydir River catchment. The percent (%) probability of the occurrence of diuron concentrations exceeding the HC_x toxicity threshold, as determined using the joint probability method of Solomon et al.,[56] is given by the height of the black bars, which can be estimated relative to the black vertical bar given in the map legend (taken from ref 52).

management practices undertaken by the farmers. Other factors likely to influence the risk include the types of crops grown and soil and climatic conditions. These results suggest a need for subcatchment management strategies that aim to limit the risk from diuron exposure to the aquatic environment of each subcatchment.

To gain some insight to diuron loading in the Gwydir wetlands subcatchment, an area of high ecological importance, this region was further assessed using a spatial modeling approach of Hoogeweg et al.[58] This approach involved generating hydrological response units (HRUs) by overlaying subcatchment boundaries with land use and soil and weather station spatial information (Figure 8). These HRUs were used as inputs to the Pesticide Root Zone Model-Riverine Water Quality (PRZM-RIVWQ) model framework of Hoogeweg et al.[58]

The results from the study provided the ability to identify the loading points in the catchment and in the temporal variation in loading. Although this model requires further validation and calibration to improve its reliability as a risk assessment tool for this catchment, the model does support that a further refining of the management unit is possible to even greater resolution than the subcatchment level.

From the perspective of risk communication, the current scope for the management of pesticide use in Australia is at the national level,[59] but at this level the capacity to distinguish unique risk profiles at the catchment and subcatchment levels is lost. Our findings indicate that the risk posed by diuron in the subcatchments of the Gwydir River, and indeed in other catchment ERAs, is site/region-specific. This can support a local management initiative, one that requires a strong relationship between the ERA practitioners, environmental managers, and local stakeholders (e.g., farmers, citizens, etc.).

In Australia, local level ERAs would be best executed by catchment management organizations (CMOs). There is currently one CMO for each catchment. The current role of CMOs does not include pesticides as part of their assessment and management. Pesticides only receive attention when acute exposure events occur that result in obvious harm to local ecosystems such as fish kills. The response is an investigation from an environmental protection authority (EPA) that investigates the source of contamination. However, over the years ERA research has been focusing on loading of pesticides that originate from diffuse sources, such as those observed in catchments.[52,60] Management of the diffuse nature of pesticide loading in agricultural catchments should be occurring at the subcatchment level. CMOs would be best suited to devising and implementing the appropriate pesticide management strategies, given their knowledge about the catchment dynamics as well as their strong relationship with the local community.

The risk from diuron used in the Gwydir River catchment varies both spatially and temporally. Using GIS technology, risk was displayed to highlight subcatchments of concern. Furthermore, spatial exposure modeling was a useful approach to supplement when data were not available and to highlight sources of pesticide loading in the subcatchments. Catchments are the most appropriate management unit, and CMOs might be the most appropriate group of environmental managers to extend results from ERAs and to implement and direct management solutions.

From a current review of diuron being conducted relative to its label uses in Australia,[59,61] much of the focus was on adverse impacts of diuron in outflows toward the Great Barrier Reef. The chemical review of diuron commenced in 2005 and has undergone a number of rounds of feedback and revision by the Australian Pesticides and Veterinary Medicines Authority (APVMA). Excerpts from the 2005 Preliminary Review Findings[62] and some suggestions for addressing salient points from the review follow.

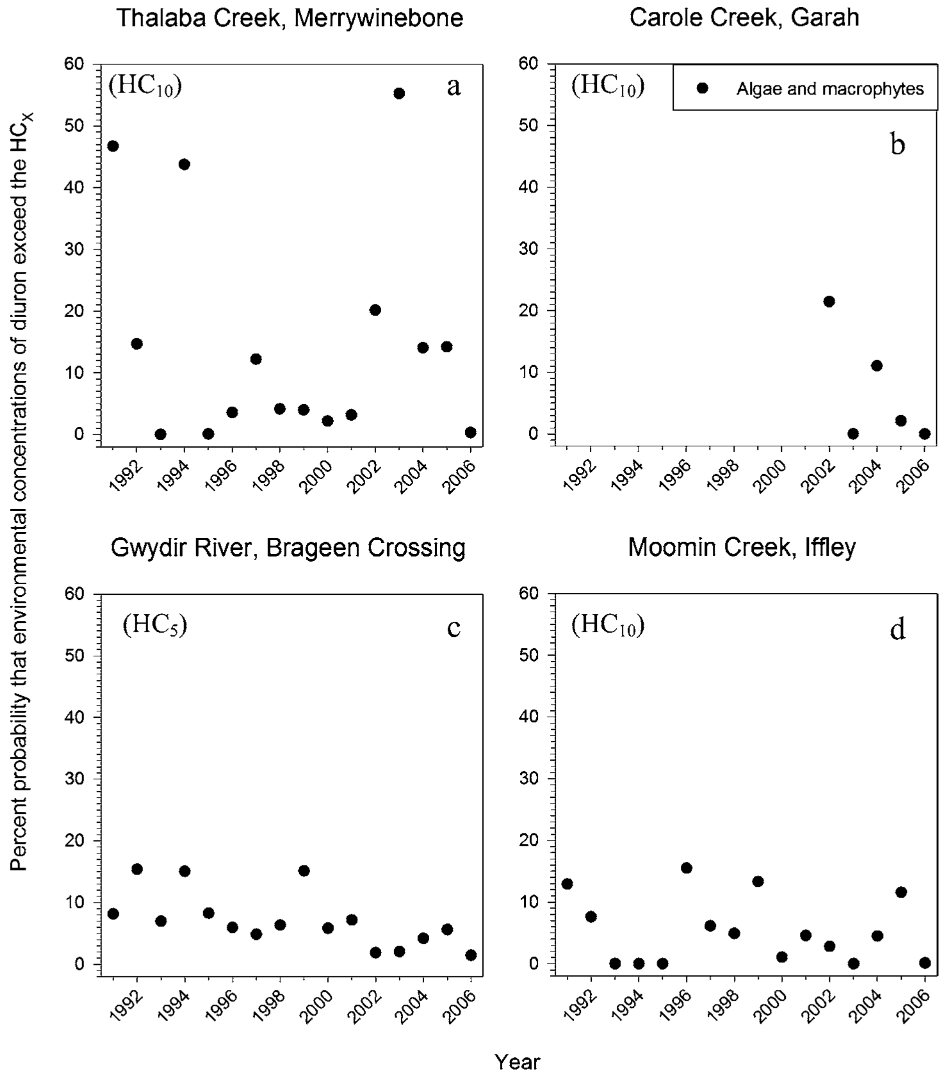

Figure 7. Four examples of annual risk of diuron exposure exceeding the HC_5 or HC_{10} (HC_x) at (a) Thalaba Creek, Merrywinebone (1991−2006); (b) Carole Creek, Garah (2002−2006); (c) Gwydir River, Brageen Crossing (1991−2006); and (d) Moomin Creek, Iffley (1991−2006). The acronyms in brackets located in each graph indicate the HC_x used to calculate risk, with respect to assessment end points (reprinted from Burns, 2011[52]).

- Uses of diuron at current label rates on sugar cane, cotton, citrus, and horticultural crops are likely to have an **unacceptable environmental impact**.
- APVMA cannot be satisfied that use of diuron products on the above crops would not have unintended harmful effects on animals or plants or to the environment. It is recommended that product labels be varied.

Key Findings for the Great Barrier Reef (GBR) in 2005 were that

- "...measured levels of diuron in the Pioneer River due to runoff, as well as in sediments in the drains and river/estuary systems that drain sugarcane growing regions, are higher than those acceptable to protect algae and aquatic plants..."
- "There is a growing body of evidence to show that diuron in sediments in the Pioneer River estuaries has affected mangroves..."
- "...there is a risk to seagrasses due to diuron in sediment, which was considered unacceptable due to the key ecological role of seagrasses."
- "There is also a risk to crustose coralline algae and corals offshore from the currently measured levels of diuron in the Pioneer River."

As a result of this APVMA issued a Revised Environment Report on Diuron (July 2011).[59] Key findings in 2011 were that

- There is an **unacceptable risk** from runoff to algae and aquatic plants in primary streams at rates of application >160 g/ha and in secondary streams at rates of application >900 g/ha.
- There is an **unacceptable chronic risk** to birds from application of diuron at rates >350 g/ha.
- There is **uncertainty** about the potential for diuron and its metabolites in pore water to pose risk to sediment algae and rooted aquatic plants.
- On the basis of current data, the risk (as determined by a risk quotient approach) to primary producers (algae and aquatic plants) and primary and secondary consumers (aquatic invertebrates and fish) in the GBR lagoon is acceptable. APVMA's prior opinion was revised as a result of extensive studies with passive samplers showing that levels of diuron in the lagoon were predominately 2 orders of magnitude less than those of ecological concern.

One of the strengths of the APVMA review process is the inclusion of public comment feedback cycles, which provides

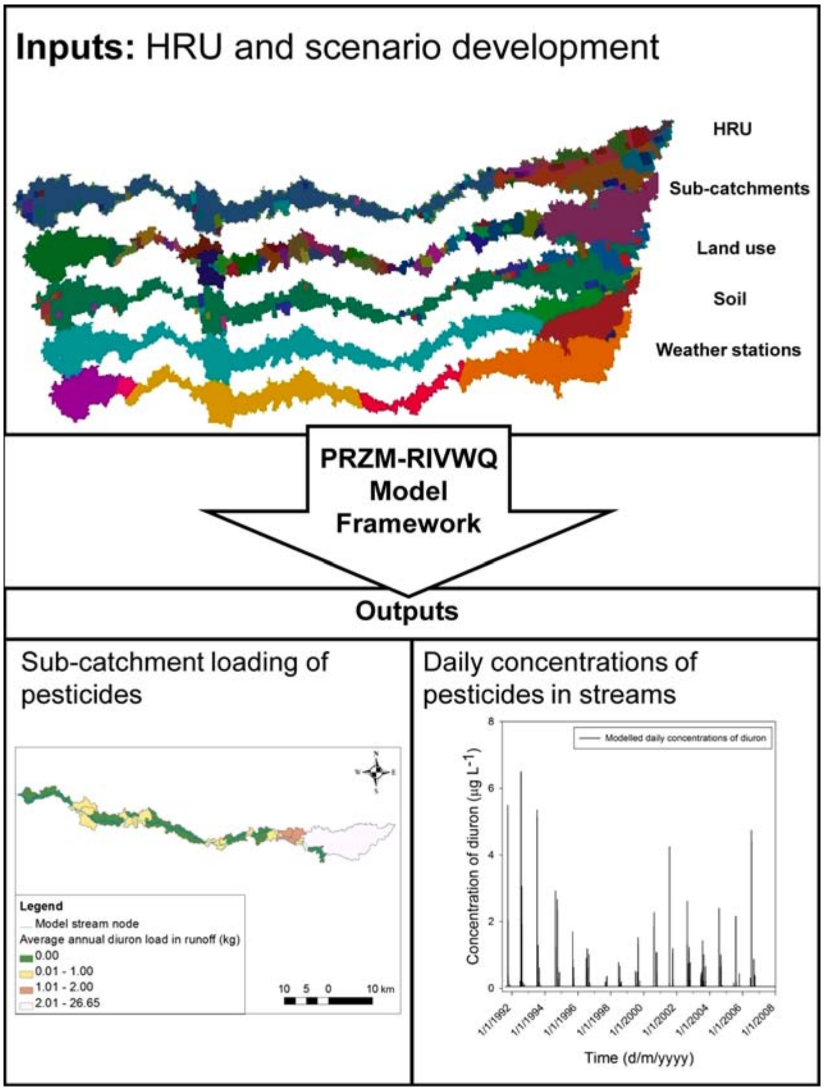

Figure 8. Schematic diagram of the PRZM-RIVWQ spatial modeling framework used to estimate diuron loading into the Gwydir wetlands subcatchment. The scenarios that were used as inputs into the model were generated from hydrological response units (HRU). These HRUs were developed by overlaying spatial information of subcatchment boundaries, land use, soil, and weather station spatial information (shown in the "Inputs" schematic). The "outputs" generated from running this model framework included maps of subcatchment loading and daily concentrations of pesticides occurring in the reaches of the Gwydir wetlands.

external inputs of knowledge that may have been missed during the internal review periods. Nevertheless, the APVMA has recently been criticized for the amount of time taken to complete chemical reviews.[63] Faster review times would undoubtedly be a welcome goal so long as all applicable scientific knowledge could be integrated. One of the key limitations to the speed of review is the lack of a consistent, transparent framework for ecological risk assessment. This leads to ambiguities in the goals of the review, the methodologies used, and the final end points of the assessment, making it difficult to understand what is at risk and the probability of any negative impacts.

Also, "contamination", rather than probabilistic risk, still dominates the focus (see, for example, Lewis et al.,[64] Kennedy et al.,[50] and Kennedy et al.[65]). Suggested changes or improvements might include the design and implementation of a risk assessment framework in the review process; technical review to ensure rigor and links with regulation and enforcement; site-specific review and management; employment of tools for management (GIS and monitoring); and development of rapid chemical analysis tools.

As a result of these needs, an easily deployable immunoassay-based test kit has been developed which provides rapid results (2–4 min) and is low in cost, easy to use, and readily integrated into existing management systems. Use of in situ tests of this type can serve to validate model predictions, stimulate model improvements, and ultimately improve the communication of ecosystem risks to all stakeholders.

DISCUSSION AND CONCLUSIONS

General Observations from Case Studies. Agricultural biotechnology results in higher yields of safe food for consumers and thus helps to meet global demand and stabilize food prices. However, mistrust of technology in some sectors of the public persists in limiting use of the tools of biotechnology. Communication regarding biotechnology in food production has fallen short in this area, and new approaches are needed.

Interagency cooperation was critical to the successful phase-out and communication of risk associated with an arsenical feed additive, Roxarsone. State of the art probabilistic tools were employed in assessing the risk from inorganic arsenic associated with Roxarone and in communicating this message within and between relevant agencies and with the public. Such cooperation must be encouraged if the best use of public funds is to be achieved.

Putting into place an immediate and comprehensive monitoring of seafood was instrumental in communicating the low level of risk to the public in the case of oil spilled in the Gulf of Mexico. Comparison of postspill levels of the toxic components, polycyclic aromatic hydrocarbons, with those determined prespill were useful in this risk communication and alleviating public concern over the safety of the supplied from the Gulf.

Biomonitoring studies need to proceed in parallel with chemical monitoring to provide a balanced picture of the risk posed by chemicals in the environment. The merits of biomonitoring, particularly the concept of absorbed (internal) dose versus external dose, need to be better communicated to the public and with regulatory authorities.

The need to limit fumigant exposure has prompted the development of models for exposure that can track the temporal and spatial distribution of these chemicals downwind. This tool helps in setting regulatory limits such as buffer zones around use areas. More tools of this type are needed to help communicate and implement risk and safety concepts with the public.

Sole reliance on criteria using physicochemical properties and findings of chemicals resulting from long-range transport is not sufficient for the evaluation of chemicals for regulatory control as POPs or PBTs. A more rigorous and detailed assessment is needed for those chemicals having properties that are "on the cusp" of guideline criteria, as illustrated by shortcomings in the process for listing of the insecticide endosulfan as a POP.

Community protection values need to be factored into the collection and use of exposure data, as illustrated with environmental risk assessment based upon water catchment basins near heavier zones of pesticide use. The catchment basin approach to protecting human health and the environment is beginning to be employed in Australia (as shown in the case of diuron herbicide) as a guide for data collection and follow-up actions that can be taken to reduce risk. Protecting unique and valuable resources such as the Great Barrier Reef provides an example of the beneficial use of catchment basin analysis, as well as other tools such as GIS and field kits to aid in monitoring.

Some of the measures needed to put human reasoning into risk communication include recognizing concerns and sharing them challenging scare tactics with scientific facts insisting on high-quality, independent, and critical peer review acting to manage and reduce risk when indicated considering farmers' needs for effective tools to grow enough food considering both the cost and benefit of particular courses of action taking measures to manage and make others aware of the science seeking a community role in setting protection goals

Suggestions for the Future. Society will need to learn from experience, remembering DDT, the disaster at Bhopal in India, and Agent Orange in Vietnam as examples that could have benefitted from more effective and balanced risk communication. The community needs to be reassured that rational means of managing environmental risk are increasingly available and that safety is one of the main reasons for regulation.

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Notes

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