Defining the problem: terminology and progress in ecology

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A genre of papers has arisen around the premise that ecological progress and communication with non-specialists are impeded because (1) many ecological terms have multiple meanings and (2) many ecological terms have meanings similar to each other. There is a repeated call for ecological terminology to be standardized and for terms to be defined more concretely. These calls for the standardization of definitions are based on faulty premises about the way language conveys meaning. Most recommendations for definitional reform are unlikely to take hold due to properties of language and they are unlikely to stimulate increased ecological understanding. Precisely delimited definitions are necessary in very few instances, whereas extensive and prescriptive classification can hinder the development of a field by preventing some types of questions from being asked. Useful lexical reviews should focus on the development of ecological knowledge that is signaled by a wealth of terms and meanings, rather than critiquing the terms employed.

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Many recent papers have called for ecological terminology to be standardized, to prevent confusion and to advance environmental decision making. These papers often review existing terminology, note multiple meanings for the same word or multiple words with the same meaning, argue that this lexical richness impedes understanding, and then derive recommendations for how particular words should be used. Words drawing such scrutiny resemble a who's who of ecological concepts – biodiversity, ecosystem, ecosystem engineer, habitat, invasive, keystone, population, and more (see WebTable 1 for more terms and references). I argue that papers of this type do little to advance either the science or its application and that terminological reviews should refocus on advances in the underlying science rather than on the terms themselves.

According to this literature, imprecise, vague, and redundant language hampers ecological research and its application. For example,

- "Until a commonly accepted vocabulary is adopted by invasion ecologists, we think the field will continue to have difficulty developing reliable generalizations, partly due to misunderstandings and misinterpretations among investigators" (Davis and Thompson 2000).
- "To advance wildlife ecology, we must be sure that the fundamental concepts with which we work are well defined, and hence, well understood…vagueness and variability [of terms] is non-productive because it detracts from the ability to communicate effectively about habitat-related subjects" (Hall *et al*. 1997).
- "Imprecise terminology lead[s] to misunderstanding and division among parts of the scientific community" (Wells and Richmond 1995).

In a nutshell:

- Reviews of ecological terminology that recommend particular and precise definitions for terms are common in the literature
- These reviews often make unwarranted assumptions about language, meaning, and how language interacts with scientific progress
- Ecological terminology should not be blamed for any perceived lack of progress in the field; instead, the complex language may actually foster rapid development of ideas

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The papers addressing lexical richness have been motivated by a number of concerns. One such concern is whether a lack of generalities stunts the conceptual development in a field (Peters 1991). Another is the need for effective communication between scientists and non-scientists (Daehler 2001; Davis and Thompson 2001). A third is the negative connotations of some terms (eg the evocative terms "exotic", "invader", "alien"), with some authors arguing that strongly connotative terms should be avoided (Colautti and MacIsaac 2004). Despite these disparate motivating concerns, ecological lexical reviews often recommend standardizing the terminology and definitions as a solution.

Proposals to standardize terminology rely on several lexical and philosophical assumptions addressing how language creates meaning and scientific understanding. These are: (1) that multiple definitions for one word (polysemy) or multiple terms meaning the same thing (synonymy) impede understanding; (2) that terminology can be standardized by lexical reviews and recommended definitions; and (3) that clarifying and standardizing ecological terminology is essential for maximizing research

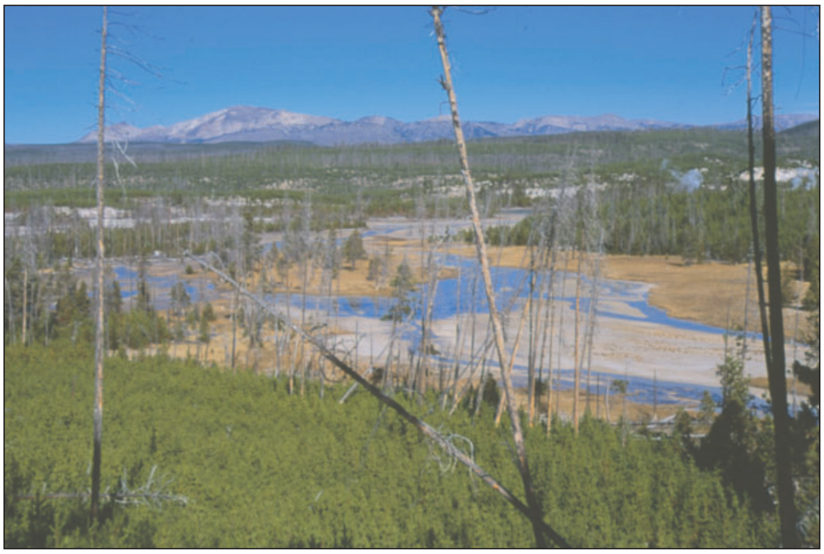

Figure 1. *Is this landscape connected or fragmented? Answering this question will depend on the species at issue and the attributes measured. "Functional connectivity" measurements would address movement rates, but "structural connectivity" measurements would address attributes such as forest density for vole habitat or water temperature for the bacteria in the hot springs. Norris Geyser Basin, Yellowstone National Park.*

efficiency, developing knowledge, communicating with non-ecologists, and providing meaningful policy recommendations. Another common assumption is that terms that are "operationalized" (defined with specific reference to the process by which data would be collected) are superior to those that are not (Peters 1991). These assumptions are flawed; standardized ecological terminology is unlikely, unnecessary, and even undesirable.

Lexical ambiguity

A fundamental concern is that differences in meaning can impair communication if writer and reader obtain different meanings from a term. Is ambiguity arising from polysemy in fact rampant in the ecological literature? Certainly, the *assertion* that it is appears often:

- "Ambiguities in definitions likely will lead to misapplication of the concept" (habitat and associated terms; Morrison 2001).
- "The multiple layers of meaning and use can result in confusion" (ecosystem; Pickett and Cadenasso 2002).
- "Because terminology for describing population structure is not standardized, many terms are confusing" (Wells and Richmond 1995).
- "Without a precise definition and sound quantification of heterogeneity, statements involving the concept will continue to be confusing" (Li and Reynolds 1995).
- "Using terms with different operational definitions, particularly key words such as 'invasive species', is going to result in confusion that will only impede understanding and effective management efforts" (Davis and Thompson 2001).

Do ecologists or practitioners frequently misunderstand the science presented in research papers because of polysemous and synonymous terms? Evidence showing pervasive misunderstandings is lacking. Many of the polysemous terms cited in language review papers are clearly understood in the source papers, either through context or because the terms are explicitly defined. In fact, several papers present tables or other compendia categorizing ways in which authors have used terms (eg Grimm and Wissel 1997; Hall *et al.* 1997; Tischendorf and Fahrig 2000), thus demonstrating that the research papers are *not* chronically hard to interpret because of polysemy or synonymy. The "confusion" cited above appears to refer primarily to the fact that polysemy and synonymy occur, rather than pinpointing fallacious reasoning resulting from these lexical patterns.

Genuine ambiguity caused by polysemy is limited to the case where an author never explicitly defines a term *and* it is not clear from context which meaning is intended. Confusion results when the reader uses a different definition than the one intended by the author or when the term is used in several ways within the paper and it is not clear what is meant in each case. The logical "fallacy of equivocation" occurs when the meaning of a term changes during an argument, and faulty conclusions will usually occur as a result. The confusion resides in the lack of contextual or explicit clues that identify which meaning is intended, rather than in the fact that the term itself is polysemous. Unlike polysemy, synonymy does not cause ambiguity, but can lead to people missing relevant literature as similar phenomena are described using different terms (see also Sorokin's [1956] description of "the discoverer's complex", which arises when people fail to check the literature for synonymous terms).

There are a few anecdotes of genuine confusion, where authors conflated dissimilar observations that shared the same terminology (Mikkelson 1997; Richardson *et al.* 2000; Tischendorf and Fahrig 2000; Figure 1). Despite these anecdotes, substantiated evidence that lexical ambiguity in ecology is common or severe has yet to be provided (contra Shrader-Frechette and McCoy 1993). Such documentation would need to show both how a source paper's meaning was ambiguous and the misinterpretation arising from that ambiguity.

Definition and knowledge

Some scientists have argued that definitions should be developed as part of a logical framework that is formally constructed at the beginning of a research project or program (Peters 1991; Shrader-Frechette and McCoy 1993).

Disciplines such as geometry and physics often use this formalistic approach, with constrained definitions arising early in the development of a project, reasoning from first principles composing a large part of the research, and definitions not changing during the project. Jones *et al.* (1997) encapsulate this view: "Since many areas of ecology do not yet use unambiguous formal language (unlike the equations and formulas of mathematicians, physicists, and chemists), we must pay particular attention to terminology. After all, we cannot have scientifically meaningful dialogue unless we first agree on the definition of what we are studying."

Figure 2. *For species-based conservation, such as protection of grizzly bears* (Ursus arctos)*, many laws and endangerment ranking schemes exist. Biologists, policy makers, and the public continue to wrestle with important questions about what to protect and how to label different degrees of endangerment. A plethora of population-related terms have been used, because conservation is a complex issue. These terms include species, subspecies, population, evolutionarily significant unit, designatable unit, and others.*

In contrast, knowledge often develops in a strikingly different way (Burian 1985; Bowker and Star 1999; Ford 2000; Keller 2000). Polysemy and synonymy may stimulate rapid growth in a field, vague terms are not necessarily problematic, and creating rigid definitions and standardized terminology too early may stunt the growth of a field. The argument that polysemy and synonymy stimulate the generation of knowledge is deeply rooted in how classification enables us to interpret the world (Bowker and Star 1999).

Knowledge implies being able to assign observations unequivocally to appropriate categories (ie this observation fits *here* because it has the attributes of this class of things and not of that other class). Note that "attributes" could refer to state variables such as size and color, to shared processes, or to causal or trophic relationships. In advance of collecting the observations, it is not possible to know that appropriate categories and category boundaries have been chosen; we cannot *know* that all observations will fit into the classification until we have the observations in hand (see also Ford's [2000] discussion of the "domain" of a classification).

Strongly demarcated definitions and classificatory decisions can therefore have serious negative effects on a discipline by constraining inquiry (Bowker and Star 1999). For example, Bowker and Star examined the International Classification of Diseases (ICD), a system for recording causes of death in humans. The ICD is updated regularly by the World Health Organization, both by omitting some causes of death (in the 1913 ICD, one could die from "want of vitality" or by being "worn out") and by adding others (eg AIDS, radiation sickness). Changes in categories make it difficult to analyze changes in those causes of death through time. Additionally, the way the categories are constructed makes it easier to document some patterns than others; Bowker and Star (1999) mention the underdefined "death from snake-bite". Although doctors can readily identify which species of snake killed a person, the ICD records the composite cause of "venomous snakebite". As ecological examples, people studying invasive species or ecosystem engineers are debating how to classify when a species is invasive or an engineer (see WebTable 1 for references). Thus, the particular classification scheme chosen by a researcher or research community shuts down some lines of inquiry even as it enables others.

Polysemy is often useful during the development of a field because several classificatory schemes might work, with each observation fitting unequivocally into one and only one category, but some classifications might be much more useful than others. For example, it would be possible to classify birds by the colors of their longest tail feathers, but this classification is unlikely to be particularly insightful. This trial-and-error phase of fitting language to cases is a true reflection of scientists learning how to group and distinguish observations in ways that will advance the field (Williams 1998; Ford 2000; Regan *et al.* 2002). In large part, lexical richness in ecology arises from ecology's many subdisciplinary approaches, including behavior, population dynamics, landscapes, foraging theory, biogeochemistry, evolution, and conservation biology. Each subdiscipline offers unique classificatory approaches, with concomitant lexical richness.

Rigid classification done too early in a research program will almost certainly contain arbitrary boundaries between categories. This problem is especially likely for ecological problems that address continuous rather than discrete systems or processes. In part, this problem resides in the difference between "natural" language and "operational" language. Natural terms permit boundary cases much more readily, whereas operational terms require strict division of cases into categories (Camus and Lima 2002; Regan *et al.* 2002; Figure 2). As an example, Regan *et al.* (2002) use "critically endangered" – as a natural term, people understand it to mean species with a high risk of imminent extinction. Classificatory systems like the IUCN Red List operationalize the term to mean populations with "< 50 mature individuals", yet few ecologists would genuinely argue that populations with 51 mature individuals are not imperiled.

Even poorly defined and imprecise terms may be extraordinarily useful as "placeholder" terms (Burian 1985; Locke 1992; Ford 2000). For example, "gene" has been with us for a long time, well before the description of DNA and the advent of modern molecular techniques (Burian 1985; Keller 2000; Commoner 2002). Its definitional inconstancy has been an asset, because it has wide "reference potential" (Burian 1985) – "gene" could have referred to any number of possible molecular configurations and "genes" could have helped to form proteins in any number of ways. Its meaning has shifted substantially as our technology has enabled elimination of some possibilities. Slipperiness of a term often marks an area in need of research: meanings come and go until understanding has crystallized (Regan *et al.* 2002). Thus, terms may be indefinable until a field is far advanced, because new discoveries continue to change the meanings. Even now, the broad reference potential of "gene" is still with us, as geneticists explore how DNA interacts with cellular constituents to produce new proteins (Oyama 2000; Commoner 2002).

In ecology, a number of the criticized polysemous terms, such as "invasive species", "community", "connectivity", and others listed in WebTable 1, have large reference potential. Many terms have also attracted a wealth of modifier terms, for example, "assembly" (or "assemblage") and "succession" (Booth and Larson 1999; McIntosh 1999). Terms with many modifiers are probably good signals for concepts that do not yet have satisfactory classification schemes. Many such areas of research have experienced explosive growth in recent decades (Nobis and Wohlgemuth 2004), precisely because the conceptual domain in need of explanation is large (Locke 1992; Ford 2000).

Polysemy and ecological progress

In addition to repeated calls to reduce polysemy and synonymy in ecological English, many authors of terminological reviews have suggested that terms must be operationalized for ecological understanding to be achieved efficiently. In so doing, most authors are borrowing arguments from Peters (1991) or Shrader-Frechette and McCoy (1993). In this view, polysemous language and poorly defined terms provide convenient hiding places for insufficiently developed hypotheses, lack of evidence, and untestable assertions. Peters (1991) concludes, "Different uses of the same term and different terms blend into one another. Thus, one term may come to represent a multiplicity of divergent, even opposing, meanings. The complex concept represented by this term can then be fragmented into smaller concepts, which may receive terms of their own. Terminological proliferation thus attends conceptual fragmentation and a welter of terms often signals underlying operational difficulties." Peters argues that swift scientific progress demands that terms be defined operationally during initiation of a research program, with scientists then using the same meanings for terms as the discipline matures.

I suspect that polysemy and synonymy are falsely targeted as a problem preventing rapid scientific progress, when instead the major problem is asking theory at a high level of generality to do work it cannot do (Odenbaugh 2001). Formulating operational definitions for broad concepts is probably impossible, as operational definitions are often so narrow that they are useful only in localized cases (Hull 1968; Mishler and Donoghue 1982; Ford 2000; Regan *et al.* 2002). To illustrate the difference between ambiguity and mismatch of levels of knowledge, consider "cats". This term is polysemous and non-operational: it could mean house cats, lions, sabertooths, caracals, or all Felidae (never mind colloquial meanings of spiteful women or jazz enthusiasts). Suppose I asked an ecologist to design a conservation strategy for the Felidae; Felidae has a much narrower definition, yet the task imposed is impossible as stated because detailed local biological and social information is needed for the conservation strategy to be at all useful anywhere. If I had phrased my request as conservation for "cats", a momentary ambiguity might result as the ecologist determined whether all Felidae were included in the domain of the request, but the central problem is that the intended category is very broad with respect to the detail needed. Polysemy can occur even when terms have underlying mathematical expressions associated with them; for example, there are a variety of operational "diversity indices".

How words obtain meaning

Meanings are created in three basic ways: through definitions given to neo-terms (neologisms and neo-concepts), through context, or through classificatory reviews. Neologisms are new words created for particular concepts, such as "metapopulation" (Levins 1969) and "biodiversity" (reviewed in Takacs [1997]). Neo-concepts are existing words given new ecological meanings, such as "global warming", "keystone species" (Paine 1969), and "community". Neo-terms typically originate when some researchers recognize that existing language is inadequate to categorize a phenomenon and borrow or create words to reflect new categories.

The dominant origin of meaning is through usage (Williams 1998; Landau 2001; Figure 3). Most dictionaries are based on analyzing many phrases using each word to trace words in context to determine what the words mean (Landau 2001). For example, Takacs (1997) has explored "biodiversity", with potential meanings including genes, species, ecosystems, and other levels of biotic organization. Several reviews of ecological English complain that research papers use definition-by-context rather than providing explicit definitions (eg Jax *et al.* 1992; Hall *et al.* 1997). The premise that contextual definitions are inferior to explicit definitions comes despite the fact that humans are extraordinarily good at understanding meaning from context (Lynch 1993; Williams 1998; Norman 2002).

For example, suppose I asked someone at a conference for a pencil – I could easily be offered a pen instead. The lender will have understood that I want a writing implement to make a note. If I were in an art class, my neighbor is unlikely to offer me a pen, understanding that I want graphite instead of ink. Thus, even the meaning of "pencil" depends upon context, even though none of us would ever actually confuse a pencil with a pen. Similarly, try asking for a glass of water and see how often the water actually comes in a glass. The same principle is true for ecological terms, and indeed is magnified because many of the contentious terms are abstract rather than concrete nouns.

The third avenue for definition, classificatory review and prescription, is the one attempted by many of the language review papers. For example, Richardson *et al.* (2000) and Davis and Thompson (2000, 2001) address the language of plant invasions. They take terms with diffuse definitions and suggest precise definitions, sometimes adding neo-terms to take supplemental meanings (eg Richardson *et al.* [2000] champion "transformer species" for invasive species with big impacts on a host ecosystem, so that "invasive species" can include species with little impact). In this quest, ecologists resemble taxonomic splitters, assigning fewer meanings to each term. As fields mature, such approaches are useful because adding to the language reflects our increasing understanding of the systems we are studying; our classificatory ability increases.

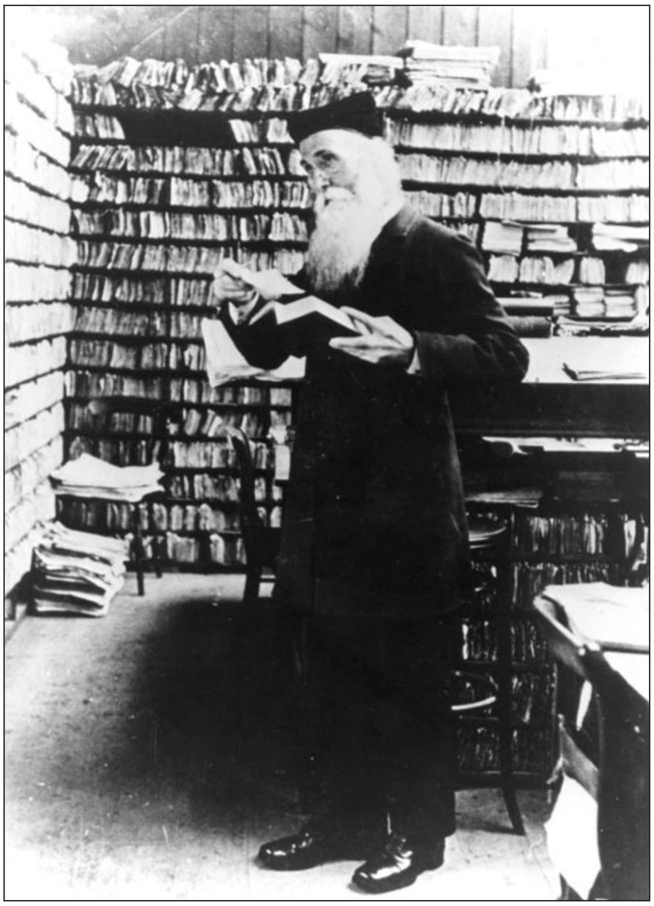

Figure 3. *Photograph of James Murray in his Scriptorium c 1880. Definitions of words accrue through usage. James Murray was the primary editor for the initial Oxford English Dictionary, and this photograph shows the "Scriptorium" where he and his assistants collected thousands of phrases that show words in context. They worked from these notes to develop the "dictionary definitions" with which we are familiar today. Reprinted by permission of the Secretary to the Delegates, Oxford University Press.*

Why suggested language reforms fail

The history of scientists attempting language revision dates back at least into the 17th century, when the fledgling Royal Society initiated an assembly to develop rules for the way English should be structured and used. This committee disappeared soon thereafter, but attempts to revise the language have persisted. Such efforts blossomed in the 18th century's "Authoritarian English" movement, when many early grammar books and dictionaries were written (Baugh and Cable 1978). Similarly, the Ecological Society of America formed an Advisory Committee on Ecological Nomenclature in 1931 (Shelford *et al.* 1931), its purpose being to develop lists of terms that "need interpretation or clarification". This committee generated four lists of terms, but these were not widely circulated (Eggleton and Clarke 1952). Independently, several ecological glossaries have been written, with varying standards used in the way terms were selected and defined (Carpenter 1938; Hanson 1962; Lewis 1977; Lincoln *et al.* 1982). The major difficulty with such reform efforts is that language seldom changes by prescription, as shown by over 350 years of failed attempts (Landau 2001; Norman 2002).

There are at least three reasons why prescription is unlikely to create lexical reform. First, for a word with a diffuse definition set to become precisely defined, everyone who uses the word has to start using only one definition. It is unlikely that all users of a term will even become aware of a suggested terminological revision; few papers have such a broad readership. Second, readers will continually stumble across older references that remind them of other potential meanings, especially as ecological terms targeted for definitional reform are widely published. There will be continual recidivism as readers remember and re-use older meanings. Third, new meanings continually adhere to all but the most precisely defined terms (eg terms with mathematical underpinnings such as "median") because slightly different con-

Figure 4. *Many habitat-related terms, such as "habitat", "habitat availability", "habitat use", and "critical habitat", have been targeted for definitional reform. These elk* (Cervus elephus) *near Mammoth Hot Springs, Yellowstone National Park, do not know about this debate and are content to enjoy a quiet afternoon on some old travertine terraces. Most elk populations do not live in places that have travertine terraces, so such terraces cannot be habitat for elk in most places.*

texts are used. Writers who urge definitional reform are asking for speakers of ecological English to do something counter to inherent properties of language. Because it is ineffective to urge people to use only one or a few definitions, reviews that focus on clarifying conceptual domains and developing better classificatory ability are more useful.

When are precise definitions necessary?

I do not wish to downplay the critical nature of precise operational definitions in some contexts, even though precise local definitions cannot and should not be applied globally (Figure 4). It is often useful to provide sharply delimited definitions in classes, as we introduce students to concepts (although in the classroom these definitions may not need to be operational). One clear case requiring operational decisions is in individual research projects, where we must design and apply consistent protocols for our data to be believable and useful. Another case that requires careful local definition is when researchers are compiling diverse sets of information for review, meta-analysis, or synthesis. It is inappropriate to lump all cases using the same word together as instances of the same thing (see Barber and Barber [2004] for an amusing account of "dragons" accumulating attributes from very different source myths). Richardson *et al.* (2000) provide the ecological example of authors comparing attributes of invasive and non-invasive species; when the source data are based on taxonomic lists with differing or unspecified criteria for "invasive", "casual", "naturalized", and related terms, faulty inferences can result as species are classified differently in the various sources. Similarly, Tischendorf and Fahrig (2000) argue that "connectivity" can be used as a structural variable that reflects patterns in plant cover, or as a functional variable that describes how individuals move through a landscape; conflating results from studies using these different meanings leads to faulty inference.

Reviews or analyses that conflate cases with similar terminology but dissimilar ecology are like analyses that uncritically combine numeric data. For example, numerous analyses have examined synchrony of time series of abundance data for lynx (*Lynx canadensis*) or snowshoe hares (*Lepus americanus*). These statistical analyses have often lumped together different types of time-series data (eg sightings, harvest records, track counts, mark–recapture data), despite these metrics having different relationships to the true abundance of hares or lynx. In both the numerical and the verbal cases, clear operational definitions are critically needed if meaningful ecological understanding is to result. Polysemy or synonymy, by themselves, are not to blame if an author conflates unlike cases.

Ecologists providing syntheses thus need to state what criteria were used for inclusion and exclusion of cases or data. Responsibility for a good, local, operational definition resides with the authors: they compile, organize, and synthesize the results, so they have both the prerogative and the responsibility to define their categories. If other ecologists disagree with their definitions, that provides useful impetus for future work or for alternate reviews. At issue is identifying the most informative way of classifying observations. Such a scenario shows that richness in language reflects and stimulates rather than prevents ecological inquiry and understanding.

Recommendations

Many language review papers plead for clear, explicit, and consistent definitions to be provided in research papers. This suggestion is unworkable and unnecessary, since most papers use many ecological terms and people are skilled at deciphering meaning from context. Explicit definitions are needed only for the local operational cases where boundaries between categories need delineation, as in review papers or meta-analyses. Peer reviewers and editors can facilitate clarity by asking whether sufficient definition for inclusion and exclusion of cases is presented.

The approach espoused by Peters (1991) and others (eg Niven 1982; Jones *et al.* 1997), which requires early classification, broad operationalized definitions, and standardized terminology, comes at a high cost. The initial classification must be arbitrary (because its relation to the observations is necessarily unknown in advance of obtaining those observations), and other classifications that might be more informative are not considered as a result of adherence to the initial classification. Although localized definitions are indeed needed for particular projects, recommendations to standardize ecological terminology or to develop rigid classificatory schemes in advance of our datasets do not advance our science or its application. Polysemy and synonymy are not the major cause of confusing papers in the ecological literature, nor are they impediments to ecological progress.

Knowledge is developed in a complex and inseparable feedback system with the language used to describe the ideas (Locke 1992; Ford 2000; Ceccarelli 2001). Synonymy and polysemy are natural features of language, which assist in the development of knowledge by providing input about what classifications and definitions are most useful for the systems under study or application of knowledge in policy or management (Bowker and Star 1999). For example, Rojas (1992) emphasized the consequences of different "species" definitions on legal protection, and reviews of "keystone species" have highlighted and separated multiple ecological relationships (Mills *et al.* 1993; Power *et al.* 1995). Review papers can usefully focus on language to tease apart distinct concepts and to join similar concepts to develop better classifications; for example, Regan *et al.* (2002) separate several types of lexical uncertainty from different types of epistemic uncertainty. Lexically-based reviews can also usefully look at processes underlying the terms. For example, Richardson *et al.* (2000) frame their terminological review on "invasive" species around species surpassing barriers, whereas others emphasize impacts that the novel species have in new environments (Davis and Thompson 2000, 2001). The genre of ecological language reviews urging definitional reform should be allowed to fade into obscurity. Insightful language reviews will focus on developing more useful classifications of the concepts that our language imperfectly captures, rather than offering prescriptionist approaches to our terminology.

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