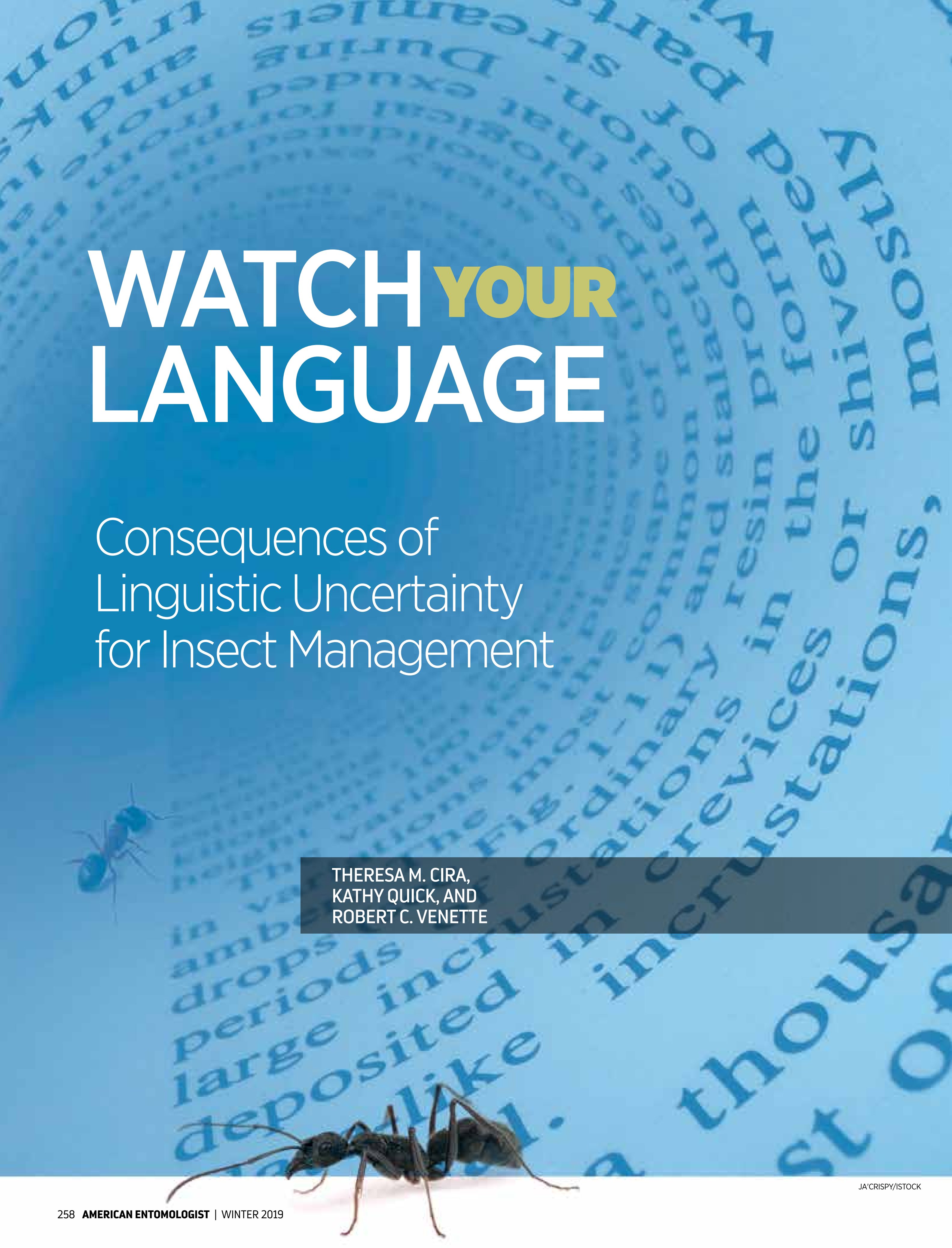
WATCH YOUR LANGUAGE

Consequences of Linguistic Uncertainty for Insect Management

THERESA M. CIRA,
KATHY QUICK, AND
ROBERT C. VENETTE



JA'CRISPY/ISTOCK

This is a call to entomologists to consider the uncertainty introduced into our works through the language we use. Albert Einstein remarked, "Everything depends on the degree to which words and word-combinations correspond to the world of impression," which makes language a "dangerous source of error and deception" (Hawking 2007). Scientists usually research and deliberately choose the language they use to propose new concepts or terminology. Often, however, terms slip into the lexicon through less systematic means. Words may seem to have meanings so obvious that broad understanding of the term may be taken for granted, but individual contexts are diverse, and to assume that a word's meaning is unchanging across time and space is to overlook the uncertainties of language. Thus, communication through even the most common entomological vocabulary can fail. Language is a mutable, uncertain, and imperfect way of representing the world. Because language is integral to science and yet inherently imprecise, it is important for scientists to recognize and address uncertainty in the language of our works.

Uncertainty, as defined by the Society for Risk Analysis (2015), is "not knowing the true value of a quantity or the future consequences of an activity," or "imperfect or incomplete information/knowledge about a hypothesis, a quantity, or the occurrence of an event." This state of not knowing arises from a lack of knowledge, inherent variability in systems, and/or inconsistencies introduced by language (i.e., epistemic uncertainty, aleatory uncertainty, and linguistic uncertainty, respectively; Hoffman and Hammonds 1994, Regan et al. 2002, Society for Risk Analysis 2015). All types of uncertainty can impede effective decision-making (Carey and Burgman 2008, Milner-Gulland and Shea 2017). Certainty about natural phenomena increases through the convergence and agreement of perceptions among people and across time (Eckhardt 1981), but will never be fully achieved (Popper 2012). The scientific process primarily addresses epistemological and aleatory sources of uncertainty. The empirical nature of the scientific process is, in part, what makes scientific knowledge useful. If a phenomenon is repeatedly observed and individuals agree that measurements converge, to some degree, on a specific point, more certainty about the true nature of the phenomenon can be asserted. However, that agreement assumes a common use of language to describe phenomena.

Language is a "system for describing perceptions" (Zadeh 2004); however, language is dynamic and in a constant state of change. In 2000, there were approximately 1,022,000 words in the English lexicon, nearly double the 544,000 words in 1900 (Michel et al. 2011). Not only do new words arise and unused words fall away, but one word may have many meanings (polysemy), and the meanings of words change over time (semantic change). Britton (1978) analyzed the 100 most frequently used English words for polysemy and found, conservatively, that 32% of these words had more than one meaning, and the median number of meanings for an ambiguous word was three. More than half (52%) of the English lexicon was found to be completely undocumented in the Oxford English Dictionary, so-called "dark matter" (Michel et al. 2011). Similar challenges affect communication in any language.

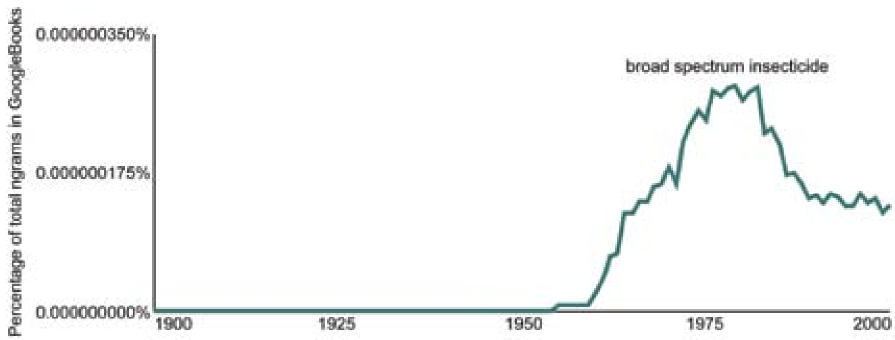
Within the context of pest management, the uncertainty of some terms has been noted or examined. Horowitz et al. (2009) introduce their book on biorational control of pests by noting the confusion caused by a lack of a standardized definition of the term "biorational." Eilenberg et al. (2001) found that different disciplines that encompass biological control research use different terms, which has led to confusion among people such as extension agents and regulatory officials. Crump et al. (1999) identified confusing terminology related to biological weed control and pointed out that the connotations of certain words, such as "chemical" and "synthetic," could affect the public trust and, ultimately, the fate of one type of control over another. They concluded that allowing terms to be defined individually in each paper, rather than insisting on a common definition, complicates communication and increases confusion, and that "Clear, meaningful terminology is one essential step in gaining public confidence."

The occurrence and consequences of linguistic uncertainty in entomology have rarely been considered, meriting attention as potentially significant barriers to the development of concepts and effective communication within the discipline. Do ambiguous and indeterminate terms provide flexibility, or do they increase confusion? Table 1, a summary of a taxonomy of linguistic uncertainty proposed by Regan et al. (2008), illustrates this point with entomologically relevant examples. We intend to illustrate how linguistic uncertainty may affect the strength, validity, reproducibility, and long-term stability of research. Our assertion that linguistic uncertainty is commonplace and consequential is illustrated through an analysis of how insecticides have been described and categorized in entomological publications, particularly with respect to broad-spectrum insecticides.

Table 1. The five types of linguistic uncertainty according to Regan et al. (2008), with entomologically relevant examples.

Ambiguity	When a word has more than one meaning and the intended meaning is not stated.	The term "significant" has multiple meanings (e.g., statistically significant, or subjectively perceived to be important), and often the intended meaning is not stated.
Context dependency	When the context a statement should be understood in is not stated.	The sentence, "Syrphid flies are predators" lacks context because it does not specify which life stage (the larva) is predatory.
Underspecificity	When the necessary degree of specificity to understand a statement is not stated.	To say "the specimen was found east of Minneapolis" is underspecific because it would not be possible to determine exactly where the specimen was found.
Indeterminacy of theoretical terms	When the meaning of a term changes over time.	In the 16th century the term "pest" arose from the term pestilence, or a fatal epidemic, specifically the bubonic plague, and "pest" referenced the plague or a contagious disease. Through semantic change, "pest" has since come to mean noxious people or things (Onions et al. 1966).
Vagueness	When a sharp boundary cannot be drawn around the meaning of a term.	In the spectrum of visible light, it is difficult to draw a sharp boundary around the specific wavelengths that constitute the color red.

Fig. 1. Relative frequency of use over time of the term "broad-spectrum insecticide" compared to other tri-grams (three-word phrases) in books scanned by Google.



Case Study: Insecticide Categorization and Broad-Spectrum Insecticides

Categories can be shortcuts to convey meaning without extensive description. The concept of a specific category, such as "insect," is not independent from a person's acquaintance with members of that category. Although a dictionary definition of "insect" indicates an animal that has six legs, familiarity with insects and the world enables us to call an ant that has lost two legs an insect. This individually unique and vast prior knowledge builds the matrix for a person's mental representation of a typical member in a category, and guides where they believe the delimiting bounds of the category should be (Taylor 1995). Individual understandings of a category are never identical, yet, in general, the overlap of individually created meanings for a category is substantial enough to communicate with an adequate level of precision and accuracy.

Insecticides are categorized and described in a variety of ways. In some cases, categories have been structured by governments, non-governmental certifying agencies, or research communities (Table 2). Regulating bodies can outline the category or set of categories and/or certify which insecticides are in different categories. In addition to formalized lists of categories, less-structured categories are commonly used to describe or classify insecticides (e.g., "biorational," "botanical," "soft," "persistent"). These less-structured categorization schemes sometimes make sense and are useful. However, there is neither consensus about what these categories mean nor a consistent set of guidelines for placing different insecticides in given categories. No categorization system captures the entire profile of an insecticide, from its chemical makeup to its effects on various living organisms. Even so, assigning an insecticide to a category frames research results and implications, which, in turn, can strongly influence decision-making and insect management practices. It is important to understand, acknowledge, and consider the mechanisms used to create categories for insecticides when choosing which insecticide categories to use in scientific writing.

Table 2. Categories of insecticides defined or certified by an organization, with aspects of linguistic uncertainty noted.

Terms	Regulating body*	Characteristics on which membership is based
Reduced risk	US EPA	Risk in comparison to alternatives (USEPA 2016)
Organic	OMRI	Physical components of insecticide (OMRI 2016)
Group, subgroup, chemical class, active ingredient	IRAC	Insect physiological systems affected; mode of action classification informs the symptomology, speed of action, and other properties of the actives therein (IRAC 2017)
Level of harm (e.g., harmless, slightly harmful)	IOBC	Harm to natural enemies, where harm is evaluated as either mortality or a reduction in beneficial capacity (i.e., parasitism) compared to a control (Hassan et al. 1994)
Biopesticide	US EPA	Containing naturally occurring substances that control pests (biochemical pesticides), microorganisms that control pests (microbial pesticides), or substances produced by plants containing added genetic material (plant-incorporated protectants) (USEPA 2017)

*Acronyms: US EPA = United States Environmental Protection Agency; OMRI = Organic Materials Review Institute; IRAC = Insecticide Resistance Action Committee; IOBC = International Organization for Biological Control

Materials and Methods

To investigate linguistic uncertainty in the categorization of insecticides, we explored one unregulated category in detail: "broad-spectrum." We chose this term because of the prevalence and long history of its use in the entomological literature (Fig. 1). We surveyed literature containing the term "broad-spectrum" in conjunction with the word "insecticide," with the following questions in mind:

- How is "broad-spectrum insecticide" explicitly defined?
- How is "broad-spectrum insecticide" implicitly defined?
- Which insecticides are considered "broad-spectrum"?
- What is the utility of the category "broad-spectrum insecticide"?

These questions helped us determine whether the category "broad-spectrum insecticide" was clear, consistent, and useful.

Explicit Definitions of "Broad-Spectrum Insecticide"

We sought the earliest publication of the term "broad-spectrum" in relation to insecticide; our hypothesis was that at the time of its first use, a definition would have been proposed. We also searched a subset of standard entomological references in print and on the Internet. Additionally, using 60 recent (2006–2016) peer-reviewed papers from the top 10 entomology journals that employed the term "broad-spectrum" to describe an insecticide, we examined their cited work for explicit definitions (see supplementary material at https://doi.org/10.1093/ae/tmz068 for details about these methods).

Implicit Definitions of "Broad-Spectrum Insecticide"

Using the 60 recent papers referred to in the previous paragraph, we recorded terms that conveyed an inferred meaning to the category of "broad-spectrum insecticide." These terms were taken from the sentence in which the phrase "broad-spectrum" was used, or from the preceding or following sentences (see supplementary material for details on these methods).

Membership in the "Broad-Spectrum Insecticide" Category

From each of the aforementioned papers, two things were recorded: 1) the categorization of the insecticide(s) (groups, subgroups/chemical classes, and active ingredients), as defined by the Insecticide Resistance Action Committee (IRAC); and 2) whether or not the insecticide(s) was/were considered "broad-spectrum" based on the explicit and/or implicit language.

Utility of the "Broad-Spectrum Insecticide" Category

We used thematic coding and categorizing to evaluate how the term "broad-spectrum insecticide" was used. The categories covered the full range of uses, with minimal overlap or difficulty differentiating between them: 1) descriptive use; 2) comparative use (i.e., in relation to another category); and 3) evaluative use (i.e., associating a negative or positive suite of characteristics). In the evaluative-use category, we qualitatively assessed positive and negative valences, assuming a human-centric, profit-driven perspective (see supplementary material for details on these methods).

Results and Discussion

We strongly emphasize that in this case study, we are not criticizing the cited literature or disparaging the language choices of individual authors. Rather, we use the whole set of papers that matched our search criteria to draw attention to the collective problem that arises from one linguistically uncertain term.

Explicit Definitions

The term "broad-spectrum insecticide" has been integrated into the entomological lexicon without a unifying definition, whether in the oldest literature or in more recent papers. The use of the term markedly increased around 1950 (Fig. 1). We found no seminal paper that coined the term "broad-spectrum insecticide." The earliest record in the electronically searchable and verifiable literature that described an insecticide as "broad-spectrum" (Cooper 1958) was written as if the term was already understood in the lexicon. None of the 60 recent papers or the cited works within

Table 3. Subset of definitions for the term "broad-spectrum" in relation to insecticides.

Term	Definition
Broad-spectrum	Relating to pesticides, killing a wide range of target organisms (Torre-Bueno et al. 1989).
Broad-spectrum pesticide	Chemicals that affect pests and beneficial organisms (Gordh and Headrick 2011).
	A pesticide that kills a large number of unrelated species (University of California Agriculture and Natural Resources Statewide IPM Program 2016).
Broad-spectrum insecticide	Broad-spectrum insecticides are effective against all insects, even the good ones (National Pesticide Information Center 2015).
	Many insecticides are general purpose or wide range killers. These "broad spectrum" pesticides are used when several different kinds of insects are a problem. One chemical can kill them all. No broad-spectrum insecticide kills all insects; each varies as to the kinds of insects it controls (Cornell University Cooperative Extension 2012).
	Insecticides affect various insects differently. An insecticide that is lethal against one group may have little, if any, effect on another. Generally, however, most insecticides kill many kinds of insects: broad-spectrum insecticides are those that kill more kinds than others (Ware and Whitacre 2004).

Notable references that lack definitions of "broad-spectrum insecticide" include *Encyclopedia of Entomology* (Capinera 2008) and a foundational integrated pest management publication, *The Integrated Control Concept* (Stern et al. 1959).

Fig. 2. Terms A) associated with and B) distinguished from the "broad-spectrum insecticide" category. Size of the word represents relative frequency of its use in the 60 recent papers we surveyed, compared with the other words in the figure.

them provided an explicit definition of the term "broad-spectrum" in reference to insecticidal activity or as an insecticidal category. In the expanded search for definitions of "broad-spectrum insecticide" in a subset of standard entomological references (Torre-Bueno et al. 1989, Capinera 2008, Gordh and Headrick 2011), pest management books (Ware and Whitacre 2004), and extension websites (Cornell University Cooperative Extension 2012, National Pesticide Information Center 2015, University of California Agriculture and Natural Resources Statewide IPM Program 2016), the term is defined in different and, at times, conflicting ways (Table 3). The ambiguous nature of the term "broad-spectrum insecticide" was neither acknowledged nor addressed in any of the papers surveyed. Authors did not specify which definition of "broad-spectrum insecticide" should be applied to their work, so it seems that writers take for granted a uniform understanding of "broad-spectrum," or they simply accept the level of uncertainty associated with the term.

Not only is the term "broad-spectrum insecticide" ambiguous, but definitions of the term are also vague (i.e., defined with words that do not specify clear boundaries). Using terms such as "wide range" in the definition of "broad-spectrum insecticide" leaves unanswered questions. Where is the cutoff for "wide"? More than one species? More than one family? More than 10 families? Is the range of affected insects determined by anthropocentric means, such as the destruction of pests versus beneficial insects? Within the explicit definitions we found, additional vague terms were used: "affect," "large number," "unrelated," "effective," "good insects," "killer," and "several kinds of insects" (Table 3).

"Broad-spectrum" as a category contains further linguistic uncertainty because it is inherently a relative term: "broad" in relation to what? Relativity is not specifically addressed in the taxonomy used by Regan et al. (2008). However, the relative nature of the word "broad" increases the likelihood of under-specificity and "indeterminacy of theoretical terms" (i.e., semantic change). When authors do not explicitly state what "broad" is in relation to, or which insecticides they consider to be or not be "broad-spectrum," the term is under-specified. Additionally, the relative nature of the term "broad-spectrum" makes it unstable over time, increasing the chance of semantic change. As different, and possibly more selective, insecticides become available across time, the boundary of "broad" can shift. New information may change what constitutes "destruction," and values may change what constitutes "wide." These fluctuations may cause readers in the future to see the boundaries of the category differently than the authors intended.

Implicit Definitions

When an explicit definition is lacking, terms associated and dissociated with "broad-spectrum" could assist a reader in building an inferred definition. However, contextual cues to intuit the meaning of "broad-spectrum insecticide" among the papers surveyed were diverse and, at times, contradictory (Fig. 2). Our inventory of terms associated with and distinguished from "broad-spectrum" provides useful information about the matrix of mental representations of the category and allows us to compare the delimiting bounds of the category "broad-spectrum" across papers (Fig. 2). Terms associated and dissociated with "broad-spectrum insecticide" were not mutually exclusive. For example, the term "reduced-risk insecticide" was often dissociated from "broad-spectrum"; however, the terms "synthetic" and "contact," when associated with "broad-spectrum," can also describe "reduced-risk insecticides" (Fig. 2). It is not possible for someone to build a logically consistent definition of "broad-spectrum insecticide" based on what the current literature infers "broad-spectrum insecticides" to be.

Membership in the Category

Several nouns among the papers surveyed were described as "broad-spectrum," and, in other cases, as a category distinguished from "broad-spectrum"; these terms are shown in bold in Table 4. We found two reasons for this discrepancy:

1. The term "broad-spectrum" was used primarily to modify the term "insecticide" or a synonymous term (e.g., a specific insecticidal subgroup/chemical class or active ingredient). In fewer instances, the term "broad-spectrum" was used to modify activity in relation to a specific insecticide, subgroup/chemical class, or active ingredient. The relationship between "broad-spectrum" used as an adjective (e.g., "broad-spectrum activity") and "broad-spectrum" used to define a category (e.g., "broad-spectrum insecticide") was not clear (Table 5). It seems counterintuitive that an insecticide described as having "broad-spectrum activity" would not be considered a "broad-spectrum insecticide." However, only a narrow group of insecticides stated to have "broad-spectrum activity" were not categorized as "broad-spectrum insecticides" (i.e., spinetoram, chlorantraniliprole, acetamiprid). Yet the question remains, when does something with "broad-spectrum activity" become a "broad-spectrum insecticide"?
2. In other cases, such as with the IRAC insecticide subgroup neonicotinoids and some active ingredients in this subgroup, discrepancies in categorization reflect the linguistic uncertainty of "broad-spectrum" as a category. Ambiguity and vagueness allow authors to subjectively determine the boundaries of the "broad-spectrum insecticide" category (Table 6). Typically, three to four IRAC subgroups, including neonicotinoids, were listed when an author gave examples of "broad-spectrum insecticides" (e.g., Sisterson et al. 2008, Hamby et al. 2015, Morrison et al. 2016), or it was

Table 4. The insecticide classes, active ingredients, and trade names stated to be broad-spectrum or not broad-spectrum in the 60 recent papers we reviewed. From this list, membership in the broad-spectrum insecticide category can be created.

Insecticide groups:		
Considered to be broad-spectrum		Considered to **NOT** be broad-spectrum
acephate	Gusathion	**acetamiprid***
acetamiprid*	**imidacloprid***	buprofezin
aldicarb	lambda-cyhalothrin	**chlorantraniliprole***
azadirachtin	Maldison	**diamides***
azinphos-methyl	methomyl	emamectin benzoate
Besiege	methyl bromide	flubendiamide
beta-cypermethrin	naled	**imidacloprid***
bifenthrin	**neonicotinoids***	indoxacarb
carbamates	organochlorines	methoxyfenozide
carbaryl	organophosphates	**neonicotinoids***
chlorantraniliprole*	phorate	oxadiazine
chlorfenapyr	phosmet	pymetrozine
chlorpyrifos	pyrethroid	pyriproxyfen
cyfluthrin	pyrethrum	**spinetoram***
cypermethrin	**spinetoram***	spinosad
diamides*	spinosyns	sulfoxaflor
dinotefuran	Temik	thiacloprid
endosulfan	Thimet	thiamethoxam
esfenvalerate	α-cypermethrin	

* These insecticide groups were considered in some papers to be broad-spectrum insecticides and in other papers to **not** be broad-spectrum insecticides (i.e., they appear in both columns).

Table 5. Examples of discrepancies in the literature between "broad-spectrum" insecticidal activity and "broad-spectrum" insecticidal category for a given active ingredient. In most cases, discrepancies occur across papers.

Active ingredient	Insecticidal activity	Insecticidal category
Spinetoram	"Like other spinosyns, it has broad-spectrum activity causing hyperexcitation of the nervous system by activating the Da6 subunit of the nicotinic acetylcholine receptor while maintaining a safe environmental and toxicological profile" (Hamby et al. 2015)	Reduced-risk (Sial and Brunner 2010, Roubos et al. 2014, Hamby et al. 2015) to identify products with low toxicity or short duration effects on biological control agents. In total, 14 insecticides were evaluated using treated petri dishes and four commercially available natural enemies (*Aphidius colemani* Viereck, *Orius insidiosus* [Say], *Chrysoperla rufilabris* [Burmeister], and *Hippodamia convergens* [Guerin-Meneville]
Chlorantraniliprole	"Provides potent and broad-spectrum activity within the insect order Lepidoptera" (Wang et al. 2010)	Anthranilic diamide group (Wang et al. 2010) Selective (Whalen et al. 2016) Reduced risk (Sial and Brunner 2010, Hamby et al. 2015)
Acetamiprid	"Exhibited broad-spectrum insecticidal activity that included toxicity to predatory beetles, predaceous and omnivorous bugs, green lacewings, predatory flies, and several moth species" (Rill et al. 2008)	Broad-spectrum (Rill et al. 2008) Reduced-risk (Roubos et al. 2014) Not a "conventional broad-spectrum" (Wise et al. 2010)

Table 6. Categorization of neonicotinoid active ingredients.

Active ingredient	Insecticide category	Excerpt
Acetamiprid	Broad-spectrum	"The broad-spectrum neonicotinoid acetamiprid ..." (Rill et al. 2008)
	Compared against broad-spectrum	"The reduced-risk products, acetamiprid and spinetoram, were as toxic as some of the broad-spectrum insecticides." (Roubos et al. 2014) "For *H. convergens*, indoxacarb, acetamiprid, imidacloprid, and the broad-spectrum insecticides caused significant acute effects." (Roubos et al. 2014)
	Distinguished from conventional broad-spectrum	"The neonicotinoids thiacloprid and acetamiprid demonstrated strong larvicidal and ovicidal activity but were somewhat weaker adulticides than the conventional broad-spectrum compounds." (Wise et al. 2010)
Dinotefuran	Broad-spectrum	"Dinotefuran is the third neonicotinoid which possesses a broad spectrum and systemic insecticidal activity." (Mu et al. 2016)
Imidacloprid	Broad-spectrum	"Sprays of Azadirachtin (Neem), Tropane (Datura), Spirotetramat, Spinetoram, and broad-spectrum Imidacloprid were evaluated to control ACP in spring and summer on 10-year-old "Kinow" *Citrus reticulata* Blanco trees producing new growth." (Khan et al. 2014)
	Compared against broad-spectrum	"We compared three insecticides (imidacloprid, thiamethoxam, and pymetrozine) to a broad-spectrum insecticide (lambda-cyhalothrin) and an untreated control." (Ohnesorg et al. 2009)
Thiacloprid	Distinguished from conventional broad-spectrum	"The neonicotinoids thiacloprid and acetamiprid demonstrated strong larvicidal and ovicidal activity but were somewhat weaker adulticides than the conventional broad-spectrum compounds." (Wise et al. 2010)
Thiamethoxam	Compared against broad-spectrum	"We compared three insecticides (imidacloprid, thiamethoxam, and pymetrozine) to a broad-spectrum insecticide (lambda-cyhalothrin) and an untreated control." (Ohnesorg et al. 2009)

stated directly that neonicotinoids are "broad-spectrum" (Moser and Obrycki 2009). Conversely, neonicotinoids were also distinguished as an alternative to or substitute for "broad-spectrum insecticides" (Chuang and Hou 2008) or as preferable to "broad-spectrum insecticides" (Ohnesorg et al. 2009). This trend held for specific active ingredients within this subgroup, as well (Table 6).

Table 4 represents the first attempt, to our knowledge, to create a systematic inventory of insecticides categorized as "broad-spectrum" or characterized as distinct from "broad-spectrum" (i.e., they are not considered "broad-spectrum"). This analysis allows us to see how consistently membership to the "broad-spectrum" category is assigned, without necessarily providing clarity about what belongs in the category or the rules for categorization.

Utility of the "Broad-Spectrum Insecticide" Category

The term "broad-spectrum" was used 255 times in the 60 recent papers we surveyed. We categorized its appearance into three types of use: 1) stand-alone description; 2) a term in opposition or in relation to another category; or 3) a term connoting positive or negative value to an insecticide. We found that the term "broad-spectrum" was used as a stand-alone descriptor, unattached to any value-based connotations or in comparison to anything else, 33.3% of the time; e.g., "Within these areas, use of broad-spectrum insecticides is higher in Fresno County than in Madera County" (Sisterson et al. 2008). In 40.4% of cases, "broad-spectrum" was used in relation to or in opposition with another category; e.g., "The impact of imidacloprid on predatory hemipterans was shown to be less than that of a broad-spectrum insecticide" (Ohnesorg et al. 2009).

"Broad-spectrum" was used to connote the positive or negative value of an insecticide with desirable traits in 5.5% of uses and undesirable traits in 16.1% of uses. For example, the statement "Foliar sprays of broad-spectrum insecticides applied during tree dormancy kill the majority of overwintering adults leaving few to infest new shoots in spring" (Khan et al. 2014) was considered to be desirable. The statement "Broad-spectrum insecticides can negatively impact the natural enemies associated with aphids" (Tran et al. 2016) was considered to be undesirable. A small portion of uses (4.7%) encompassed more than one of our evaluative categories.

The term "broad-spectrum" was used most often in comparison to another insecticidal category. Establishing these comparisons enables authors to imply membership and non-membership within a category, without actually categorizing an insecticide. For example, if a study stated a comparison of imidacloprid to a "broad-spectrum insecticide," the framing eases a reader into thinking that imidacloprid is not "broad-spectrum" (Table 4). When the boundaries of an insecticidal category are ambiguous, vague, and/or relative, subjective decisions about how the category should be applied are required. The high degree of flexibility for defining "broad-spectrum" category membership and lack of explicit definitions made it impossible, in many cases, to discern the mechanisms authors were using to categorize insecticides. Individuals designate which insecticides are or are not "broad-spectrum," and apparently there has been no discussion about dissimilar categorizations among papers. Subjective judgment is used to determine "broad-spectrum insecticide" category membership, but this has not been acknowledged.

The second most common usage of the term "broad-spectrum" was to describe a noun unattached to any value-based connotations. An author may think that describing an insecticide as "broad-spectrum" is increasing clarity; however, using "broad-spectrum" as a descriptor decreases certainty, if an author does not define the term. There is no commonly understood and accepted meaning of this term in our field. Additionally, we were unable to find a list of insecticides considered to be "broad-spectrum" (i.e., Table 4). The third and fourth most-common use of "broad-spectrum" was to connote undesirable and desirable qualities, respectively, indicating that, at least during 2006–2016, the category "broad-spectrum" generally carried more negative connotations. Thus, when framing research, it is possible for an author to use the term intentionally or unintentionally to alter readers' perceptions of risk and benefit. In our inventory of terms used in association with "broad-spectrum" (Fig. 2), many terms with negative valences (e.g., "poison," "toxicant") were associated with "broad-spectrum" and placed in opposition with alternatives described in positive terms (e.g., "softer chemistries," "less harmful to humans," "less toxic"). Thus, to categorize something as "broad-spectrum" often insinuates that it is undesirable.

AN AUTHOR MAY THINK THAT DESCRIBING AN INSECTICIDE AS BROAD-SPECTRUM IS INCREASING CLARITY; HOWEVER, USING BROAD-SPECTRUM AS A DESCRIPTOR DECREASES CERTAINTY, IF AN AUTHOR DOES NOT DEFINE THE TERM.

Are You (Un)certain?

A Broad Spectrum of Uncertainty

Our case study highlights the consequences of ignoring the linguistic uncertainty of a commonly used and long-standing term. Despite analyzing only a small fraction of the papers that included the term "broad-spectrum insecticide," we found disagreement among the papers in explicit and implicit definitions of "broad-spectrum insecticide." We found that "broad-spectrum" as a category of insecticides is ambiguous, vague, relative, and subjective: linguistic uncertainties that result in confusion about the bounds of this insecticidal category. This has led to specific insecticides and groups of insecticides being described as both "broad-spectrum" and not "broad-spectrum," difficulty in interpreting and comparing results across studies, and instability of the term's meaning over time. Of particular concern was the unacknowledged contradictory categorization of neonicotinoid insecticides. This linguistic uncertainty is highly consequential for the quality of communication among scientists and for the legitimacy of our science to be used in public and policy dialogue.

It seems that writers and readers are likely unaware of the miscommunication that occurs when this linguistically uncertain term is used. By not defining the term in a paper, authors are relying on reader-created definitions of "broad-spectrum insecticide," which decreases certainty in communication because readers' contexts (e.g., cultural, linguistic, historical) may differ from the writers' contexts. This linguistic uncertainty becomes particularly problematic when the rationale, premise, conclusions, and/or implications of a paper rely heavily on the "broad-spectrum insecticide" category. Combined, these linguistic uncertainties interfere with clear communication and complicate attitudes about insecticides.

Entomologists need to grapple with the question, "Which, if any, linguistic uncertainty should be reduced for the broad-spectrum insecticide category?" We describe potential options in this article, but we believe the answer must derive from a broader discussion among entomologists. At one extreme, the linguistic uncertainty could be accepted as is. Absent any changes to the meaning or use of the term "broad-spectrum insecticide," contradicting categorization will likely continue, the boundaries of the category will remain difficult to determine, and highly subjective determination of membership in this category will persist. To reduce some, but not all, linguistic uncertainty, the "broad-spectrum insecticide" category could be explicitly defined in each individual context or paper in which it is used. If vague words are used in the definition, further clarification will be needed to address that type of linguistic uncertainty. Additionally, clarifying use of the word broad by specifying the context in which category membership was determined (e.g., crop system) should continue to reduce linguistic uncertainty. Individually determined definitions maintain the flexibility of the term while addressing writer-to-reader miscommunication. However, multiple definitions reduce a reader's ability to compare across studies that use different definitions.

Even greater reduction in linguistic uncertainty around the term "broad-spectrum" could result from choosing one definition for the term, which should eliminate ambiguity. Without a paper that coins a term, the authority to dictate the "right" definition is unclear. Strong institutional organization and power likely would be needed to make such a reform. Like Horowitz et al. (2009), we believe the United States Environmental Protection Agency (EPA), or a similar regulating body that can independently assess existing and future insecticides, should be involved and could make category membership criteria widely available, or could create a list of insecticides they determine to be members of this category, similar to how the EPA currently defines "reduced-risk" insecticides (USEPA 2016). However, the consequences of such an extreme linguistic change merit broader discussion among the entomological community. A useful measure for determining the level of linguistic uncertainty would be for a writer to question whether a reader at any point in time would be able to use the set of criteria outlined for a category to determine whether a new insecticide fits in that category or not.

Certainty in an Uncertain World

Some authors have argued strongly for reductions in linguistic uncertainty (e.g., Peters 1991, Herrando-Pérez et al. 2014), believing the quality and efficiency of scientific discourse decrease with greater linguistic uncertainty. Others believe that lexical richness is good and that prescriptively standardizing terminology is bad (Hodges 2008). Hodges (2008) stated that precise definitions are rarely necessary and can hinder scientific advances by preventing certain lines of questioning, which ornithologists seem to agree with (Fraser et al. 2015). Even when well-defined terminology exists and writers are aware of the terms, they may not use them (Kritsky 2001). We found that the linguistic uncertainty that arises when categorizing and describing insecticides illustrates a tension between reduced quality of information and more succinct communication, and could have both positive and negative consequences.

Linguistically uncertain words can increase readers' power to define and interpret research. Without a definition, readers apply their own choice of definition and understanding of a term, which may or may not match the writers' intended meaning. In some cases, this may be desired, such as when flexibility to extrapolate results to myriad contexts is needed. Allowing readers to take liberties interpreting the meaning of research could encourage creative new lines of questioning or discovery of new understandings. However, allowing for variable understandings could allow readers' biases to arise in unexpected ways. Flexibility can also provide the ability to misappropriate results in scientifically unsound ways; e.g., pushing an agenda by using the value-laden connotations of uncertain words. It is important to consider the level of subjective interpretation that words allow.

Language can be used to shape the framing and understanding of knowledge. Commonly, results are compared to a neutral reference point in order to judge the outcome as positive or negative; changing the reference point can alter the perception of gain or loss (Tversky and Kahneman 1981). Thus, the reference points (e.g., insecticidal categories) that scientists choose can change readers' perceptions of risk or benefit, a shift that can critically reduce or undermine the validity of the information being communicated (Jamieson 2017). Science is not wholly an objective discipline, but when linguistic uncertainty is used deliberately to conceal biases in scientific writing, it threatens the credibility of the science. Linguistically uncertain terms, when recognized as such, can be used to highlight areas where more empirical work is needed (Ostry et al. 2011), where expert disagreement exists (Table 4), or where other types of inquiry (e.g., values-based analysis) are more appropriate.

Highly technical and certain language may inhibit understanding of scientific work by other stakeholder groups (NRC 1989). In an effort to make the science more accessible or applicable in decision-making contexts, it may be necessary to translate scientific results into less certain terms. Linguistically uncertain statements may make scientific work more generalizable across different contexts, but leaving out important clarifications or assumptions may lead to unsound extrapolations.

Writers must understand which words carry greater uncertainty and how that uncertainty may affect the interpretation of their work. Within a paper, the writer and the reader (usually never having met each other) must come to a shared understanding of language and meaning. Developing a shared context about the linguistic meaning of words, preferably by explicitly defining key terms, assists this process. The definition can be stated with reference to one or more foundational sources (if they are consistent) or with recognition of the range of definitions in the literature and an explanation about the author's understood definition. Similarly, we suggest that editors and peer-reviewers assess manuscripts' linguistic uncertainty (e.g., undefined terms, vague terms, insufficient context) along with our long-standing practice of assessing epistemic uncertainty (i.e., experimental design, analysis, reporting sources of error).

… ALLOWING TERMS TO BE DEFINED INDIVIDUALLY IN EACH PAPER, RATHER THAN INSISTING ON A COMMON DEFINITION, COMPLICATES COMMUNICATION AND INCREASES CONFUSION …

We hope this paper increases awareness of linguistic uncertainty regarding categorization of insecticides, and also arms readers with the ability to examine their own areas of expertise for sources of linguistic uncertainty. By facilitating recognition of this type of uncertainty, we want to encourage discussion and problem-solving among entomologists, because uncertainty inevitably arises in our communications. To improve communication across time and space, entomologists should mindfully consider where and why linguistically uncertain words are being used in our field.

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Theresa M. Cira, *Department of Entomology, University of Minnesota, 219 Hodson Hall, 1980 Folwell Ave., St. Paul, MN 55108, USA*

Kathy Quick, *Humphrey School of Public Affairs, University of Minnesota, 235 Humphrey School, 301 19th Ave S, Minneapolis, MN 55455, USA*

Robert C. Venette, *USDA Forest Service, Northern Research Station, 1561 Lindig Ave. St. Paul, MN, 55108, USA*

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