

# Ecology Needs a Convention of Nomenclature

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*Many areas of science have adopted nomenclature rules that facilitate research and communication. In contrast, ecological terminology is constantly redefined across disciplines, plagued with synonymy and polysemy, and foundational terms (and the theories and hypotheses behind them) are overlooked. We contend that this situation handicaps the progress of ecology. We review the causes and consequences of terminological uncertainty and propose a convention of ecological nomenclature (CEN) as an indispensable requirement of ecological synthesis. The core components of a CEN are its endorsement by a transnational institution; a policy framework managed by an advisory committee; and a centralized, peer-reviewed revision of terminology whereby ecologists are proponents and users of a unique, open-access repository of terms, definitions, and ontologies. A CEN should become the basis of a cross-disciplinary platform of communication among ecologists, journals, and the public and aligns with the ongoing initiative toward data globalization in ecology and other disciplines.*

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The practicalities of communicating with an international scientific audience demand that a common set of terms is available for describing particular phenomena.... Interpreting case studies in terms of popular theories is, therefore, like translating the study into an international language; it enables studies that report similar phenomena to be readily identified and linked, with the potential for synthesis of the circumstances in which those phenomena are important. (Driscoll and Lindenmayer 2012, p. 133)

It is no exaggeration to claim that ecology is among the most important of sciences for modern times. By addressing the causes and consequences of the spatial and temporal distribution and abundance of organisms (Scheiner 2010), ecology deals intrinsically with key aspects determining human survival—namely, ecosystem services, extinction processes, and global change. In the last two decades, new journals and journal sections featuring those aspects have boosted publication rates in ecology, which are growing in all subdisciplines of biology (Pautasso 2012). Nevertheless, the resources supporting ecological research are constrained and increasingly variable, owing to contingencies in national and international politics, economics, and social conflict. As a consequence, renowned authorities have urged ecologists to pursue an overall ecological synthesis by highlighting key unanswered questions (May 1999), developing pathways to identify general principles (Belovsky et al. 2004), and

establishing frameworks connecting practice and theory (Choate et al. 2012, Driscoll and Lindenmayer 2012).

The prime goals of those horizon-scanning endeavors are to avoid redundant research and to foster incremental contributions to our field that are truly novel, expand our domains of knowledge, and play an instrumental role in conserving a functioning biosphere. Crucially, a common theme across those calls is the need to improve scientific communication among ecologists and to facilitate the exchange of ideas between ecologists and society through clear language. In this Forum article, we expose the main causes of terminological uncertainty and confusion and identify the factors underpinning the need for terminological standardization in ecology. We further advocate an initiative to create a convention of ecological nomenclature (CEN) as an essential component of ecological synthesis. We hope that this proposal can be further discussed and refined through global collaboration and endorsement among ecology-focused institutions, societies, journals, and research groups.

## Causes of terminological uncertainty

Linguistic uncertainty in the ecological literature can appear in the guise of vagueness (terms lacking scrutiny for several concepts that are semantically close), ambiguity (polysemous terms that are not clearly distinguished), context dependence (terms that are framed vaguely), underspecificity (general terms unsuited for specific questions), and indeterminacy (terms subject to controversy, often competing with apparently synonymous terms) (Regan et al. 2002). To a greater

or lesser extent, those sources of uncertainty all derive from the simple fact that, when a scientist uses a key term in a publication, he or she has no obligation to define it and, at most, only needs another publication to refer to as the genesis of that term. We call this *modus operandi* the *silent rule*, because everyone follows it despite its being written nowhere.

The silent rule is reinforced within single research papers, books, and journals. To guide their readers, some journals and books wisely deem it necessary to include glossaries or encourage definitions, which authors largely adapt to suit the contents of their papers. Ecologists sometimes consult popular dictionaries of ecological terms, which are proliferating for particular topics and broad taxa (e.g., fungi, birds, entomology, herpetology, zoology, plant pathology, environment, conservation), and in which the definitions of a term do not necessarily match across dictionaries. Authors can also contemplate the advice given by *terminological gourmets*—individual ecologists who review the ecological literature to bring order to uncertain terms ranging from specific (e.g., *fledging*; Middleton and Prigoda 2001) to broad (e.g., *niche*; Kearney 2006) concepts (for more examples, see boxes 1 and 2 and Hodges 2008). The purpose of those terminological reviews—to standardize the ecological lexicon—can break down because of readership rates (no paper can be read by all ecologists), shifting baselines (often, only the most recently published definitions or meanings are retained), recidivism (people tend to remember the most popular meaning of a term), and adherence (new meanings are prone to adhere to general and imprecise terms) (Hodges 2008). Furthermore, any one ecologist might disagree with—and, therefore, not follow—a proposed terminological reform.

On a different level, there is a general recognition that ecologists often disregard past literature in which seminal terms were coined and modern concepts founded (Belovsky et al. 2004). This historical disregard fuels *synonymy* (when authors coin a new term for a concept when a term already exists) and *polysemy* (when authors redefine a term for a different semantic domain). It can also become a strategy to gain a study more prestige by connecting it with modish or brand-new terms and apparent (but not actual) novel theory. The ornamentation of language can be instrumental in seeking institutional support or attention. Adams and colleagues (1997) described an *audience effect*, whereby both the frequency and the definition of 30 broad ecological terms were correlated with the potential readership in 43 peer-reviewed journals; for instance, the use of *biodiversity* was clearly skewed toward journals amenable to funding agencies, politicians, and the general public. Finally, the English language is taken as the universal norm in nearly all scientific disciplines, but the complexity escalates if we consider the silent rule in the native languages of ecological literature in non-English-speaking countries and schools of thought (Dauvin et al. 2008a) and in the translation of English ecology books, in which meaning relies on context more than on a word-by-word translation.

All of the aforementioned actions entwine into a complex chain of lexical variability and lack the unifying criteria of nomenclature. The reality is that one word in or out of a definition can translate into a considerable change in meaning. Generally speaking, terms can lose their communicative power and their semantic boundaries when they are faced with a history of contrasting views or arbitrary adherences to different concepts. Scientists can preempt these loaded terms by resorting to other available ones that, in turn, potentially fall into conflict with the existing terminology. Although they might be unaware, authors and instructors can inadvertently influence terminological trends with the lexical usage in their scientific discourse to students and peers. At the heart of the problem lies each individual's attitude toward language. The silent rule clearly encourages egocentric styles in individual publications at the expense of general understanding across publications, thereby precluding ecological synthesis.

### The need for standardization

Hodges (2008) argued that the proliferation of synonymous and polysemous jargon in the ecological literature is symptomatic of topics in need of development, the abundance of which stimulates the progress of ecology. We agree with the former sentiment, but the latter claim contradicts published evidence and is overly optimistic with respect to the expertise and conceptual understanding of the average ecologist.

On one hand, the authors of terminological reviews in rapidly evolving fields such as animal communication (Ruxton and Schaefer 2011), biogeography (Ebach et al. 2008), invasion biology (Blackburn et al. 2011), and urban ecology (MacGregor-Fors 2011), and authors discussing transversal concepts such as *ecosystem stability* or *habitat fragmentation* (box 1), have all concluded that persistent controversies have a semantic basis and vanish—or can be attenuated—when objective definitions of appropriate terms are identified. Dubious terminology further obstructs scientific progress when alternative sets of jargon reflect competing schools of thought about common matters of enquiry; therein, terms can be created to support opinion with limited empirical or theoretical support. This is amply illustrated by long-debated concepts such as *density dependence* (box 2).

On the other hand, Hodges (2008) pointed out that “knowledge implies being able to assign observations unequivocally to appropriate categories [of theory]” and that “polysemy is often useful during the development of a field because several classificatory schemes might work” (p. 37). Such a statement might apply to a select audience of (mainly Western, English-speaking) experts in their fields and “presupposes that scientists are aware of the breadth of meanings (and, therefore, concepts) which are assembled under a particular term” (Jax and Hodges 2008, p. 178). Indeed, the majority of the research workforce is not composed of advanced experts (e.g., leaders of research groups) but of PhD students and early-career researchers (Schillebeeckx et al. 2013), who tend to read papers more thoroughly than

**Box 1. Terminological panchrestons.**

Many reviews of ecological terminology offer a historical perspective on the origin of the terms; highlight the causes and consequences of uncertainty (e.g., polysemy, synonymy); prescribe guidelines and, often, new terms to abate uncertainty; and provide insights into semantic debates between rival authors. These debates could be resolved if ecologists were to combine (rather than dilute) their efforts and expertise to forge a diversity of terms reflecting the semantic dimensions of ecological concepts. We give two examples below.

**Habitat fragmentation**

Lindenmayer and Fischer (2007) argued that the loose application of the expression *habitat fragmentation* has resulted in unproductive conceptual polemics and in many single-species and local-landscape studies of little value at wider organismal and spatial scales. They proposed a set of vocabulary (15 defined terms) that distinguished four domains of meaning: (1) effects on single taxa versus those on aggregate metrics of multiple taxa; (2) single species' versus humans' perception of the landscape; (3) the habitat suitability for single species versus land-cover patterns (e.g., vegetation configuration); and (4) the connectivity of habitat for single species, the connectivity of (human-defined) land-cover patterns, and the connectedness of ecological processes. For instance, the ecological effects of habitat loss on species distributions (as perceived by a single species) do not necessarily correspond to those of the loss of native vegetation (as perceived by humans), because species can persist in (and even become dependent on) altered landscapes. The set of terms proposed by these authors was meant to sharpen the focus of future research toward discerning the mechanisms driving species responses to habitat fragmentation and, in turn, guiding sound mitigation actions.

**Ecosystem complexity and stability**

Pimm (1984) mixed different measures (and, therefore, terms and definitions) of complexity (*species richness, connectance, interaction strength, evenness*) and stability (*stable, resilient, persistent, resistant, variable*) to demonstrate that different combinations of terms could address different questions. He attributed ongoing debates (e.g., whether simple ecosystems are more or less stable than complex ones) to authors' failing to acknowledge such semantic diversity. For instance, a theoretical expectation is that high species richness will promote the persistence of species composition but reduce population resilience and connectance across species if the community should remain stable, so the resilience of pest outbreaks could be a natural consequence of their being driven by a few species. Pimm's (1984) exercise elucidated the range of hypotheses that had been or could be addressed in future studies; the paper has yielded more than 600 citations in the Web of Knowledge to date.

**Box 2. Terminological etiquette.**

If ecology is ever to be formulated into a coherent synthesis of knowledge, a common nomenclature will be a prerequisite. The reality is nevertheless that "the field of ecology has a well-earned reputation for formidable, sometimes excremental terminology" (Whittaker 1957, p. 371). The proliferation of synonymous and polysemous jargon is indicative of how inconsistent ecologists are in their use of terminology. Even if terms are understood within single publications, can ecologists afford dozens of terms for every concept?

A remarkable case is *density dependence* (DD), a metric of the relationship between the abundance of a population (predictor) and one of its demographic rates (response) that signals trophic and social interactions among individuals. A recent review by Herrando-Pérez and colleagues (2012) showed that, from 1910 to the present, ecologists had coined more than 50 terms for four types of DD (i.e., compensation, delayed compensation, overcompensation, and depensation [including Allee effects]) associated with four population phenomena (i.e., stability, cycles, chaos, and decline). For example, DD that is compensatory has been called *facultative, environmental resistance, individualized, controlling, density-dependent, direct, dependent R-factor, delayed, disoperation, concurrent, negative, compensatory, self-decimation, density governing, self-thinning, perfectly, directly density-related, alternatively density-related, exact compensation, negative feedback, causal, intensity-dependent, effective, explicit, centripetality, classical-Nicholsonian, first-order feedback, or compensatory density feedback*. Herrando-Pérez and colleagues (2012) identified five causes for that complex vocabulary; namely, authors have (1) worked in isolation in their subdisciplines and (2) within philosophy-based paradigms, (3) neglected seminal terms in older literature, (4) proposed new jargon to ground their views on whether populations are regulated or limited (among other caveats), and (5) refined available sets of terms as ecological understanding grew. As part of a long-standing debate, DD was (and still is) erroneously equated with *population regulation*.

do their mentors within narrow areas of specialization. For the latter group, terminological uncertainty is a handicap to understanding the literature (Starzomski et al. 2004); graduate students are certainly compelled to unravel the complex jargon associated with different schools of thought, taxa, and ecosystems as they compose their compulsory literature

reviews to become acquainted with their specific fields of enquiry.

Because the same ecological phenomena are often given different names, the spread of synonymous terms in bibliographic databases (e.g., the Web of Knowledge, Scopus) can be a potential driver of redundant investigations (Driscoll

and Lindenmayer 2012). Ecologists regularly browse those databases for papers that relate to their research projects and publications; this is among the most frequent tasks of any modern scientist. But if a string of keywords does not contain all possible synonyms, relevant literature will be missed (Hodges 2008). At the other extreme, if the string contains polysemous keywords, a search will yield many potential hits well outside of the intended theme of the query. Sorting through long lists of articles and references is not only time consuming; it complicates the classification of available knowledge and confuses efforts at meta-analysis if the range of concepts hiding under the umbrella of polysemous terms entails the measurement of variables that are not comparable. Even the term *meta-analysis* suffers from confusion in ecology and conservation about its meaning and, consequently, about how a meta-analysis should be performed (Vetter et al. 2013). To deal with terminological uncertainty in databases, ecologists have developed tools such as *ontologies* (mathematical models that scrutinize the semantic relationships among terms and concepts; Jones et al. 2006, Madin et al. 2008), conceptual meta-analyses (Hofmann et al. 2011), or *fuzzy* methods (terms assigned to different borderline meanings by degrees of membership; Regan et al. 2002). Clearly, we are facing the double challenge of both unraveling accumulated terminological uncertainty and mitigating the problem in the future as our discipline's body of knowledge grows.

The challenge is certainly not purely academic. Ecology has taken the first steps to prompt an evolving social zeitgeist for a sustainable planet (Ehrlich 2009). The endeavor involves communicating science to the public and engaging lay people in the making and application of science (Bazzaz et al. 1998), but sociologists have alerted us that what ecologists mean to say is not always what nonscientists might hear (Weber and Word 2001, Pickett et al. 2007). If we tolerate language uncertainty within academia, that uncertainty will almost inevitably be inflated beyond it and will ultimately be transferred to policymaking, management, and planning (Murphy and Noon 1991). For instance, it eludes common sense that *globally endangered* species are not *endangered* nationally because of different classificatory schemes (Harris et al. 2012). Therein, terminology is not the problem per se, but the conceptualization of generic terms irrespective of their meanings in global platforms is (e.g., *endangered* and *vulnerable* in the International Union for Conservation of Nature's Red List scheme; [www.iucnredlist.org](http://www.iucnredlist.org)).

In international politics, politicians inherit the terminology of scientific advisers. Trained as a marine biologist, one of us (SH-P) was taught in the 1980s that marine habitats could be classified and named distinctly according to the English and the French schools. Because the European Union has gained environmental policymaking cohesion over time, it is unsurprising that such a dual lexicon has hampered the application of the Habitats Directive (Dauvin et al. 2008b). With steadily accelerating rates of publication and the media's speedy access to online scientific literature,

unregulated language is bound to jeopardize scientific communication about current and future trendy topics of research. For example, climate change has become a problem of overall societal concern in the last few decades, as can be seen from the ample attention it has received in both the scientific literature and the mainstream media. Unsurprisingly, experts have already detected semantic confusion (Hofmann et al. 2011) and have claimed the need for a common language in climate science (Bowman et al. 2009). Unfortunately, our style of reporting can be an obstacle to communicating our own ideas. Science might have an eternity for refinement, but our strategy of communicating our findings about the urgent problems facing the planet's imperiled resources does not. A synthetic attack on the general problem of ecological terminology therefore beckons on academic and societal grounds.

### A proposed convention of ecological nomenclature

The only attempt to forge a naming convention in ecology was made over 80 years ago, during the discipline's infancy, by the Ecological Society of America (ESA). We describe this initiative in box 3 and supplement S1. In a nutshell, the ESA created in 1931 the Committee on Ecological Nomenclature, indicating that

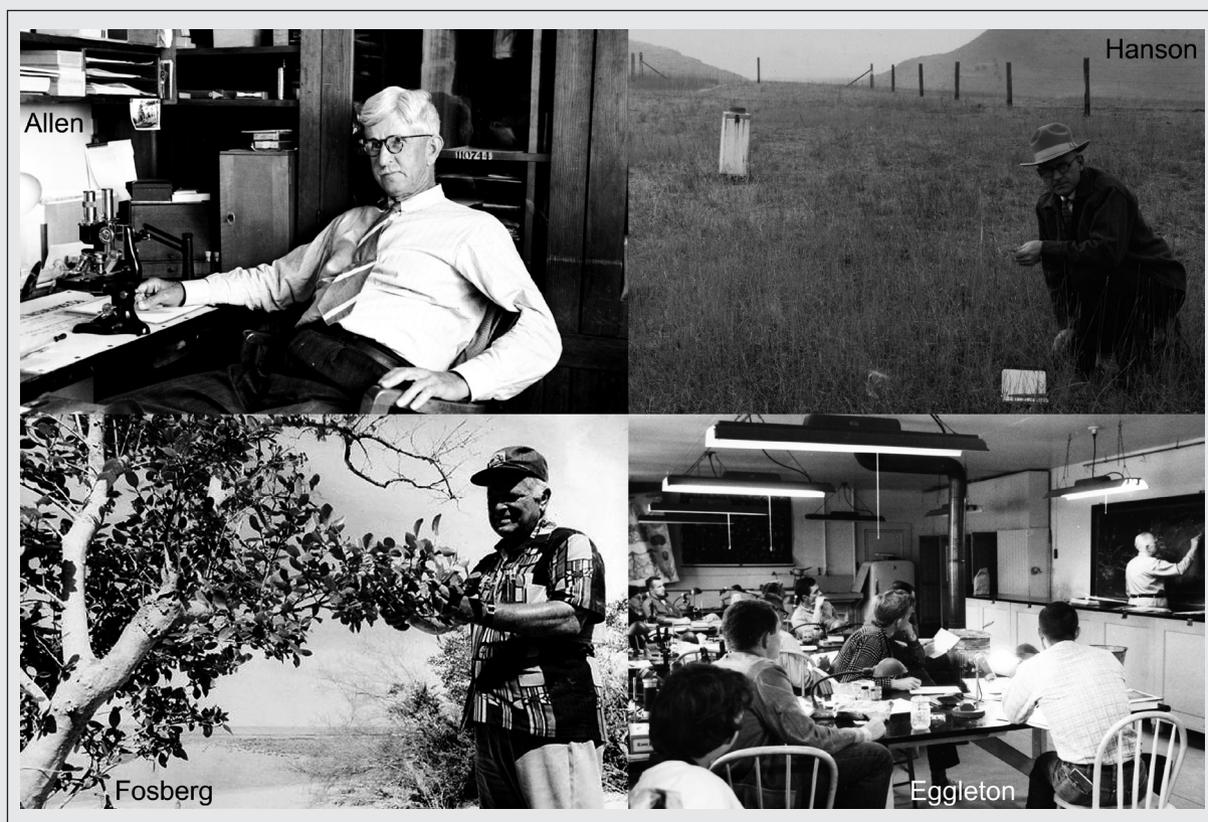
the Ecological Society cannot escape a considerable degree of responsibility for developing or promoting suitable terminology in its field and for encouraging accuracy and harmony in the use of particular terms and expressions throughout its membership. Furthermore, such encouragement tactfully applied might be expected to have helpful influence amongst biologists not directly affiliated with the Society, though using similar language at times. (McGinnies et al. 1931, p. 8)

The two principal aims of this committee were to “serve as a clearing house, or discussion center, of ecological terms” (ESA 1933, p. 232) and to provide a list of terms, including their definitions, origin, synonymy, cross references, and equivalents in foreign languages “to aid in the clarification of ecological terminology and to encourage more precise usage of terms” (ESA 1939, pp. 331–332). Crucial to this task was reaching consensus among experts and across disciplines, but a persistent drawback of the time was the slow communication technology available to panel and ESA members located in distant US states. Three successive lists of definitions of terms were compiled, refined, and mimeographed by the panel members, and exhortations to enlarge the glossary of terms were actively disseminated across the ESA membership, discipline-specific subcommittees, and one note in the journal *Science* (Hanson et al. 1931). The final product was the monograph *Nomenclature* published in 1952, which covered 789 English terms and six principles

### Box 3. The ESA Committee on Ecological Nomenclature.

The Ecological Society of America (ESA) created the Committee on Ecological Nomenclature to abate terminological uncertainty in ecology (supplement S1). This committee was chaired by the marine biologist Winfred Emory Allen (appointed in 1931), the botanists Herbert Christian Hanson (1933) and Francis Raymond Fosberg (1953), and the limnologist Frank Egbert Eggleton (1940). Here, we paraphrase the six principles that constitute the spirit of the committee.

1. Natural growth of ecological terminology should not be hampered by overly constraining rules. The Committee has attempted, however, to serve as a clearinghouse and to point out, *especially to beginners in the field* [our emphasis], what is considered to be good usage. Precedent and approval of authoritative bodies are important in the selection of terms and, thereby, in the development of any science.
2. Restricted scientific usage should not violate common literary or general scientific usage.
3. Words long used in a broad sense should not be given a new and arbitrarily restricted or special meaning.
4. Uniformity of usage is desirable within any one field and in closely related fields, such as forestry, agronomy, ecology, physiology, soil science, meteorology, and geography. If a relatively new word is commonly accepted in one branch of science, it should be adopted in other branches when it is needed there.
5. New words should be coined only when there is a distinct and justifiable need. It is desirable that ecological literature be intelligible to as wide a field of readers as possible. It is not necessary to have a separate term for every slight difference of meaning.
6. Words are tools of thought. An exact term might aid in establishing a clear-cut, distinct concept. However, the too-early coining of new terms or definitions could actually foster ambiguity and inaccuracy. Much care must be given to the choice of appropriate terms so that the writer or speaker can convey to others his exact shade of meaning. The Committee believes that the definitions given in this list will help to make ecological terms more efficient tools of thought. (Eggleton et al. 1952).



**Figure 1.** Clockwise from the upper left: Winfred Emory Allen (photograph: Eugene Cecil LaFond, 86-07. Special Collections and Archives, University of California, San Diego), Herbert Christian Hanson (photograph: Colorado State University), Frank Egbert Eggleton (the lecturer; photograph: University of Michigan Biological Station), and Francis Raymond Fosberg (photograph: Smithsonian Institution Archives).

**Box 4a. Naming conventions of the Gazetteer of Planetary Nomenclature**

The need for terminological standardization is not a radical suggestion but a clearly recognized need in other areas of research, such as astronomy, chemistry, and genetics, in which naming conventions have been operating for up to a century. We outline three of the well-established conventions, with examples of their online search menus in supplement S2. Invariably, the definition of objects and concepts (or ideas) in those conventions is made of semantic subunits that need to be defined following constrained vocabularies.

The Gazetteer of Planetary Nomenclature (<http://planetarynames.wr.usgs.gov>) is hosted by the International Astronomical Union (IAU) and the US Geological Survey, and its origins stem from the first committee appointed in 1919 to unravel confusion around lunar and Martian nomenclatures. The Gazetteer currently contains approximately 15,000 names of surface features; planets and their satellites; and other solar-system bodies, such as dwarf planets, asteroids, and comets. As high-resolution images and maps become available, researchers identify unnamed features. The proposed names are first reviewed by one of six different task groups, after which they are submitted to the IAU Working Group for Planetary System Nomenclature (WGPSN). After approval by the WGPSN, the terms are entered into the IAU database and posted to the Gazetteer Web site. The scientific community and the general public can propose new terms or oppose accepted terms. Online searches return a record showing the technical aspects of each planetary feature name (i.e., its type, identification number, name description, coordinates, an image), along with the history of the dates of the WGPSN approval and the last update of the record. The Gazetteer's names are defined on the basis of previously accepted definitions, including surface feature categories, descriptor terms, and planet and satellite names. The definitions of all of the latter terms are strictly determined by the task group, whereas the categories that classify them are suggested by individual scientists, WGPSN members, or the relevant task group.

**Box 4b. Naming conventions of the International Nucleotide Sequence Database Collaboration.**

The International Nucleotide Sequence Database Collaboration (INSDC, [www.insdc.org](http://www.insdc.org)) constitutes a triple partnership of the DNA Data Bank of Japan, the European Nucleotide Archive, and GenBank (from the US National Center for Biotechnology Information). Genetic data have been collected systematically since 1982 (although GenBank has been doing so since the 1960s) and currently cover more than  $1.5 \times 10^8$  sequence entries and more than  $1.4 \times 10^{11}$  nucleotides. Individual researchers submit sequences and associated metadata following an online menu specific to each INSDC partner. The authors keep full ownership rights over their data. The INSDC International Advisory Committee meets annually to provide advice on development, and policy issues are steadily updated on the INSDC Web site and in *Nucleic Acids Research*. All sequences are open to the public through a keyword search. The INSDC registers sequences with unique codes and metadata (i.e., taxon identity and phylogeny, bibliographic citation of data source, related sequences in the same or different projects) under a standard vocabulary. Even though molecular sequences might be considered *objects*, their descriptions rely on a constrained set of terms and concepts, the use of which is mandatory for the registration of new sequences in the database.

of nomenclature (box 3; Eggleton et al. 1952). The committee was dissolved in 1956, because the panel that had written the final monograph opposed its revision when a new panel was elected (supplement S1). Despite its ultimate dissolution, the ESA committee provides a useful precedent.

We have examined three well-established object- and concept-naming conventions in astronomy, genetics, and chemistry (see box 4a–4c, respectively, and supplement S2), which largely circumvent the logistical problems encountered by the ESA committee. Modern conventions incorporate five main elements: (1) a compendium of articles, principles, or rules setting the policy by which terms meet the standards of a given convention (see, e.g., Ebach et al. 2008); (2) a repository of terms embedded in an online search tool open to the public; (3) an expert advisory committee in charge of the policy and management of the repository of terms; (4) an authoritative protocol of the provision of terms to the repository; and (5) measures of compliance by the scientific

community represented by the convention (figure 2). We outline below how a modern CEN could embody the last four elements and propose in supplement S3 a draft of the CEN policy.

**Repository and advisory committee**

The online CEN repository should include a query menu that would allow searches by keyword, links to the CEN policy, and author guidelines for reviewing and proposing terms and ontologies (see below) to the repository. We do not delve here into the programming technicalities that should underlie the Web site, but the storage capacity and interface structure required would be well within available bioinformatics developments—that is, comparable with the International Union of Pure and Applied Chemistry (IUPAC)'s *Gold Book* (box 4c). Emulating the *Gold Book*, each ecological term in the CEN repository would be labeled with a digital object identifier (DOI) and reported in a single

#### Box 4c. Naming conventions of the Compendium of Chemical Terminology.

The Compendium of Chemical Terminology (<http://goldbook.iupac.org>) is hosted by the International Union of Pure and Applied Chemistry (IUPAC) and is known as the *Gold Book*, after Austrian chemist Victor Gold, who pioneered its first edition in 1987. It lists approximately 6400 terms across all subdisciplines of chemistry, each of which has its own *color book* (e.g., blue for organic chemistry). Records are sourced from the color books, the International Vocabulary of Metrology ([www.bipm.org/en/publications/guides/vim.html](http://www.bipm.org/en/publications/guides/vim.html)), and the International Organization for Standardization, but mostly (more than 80%) from IUPAC-recommended papers in *Pure and Applied Chemistry* (PAC). This protocol guarantees authoritative terminology subject to peer review. For inclusion in the *Gold Book*, proposed terms are drafted by subdiscipline expert committees and ratified by the IUPAC's Interdivisional Committee on Terminology, Nomenclature, and Symbols. The *Gold Book* exists as a printed document and as a Web site. The record of each term contains its accepted definition (sometimes complemented with a figure), a reference to the relevant PAC paper or color book, and a unique digital object identifier.

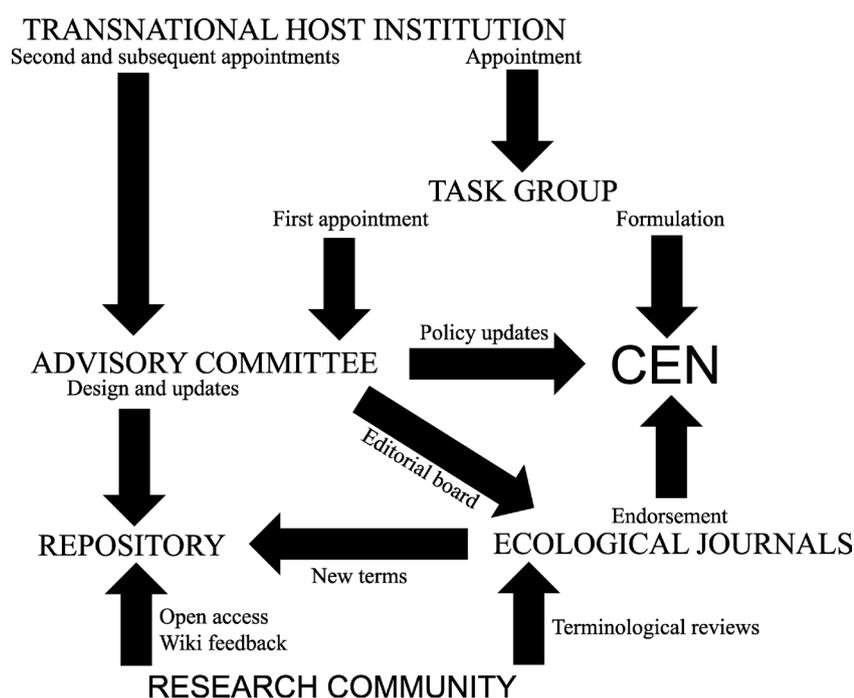


Figure 2. The development and maintenance of a convention of ecological nomenclature (CEN).

Web page that would include a definition for the term, the literature citation of the genesis of the term, the source of the term and its definition (whether a CEN-endorsed published review or an available constrained vocabulary; see below), and a historical list of referenced synonymous and polysemous jargon tracking the ecological themes for which the term was coined (see below).

The repository could, for example, be hosted by the International Association for Ecology, as a representative organization of ecological themes and ecologists worldwide, or perhaps jointly through a multilateral ecological society committee spanning major researching countries (e.g., the British Ecological Society, the American Institute of Biological Sciences, the Ecological Society of Australia,

the European Ecological Federation, the ESA); hereafter, we refer to the latter as the *host institution*. A plenary session on ecological terminology and a working group drafting the CEN policy and appointing the members of the first CEN advisory committee could be part of one of the host institution's congresses (ideally, one devoted to ecological synthesis; figure 2). This committee would consist of leading researchers specializing in all living kingdoms across the major ecological themes (e.g., behavior, chemistry, communities, ecosystems, evolution, landscapes, physiology, populations; *sensu* Likens 1992), along with experts at the frontiers between ecology and sociology and between ecology and economics. The committee would hold statutory rights to assess and incorporate proposed terms into the repository and would meet regularly to update the CEN policy and to address challenges and opportunities for improvement as they emerge.

#### The source of ecological terms

Together with the support of the host institution, the authority of the CEN should rest on (a) researchers' trusting the convention and its repository as the terminological standard in ecology and (b) a peer-review process for ecological terminology led by the research community. Trustworthiness is crucial to the International Astronomical Union's (IAU) Working Group for Planetary System Nomenclature (WGPSN). The WGPSN includes several task groups, all of which respond to what the scientific community needs in terms of naming the features of planets, satellites, and other solar-system bodies (box 4a). As new maps, images, and research papers are prepared, the need for names becomes obvious, and researchers contact the WGPSN,

whose members then work with the researchers to come up with nomenclature that meets both their needs and the requirements of the WGPSN (Jennifer W. Blue, US Geological Service [USGS] Astrogeology Science Center, Flagstaff, Arizona, personal communication, 1 August 2013). Similarly, IUPAC's Interdivisional Committee on Terminology, Nomenclature, and Symbols and its disciplinary task groups advise chemists on filling terminological gaps and submitting their proposals to the journal *Pure and Applied Chemistry* (box 4c). Clearly, the centralization of the sources of ecological terms—ideally in a single journal—is fundamental to the success of a nomenclatural system.

We foresee two exclusive options for attaining such centralization with a CEN. The CEN could be observed in an editorial section focused on terminological review in ecological journals, in which CEN committee members would act as subject editors. Alternatively, we strongly advocate the creation of a new journal exclusively devoted to terminological review. This journal could be founded and managed by the host institution, and the CEN committee would constitute its editorial board. Manuscripts would be reviewed, submitted, and made open to criticism and refinement by the research community under a novel peer-review process that would entail a majority consensus. Under current editorial standards, when conflicting opinions arise about a published paper, editors give opposing authors the chance to write responses. In that scheme, one party normally has the belief that the other party is wrong, which leaves readers (who normally have much less insight into the specific matters under discussion than do the published authors) with the option of adhering to either view or remaining indecisive. Instead, cooperative papers should be a mandatory principle in the CEN policy, with two key features: (1) Referees would coauthor the papers they assess, which, in itself, would encourage refereeing, and (2) authors submitting criticisms of papers could also be coauthors if their arguments are found to be sound by the editor and through the peer-review process. The editorial path of action could be one in which a manuscript would be accepted for review, then reviewed and accepted (or rejected), and, finally, published online after a quarantine period (e.g., 3 months) in which the editor would accept responses from rival authors and would prompt the referees, authors, and respondents to reach agreement. The full panel of authors would ultimately submit a final version of their manuscript, along with a synopsis covering the fields that would be part of the record in the repository.

The CEN is likely to encounter distinct challenges in the review process. Terms representing abstract notions would all have to be peer reviewed by the CEN. As for terms referring to physical entities and already established classification units (e.g., those of place names, soil types, or plant traits), in the manner of other scientific conventions, the CEN should not reinvent the terminology from scratch but should, instead, try to make use of constrained vocabularies from different ecological and biological subdisciplines. For instance, chemistry's *Gold Book* (box 4c) includes definitions

from bibliographic sources dealing with specific areas of chemistry (*color books*), physical constants, quantities, and units. The identification of appropriate constrained vocabularies and the terms within them that are relevant to the CEN would be a crucial task prior to its launch. The task could be undertaken through one or a few postdoctoral positions supervised by the members of the CEN committee or could be commissioned from selected experts.

### Compliance

Compliance with naming conventions relies on researchers' being compelled both to contribute terms to the repository (entry point) and to use already approved terms in their publications (exit point). As for the entry point, it is self-evident that even well-established naming conventions can produce uncertainty if new terms fail to enter a universal open-access repository. Organismal taxonomy is a clear example of a two-centuries-old, highly regulated convention for naming species under two main rules: the Linnaean binomial nomenclature and the maxim of priority by which the first name given to a taxon prevails over younger synonyms. However, 30%–90% of the names given to species in major taxonomical groups are synonymous and will take decades to reconcile (Costello et al. 2013), mainly because many descriptions take place in old or low-rank journals or because the amount of literature is overwhelming (Knapp et al. 2007). This problem is well recognized, and ongoing international initiatives (e.g., the Global Biodiversity Information Facility, <http://www.gbif.org>) are joining efforts for cataloging all living species in a unique open-access repository. Those efforts might evolve toward the mandatory registration of taxonomical names, so that valid names will have to be both published and registered (Knapp et al. 2007). That is the path taken by the International Nucleotide Sequence Database Collaboration (INSDC; box 4b). The deposition of nucleic-acid sequence data in one of the three INSDC partners' platforms and the citation of sequence accession numbers are mandatory requirements for manuscript acceptance in the journal *Nucleic Acids Research*, and the "INSDC Advisor's open letter to journal editors" ([www.insdc.org/sites/insdc.org/files/documents/open\\_letter.txt](http://www.insdc.org/sites/insdc.org/files/documents/open_letter.txt)) recommends the same for other journals.

We argue that the CEN should emulate the efforts that the IUPAC, the INSDC, and the WGPSN used over many years to popularize and implement their own conventions. In this way, the CEN outlets (whether they are in journal sections or in a new journal; see above) should be featured on the Web sites and in the regular meetings of the host institution and of national ecological associations, and they should initially be advertised in scientific journals. Ideally, CEN-endorsed articles should be open access in those journals in which they are published, which would potentially require negotiations with editors, ecological societies, and scientific publishing companies. Those negotiations would include a reward system that would provide part- or full-time jobs for the members of the CEN committee and a fixed-rate stipend for reviewers.

Recommendations should be made to ecological journals for redirecting those manuscripts addressing terminological issues to the CEN's publication outlets, and the CEN committee could initially commission reviews of terms by selected authorities until the submission rates have gathered momentum (a standard practice for new journals). To reconcile old and new terminology, CEN publication outlets should be open to accepting studies that revisit previous reviews of the lexicon (i.e., outside the CEN framework) and that include the design and testing of ontologies. Ontologies for particular themes, terms, or clusters of terms would be available in the CEN following their publication, including guidelines of use and executable files or scripts in R (or other widely used open-source programming languages, such as Python), which could be hyperlinked from the online record of CEN-endorsed terms.

As for the exit point, any attempt of terminological standardization is doomed if the repository of terms is ignored by the research community. In fields in which scientists have widely subscribed to nomenclature conventions for up to a century, the need for terminological prescription is a natural element of scientific production, so there are few major compliance issues. For instance, the WGPSN (box 4a) relies on the good faith of the scientific community to use IAU-approved names: "This is for everyone's benefit, and if a non-IAU name is used, it can introduce confusion into the literature—a situation most researchers do not want" (Jennifer Blue, USGS Astrogeology Science Center, Flagstaff, Arizona, personal communication, 1 August 2013). Similarly, geneticists (box 4b) show "no reluctance to concur with the mandatory requirement [of registering nucleic acid sequences in INSDC as part of their submissions to journals], and authors and editors usually cooperate well on this issue" (Richard J. Roberts, New England Biolabs, Ipswich, Massachusetts, personal communication, 3 August 2013). Moreover, the use of the IUPAC's nomenclature (box 4c) has been added to the policy of many journals published by Elsevier and Springer, whereby authors are "urged to consult IUPAC: Nomenclature of Organic Chemistry" ([www.elsevier.com/journals/aquaculture/0044-8486/guide-for-authors](http://www.elsevier.com/journals/aquaculture/0044-8486/guide-for-authors)) or "should use systematic names similar to those used by Chemical Abstract Service or IUPAC" ([www.springer.com/authors?SGWID=0-111-6-792358-0](http://www.springer.com/authors?SGWID=0-111-6-792358-0)), and this nomenclature is a legal requirement for compounds to pass through European Union customs, where any compounds must be identified by their IUPAC names according to International Organization for Standardization guidelines (Juris Meija, National Research Council Canada, Ottawa, Ontario, personal communication, 9 August 2013).

Despite terminological standardization in ecology's having been recognized by many as a necessity (e.g., Peters 1991, Shrader-Frechette and McCoy 1993, Driscoll and Lindenmayer 2012), we concur that persuasion and prescription alone have not improved the use of ecological terminology (Hodges 2008). Given the failure so far, we hold that the CEN could be successful only if the citation of terms and definitions from the CEN repository eventually became

a mandatory requirement for manuscript acceptance across all ecology journals. This would affect the key concepts and the list of keywords of any paper, which could be included along with their CEN's DOIs of terms; online papers could easily hyperlink those DOIs to the relevant record in the CEN's online repository. This aspect could be incorporated into the journals' instructions for authors, and those journals observing the code could show a label of terminological compliance on their Web sites.

Finally, to monitor the acceptance of published terms and definitions, each term in the repository could be associated with a wiki site that would allow scientists to post alternative definitions for that term (with citations). The site would track the use rates of CEN-endorsed and alternative definitions by authors using the repository as their source of vocabulary (they would be asked to click on the definition that they use in a given publication). Indeed, our proposed convention should not assume that concepts and terms would be fixed, nor should it negate plurality of thought. In fact, a natural outcome of the CEN would be to identify concepts that are unstable (subject to different classification schemes) and to require further investigation; for those concepts, terminology will necessarily be provisional, and nomenclature rules should acknowledge this.

## Conclusions

Open discussion and criticism propel ecological progress, but the degree by which discrepancy among authors represents available knowledge or personal views is often unclear. To bolster ecological synthesis and avoid redundancy, every effort possible must be made to share available knowledge in order to have common, updatable classificatory schemes of ecological concepts and the terms that name them. We have presented a proposal to create a CEN, which, in practice, would resolve into an open-access repository of concepts, including referenced terms and their definitions, and the history of their conceptual development through associated synonymies and polysemies. Key to this initiative would be that the research-community members become contributors and users of CEN-endorsed terms and ontologies, through refereed terminological reviews and the observance of standardized terms, with the end goal of compliance being a mandatory requirement for manuscript acceptance in ecological journals. The establishment of such a convention will prompt semantic compromises among ecologists and journals in a cross-disciplinary platform of communication.

The CEN is bound to improve the research practices of individual ecologists and their teams and will facilitate practical communication and focused debate. Peer-reviewed journal articles represent the end results of research projects, but most of the semantic scrutiny that occurs along the way is limited to unpublished debate during peer review and could be channeled through papers feeding terms to the CEN repository. Terminological reviews resemble a detective's task of combing the literature for the historical trail of synonymous and polysemous jargon. They are time-consuming

but distill the ideas behind the concepts underlying any research hypothesis; they further constitute a powerful exercise of conceptual discernment that links modern to past theoretical frameworks and prevents redundant research. In an era in which funding and academic excellence pivot on a researcher's publication record (Laurance et al. 2013), the mandatory citation of CEN-endorsed terminological papers and an open-access policy for papers reviewing ecological terminology would enhance the citation rates of those papers and so would be attractive to ecologists from early-career to seasoned researchers.

The CEN should be conceived as one component among several initiatives (e.g., DataOne, [www.dataone.org](http://www.dataone.org)) toward data globalization in ecology, which favor open-data policies and the integration of such data into federated repositories. All of these initiatives face challenges of data dispersion, heterogeneity, and provenance (i.e., information generated from multiple sources and disciplines, whose origin must be tracked and whose semantic complexity must be accounted for; Reichman et al. 2011) and are prompting the design and implementation of the required bioinformatics tools tailored to the specificities of ecological data (Jones et al. 2006). How the CEN can benefit from, contribute to, and be integrated into those initiatives will be a key determinant of its success.

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### Supplemental material

The supplemental material is available online at <http://bioscience.oxfordjournals.org/lookup/suppl/doi:10.1093/biosci/biu013/-/DC1>.

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