Discovering Ecologically Relevant Knowledge from Published Studies through Geosemantic Searching

JASON W. KARL, JEFFREY E. HERRICK, ROBERT S. UNNASCH, JEFFREY K. GILLAN, ERLE C. ELLIS,
WAYNE G. LUTTERS, AND LAURA J. MARTIN

It is easier to search the globe for research on the genes of a local plant than it is to find local research on that plant's ecology. As a result, ecologists are often unaware of published local research and unlikely to find relevant studies from similar environments worldwide. Location information in ecological studies can be harnessed to enable geographic knowledge searches and could be standardized to make searches more fruitful. To demonstrate this potential, we developed the JournalMap Web site (www.journalmap.org)*. Easy access to geographic distributions of knowledge opens new possibilities for using ecological research to detect and interpret ecological patterns, evaluate current ecological knowledge, and facilitate knowledge creation. We call on journals and publishers to support standard reporting of study locations in publications and metadata, and we advocate georeferencing past studies.*

Keywords: knowledge discovery, spatial distribution, georeferencing, semantic search, metadata

The spatial context of published research is crucial to its interpretation and use, but tools for discovering ecological knowledge have largely been focused on the *what* while largely ignoring the *where.* This is somewhat surprising, given the strong spatial focus of many ecologists and the fact that a number of powerful geospatial search tools are now readily accessible. From our perspective, the problem is that the spatial locations of ecological research are essentially hidden from public view. In some cases, this is intentional, such as in studies of rare or endangered species or in studies in which private property rights and intentional harm or disturbance can be issues. In most cases, however, the lack of spatial context for published studies is simply due to a lack of standards and requirements for including it in publications. The result is that existing ecological knowledge is often overlooked, because it is not easily found with discovery tools that do not consider the location or spatial distribution of published ecological research. As a consequence, acquired ecological knowledge fails to live up to its potential to inform managers, policymakers, and ecologists who might build on the research (Wallis et al. 2011).

Finding relevant knowledge and information to support research and effective land management has historically involved researchers' working from their own knowledge, querying people they know, and tediously searching topical literature reviews (Zimmerman 2007). Over the past two decades, vast quantities of information have been made accessible (Peters 2010), but sifting for relevant knowledge often remains difficult and inefficient (Madin et al. 2008).

The relevance of knowledge is determined by how closely the context in which it was created matches a given situation. In ecology, context includes both the patterns of the biophysical and human environment and the effects of processes operating at different scales (O'Neill et al. 1986, Urban et al. 1987, Wu 1999, Peters et al. 2004, Ellis and Ramankutty 2008). A consideration of this context is crucial to explaining local ecological dynamics (Turner et al. 2001, Browning et al. 2012). Although this multiscale context is often considered explicitly within ecological studies, much contextual information is lost during publication, because it is either omitted or not provided in a useful, searchable form. This loss of information limits the ability to search through studies on the basis of geographical factors (e.g., latitude, intersection with or proximity to other features), environmental contextual factors (e.g., soil, climate, vegetation patterns and processes), and human influences (e.g., direct impacts, legacies of land use).

Access to published literature has improved dramatically as publishers have opened their catalogs to online searching. The adoption of semantic searching (i.e., on the basis of

BioScience 63: 674–682. ISSN 0006-3568, electronic ISSN 1525-3244. doi:10.1525/bio.2013.63.8.10

knowledge context and conceptual relationships; Michener 2006, Madin et al. 2008) and aggregation searches such as Google Scholar and the Web of Science has made it easier to search across disciplines and across publishers to find useful references. However, the ability to determine what is known about a specific ecosystem or landscape is hindered by current search technologies, because they still rely primarily on keyword, topic, text, and author searching—concepts of cataloging and searching for published information that have changed little since the late 1800s (Chan 2007).

Current search technologies return results that may be topically related but irrelevant to the specific area of interest (figure 1). With the addition of geographic filters, search results could be limited to a specific area (Wallis et al. 2011). However, in many parts of the world, there has been little formal study of the structure and dynamics of local ecosystems (Wilson et al. 2007). Therefore, for all but the most studied landscapes, searches constrained to a specific area are unlikely to yield sufficient results. However, research that has been conducted on landscapes that share similar landforms, general soil properties, and climates can, in some cases, be relevant to these understudied regions (Paruelo et al. 1998). By defining important aspects of an area of interest's ecological context and then applying those criteria to available data layers and synthetic or model-based interpretations of the intersected layers, it becomes possible to identify other areas with similar ecological contexts. In many cases, the location of the area of interest alone is sufficient to define the ecological context, because it allows information, for example, about local climate and soil to be derived from online geospatial databases.

Geosemantic searching for ecological knowledge

A tremendous amount of contextual information is embedded in published field studies (see Evans and Foster 2011), including the time at which the studies were done and often some type of location information. This information can be leveraged to improve knowledge discovery and increase the relevance of search results. Much of the published ecological research is tied to specific places, and increasingly, authors report geographic coordinates in their study-area descriptions. This location information can be mined from published studies to populate a searchable geographic literature database (e.g., Wallis et al. 2011).

To demonstrate the potential of a geosemantic search for ecological knowledge, we developed a Web-based geosemantic search tool using coordinate locations extracted from the study areas and methods sections of recently published terrestrial studies in selected volumes of 14 journals ($N = 5822$ studies; see table 1). These include the set of articles from 10 leading ecology journals georeferenced as was described by Martin and colleagues (2012). Because of the diversity of formats used to report locations and challenges with automated location extraction (e.g., inconsistencies in where and how locations were reported, different character encoding of degree symbols by publishers), we extracted location information manually from each field study. If they were reported, the geographic coordinates for a study (e.g., for a centroid point or bounding box) were copied exactly as they were printed. If geographic coordinates were not reported, any reported location information was collected. Geographic coordinates were standardized to a decimal degree coordinate system and reviewed for obvious errors

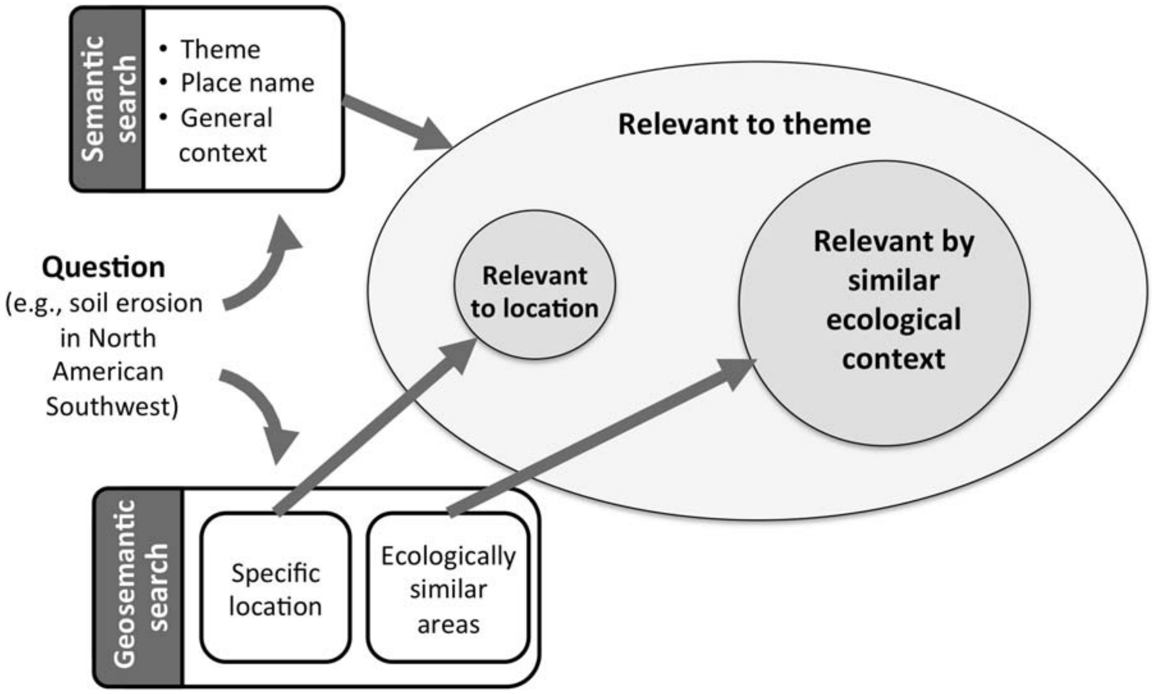


Figure 1. Conceptual diagram of geosemantic search based on location and area similarity.

Table 1. Journals and time periods included in the JournalMap demonstration.

			Articles reporting coordinates		Articles with obvious coordinate errors	
Journal	**Date range**	**Total number of articles**	**Number**	**Percentage**	**Number**	**Percentage**
American Naturalist	2004–2009	133	54	40.6	–	–
Conservation Biology	2004–2009	233	81	34.8	–	–
Ecological Applications	2004–2009	353	152	43.1	–	–
Ecological Monographs	2004–2009	66	36	54.5	–	–
Ecology	2004–2009	565	224	39.6	–	–
Ecology Letters	2004–2009	98	42	42.9	–	–
Global Change Biology	2004–2009	472	302	64.0	–	–
Journal of Animal Ecology	2004–2009	297	157	52.9	–	–
Journal of Applied Ecology	2004–2009	277	122	44.0	–	–
Journal of Arid Environments	2006–2012	1002	650	64.9	17	1.7
Journal of Ecology	2004–2009	298	158	53.0	–	–
Journal of Wildlife Management	2008–2012	695	258	37.1	1	0.04
Rangeland Ecology and Management	2000–2012	510	278	54.5	4	1.4
Restoration Ecology	2008–2012	823	511	62.1	12	1.5

(e.g., latitudes greater than 90°). No attempt was made to assign geographic coordinates to studies that reported only place names. A combination of manual and automated systems could be used in the future.

Articles with incorrect coordinate values and those appearing in obviously wrong locations (e.g., terrestrial studies located in the ocean) were flagged as erroneous. Martin and colleagues (2012) corrected errors where that was possible or removed articles with location errors but did not otherwise flag errors. No additional measures were applied to evaluate the accuracy or precision of a reported location. This level of cursory error checking was intended to catch egregious errors but would have missed instances in which there were minor errors in reported location. Verifying the correspondence of place names and coordinates for studies that report both could provide an opportunity for additional validation (e.g., Shapiro and Báldi 2012).

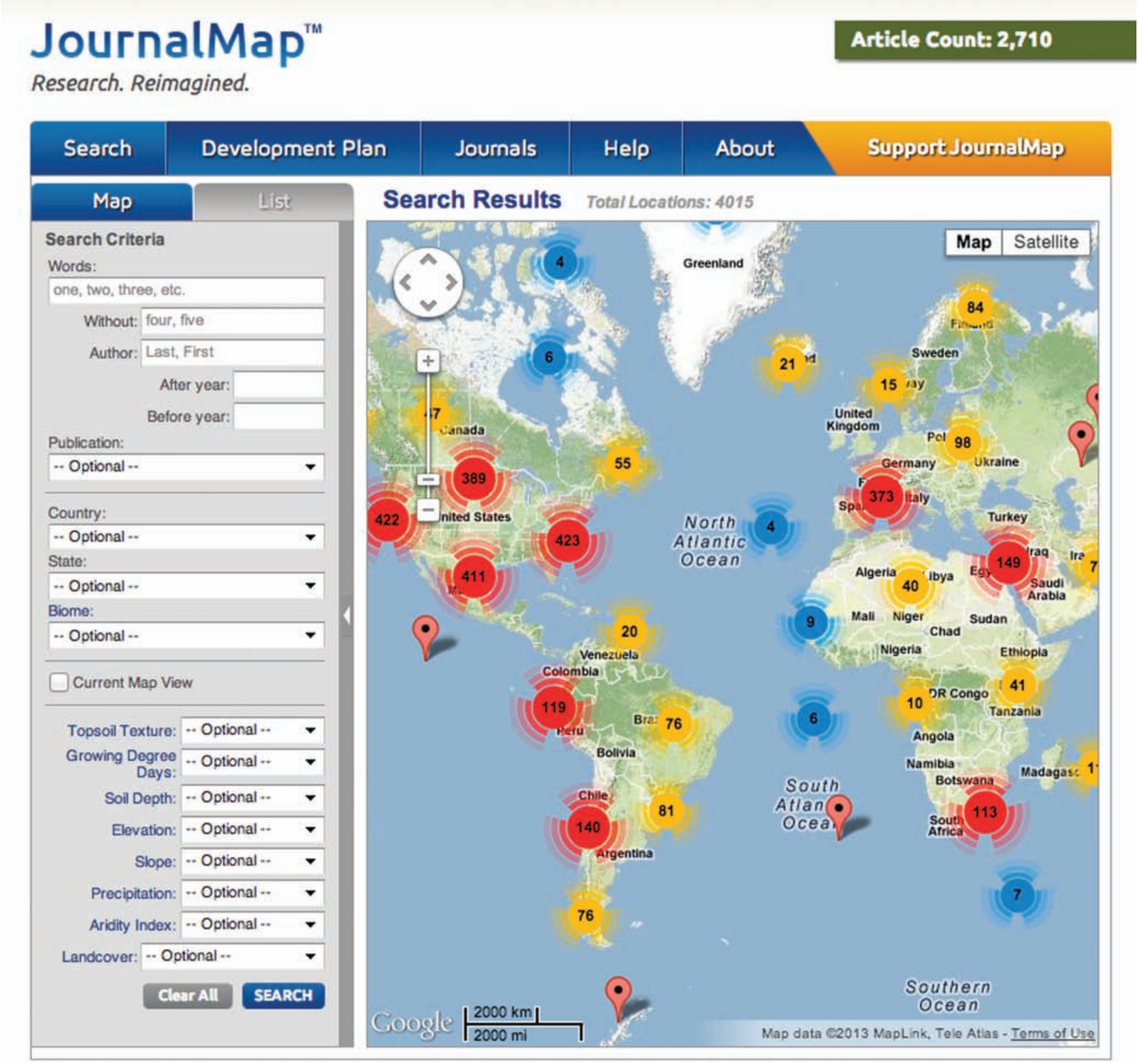
Among the journals for the time period surveyed, usable geographic coordinates were reported in 3025 studies (52.0% of the total; table 1). The formatting and precision of the geographic coordinates were highly variable. Reporting coordinates in degrees and decimal minutes to tenths of a minute was the most common (87.5% of the studies reporting coordinates), and precision ranged from reporting only integer degree values to seconds with four decimal places (equivalent to about 0.3 centimeter at the equator—far beyond the precision of most Global Positioning System [GPS] devices). A 0.1 minute latitude is approximately 185 meters anywhere on Earth, whereas 0.1 minute longitude varies from 185 meters at the equator to 131, 93, and 0 meters at 45°, 60°, and 90° latitude, respectively. Obvious errors not related to the precision of the reported coordinate values were found in 1.1% of the studies in the 14 journals assessed (table 1).

To demonstrate the potential of a database of studies reporting geographic coordinates, we created a literature search engine, JournalMap (*www.journalmap.org*), which enables geosemantic searching (figure 2). Reported article locations were assigned attributes related to the context of the region surrounding the study site, such as climate (e.g., growing degree days, average annual precipitation, aridity index), landform (e.g., elevation, slope), soils (e.g., surface texture, depth), and land-cover type (see *www.journalmap.org/help/index* for details on information sources for these attributes). Literature can be searched by location, author, topic, keyword, or any of the contextual attributes listed above. The results are shown on a map and can be exported in a variety of formats.

Achieving a sufficiently comprehensive set of location records for ecological literature to produce meaningful search results from a site such as JournalMap will most likely require many distributed but linked efforts. In our opinion, key to accomplishing this is open access to the location and citation information associated with each georeferenced study and transparency in how the locations were generated. Accordingly, the data records contained in JournalMap are freely available for download under a Creative Commons license at *www.journalmap.org/downloads*.

Realizing the potential of ecological knowledge

Adding the ability to search for knowledge geographically as well as thematically (i.e., geosemantic searching) could greatly increase the relevance of search results (figure 1) and could open new avenues for research (Bautista Cabello et al. 2006,



Search Criteria
Words: one, two, three, etc.
Without: four, five
Author: Last, First
After year:
Before year:
Publication: -- Optional --
Country: -- Optional --
State: -- Optional --
Biome: -- Optional --
☐ Current Map View
Topsoil Texture: -- Optional --
Growing Degree Days: -- Optional --
Soil Depth: -- Optional --
Elevation: -- Optional --
Slope: -- Optional --
Precipitation: -- Optional --
Aridity Index: -- Optional --
Landcover: -- Optional --

Figure 2. The JournalMap site was created to demonstrate the potential of geosemantic searching for ecological knowledge from published studies. The circles contain the number of studies in each location.

Valderas et al. 2006) and application (Herrick and Sarukhán 2007). With a comprehensive geographic literature database, it would be much easier to determine what is known about a given area (e.g., what studies have been published; see Wallis et al. 2011). Because ecologically similar areas from different parts of the world may respond similarly to ecological processes or management (e.g., Paruelo et al. 1998, Adler et al. 2005), it may be possible to identify studies from other regions that are relevant to areas that have not been thoroughly studied. For example, soils with petrocalcic (i.e., calcium carbonate–cemented) horizons are common in arid and semiarid regions throughout the world (Monger and Bestelmeyer 2006). The productivity and sustainability of these soils under cultivation depends on their ability to capture, store, and release water during droughts. Until recently, in was assumed that petrocalcic horizons contributed little to plant-available water, but recent research in the northern Chihuahuan Desert demonstrated that petrocalcic horizons hold significant amounts of water (Duniway et al. 2007) and that the availability of this water to plants is extremely dynamic (Duniway et al. 2010). Because the processes are largely physical, this information can easily be extrapolated to areas in Africa, Asia, and Australia where similar soils have been mapped. If studies in those areas were georeferenced, the information could be integrated with the results of other studies to inform interpretations about resilience and the potential responses to land-use change.

Understanding where scientific knowledge comes from may also help us interpret ecological patterns (Jetz et al. 2012). For example, the distribution of studies for a species may affect the understanding and expectations of range shifts in response to climate change. This could be the case if knowledge of a species' distribution and habitat associations were biased with respect to climatic conditions within its geographic range (Kadmon et al. 2004, Jetz et al. 2012). Furthermore, knowledge generated from the core of a species' range may not be relevant if that species collapses to its range periphery (e.g., Lomolino and Channell 1995). Considering the geographic distribution of knowledge could also promote meaningful syntheses of existing research that could be used to interpret differential responses in light of geographic context (Martin et al. 2012). For review papers, visually presenting the distribution of cited studies could help readers evaluate the applicability and scope of the ideas presented (e.g., van Vliet et al. 2012).

Geosemantic searching could also facilitate the creation of new knowledge at varying scales by identifying sets of local studies whose results could be aggregated to look for more broadscale patterns (*sensu* Arnqvist and Wooster 1995, Lawton 1999, Jetz et al. 2012, Peters et al. 2012). For example, Hughes and colleagues (2002) found latitudinal gradients in coral recruitment by looking over 21 different studies. Studying and visualizing the geographic distribution not only of studies but of the institutional affiliations of their authors could also highlight new sociological patterns and linkages (Börner 2010).

Finally, geosemantic knowledge searching could promote inquiries about the nature of our ecological knowledge through structured assessment or visualization of the geographical origin of ecological knowledge (Martin et al. 2012). This represents an exciting nexus of scientific and humanistic study and will be of particular interest to geographers and science studies scholars. Although a journal may have a stated focus that limits its scope to certain topics or regions, unintentional biases may exist that could affect the nature or meaning of the collected knowledge. For example, the geographic scope of both *The Journal of Arid Environments* and *Rangeland Ecology and Management* includes global arid, semiarid, and desert environments. However, the distributions of published studies in these two journals are very different and also underrepresent much of their stated biomes of interest (figure 3).

Fisher and colleagues (2011) and Martin and colleagues (2012) used a similar approach to mine study locations from journal articles to examine the implications of ecological knowledge distribution. Martin and colleagues (2012) found that the knowledge documented in leading ecological journals comes from a limited set of biomes and land uses; they attributed their findings to a science culture that favors temperate woodland ecosystems and protected areas. Fisher and colleagues (2011) found that the distribution of studies of coral reefs was not closely related to coral species richness or threats to reef systems. It is clear that quantifying knowledge biases and gaps that result from specific scientific cultures (see Knorr Cetina 1999) will require evaluating the spatial distribution and context of that knowledge (van Vliet et al. 2012).

Moving forward

Geosemantic knowledge-discovery tools for the ecological sciences are clearly needed. Fortunately, there are no technical barriers to their implementation. However, much work needs to be done before the geosemantic-search concept illustrated by JournalMap can realize its potential. Foremost is achieving support from authors, professional societies, and publishers for reporting and making available the geographic locations of published studies.

Achieving a meaningful spatial representation of ecological knowledge and geosemantic knowledge searching will require changes to how and what information is published (see the recommendations in box 1). Foremost are increasing the proportion of studies that report geographic coordinates or the areal extents of study areas and standardizing coordinate precision and format. We recommend adoption of the World Geodetic System of 1984 (NIMA 1997) coordinate system, reported in decimal degrees, because of its simplicity, universal applicability across the globe, and ubiquitous support in hardware (e.g., GPS devices) and software applications. The geographic context of studies that cover larger areas (e.g., more than a square kilometer) is best described using polygon geometries, such as those produced by publicly available mapping tools (e.g., Google Earth). Geographic coordinates and polygon geometries must also be validated as part of the manuscript review process in order to ensure accuracy and precision. Shapiro and Báldi (2012) found that reported coordinates did not match study-area locations in 16% of the papers published in 1 year by *Ecology* and *Oceologia*. These steps will make it easier to extract and use location information from published studies and will make it possible to develop robust geosemantic search tools. Indeed, the utility of standardized geographic data linked to journal articles is increasingly recognized and has already become an optional component of some journal articles (in, e.g., *Remote Sensing of the Environment*, *Earth System Science Data*).

At present, study location data must be mined from already-published literature, and no geographic information standard exists for citation metadata. This prevents distributed searching (e.g., Google Scholar, Web of Science), requires the locations of studies to be maintained in third-party databases, and introduces lags in database updating. Incorporation of spatial information as part of a study's basic metadata (e.g., the Dublin Core Metadata Initiative, *www.dublincore.org*) would promote the development of robust tools for geosemantic searching. We call on publishers, professional societies, and the editorial boards of journals

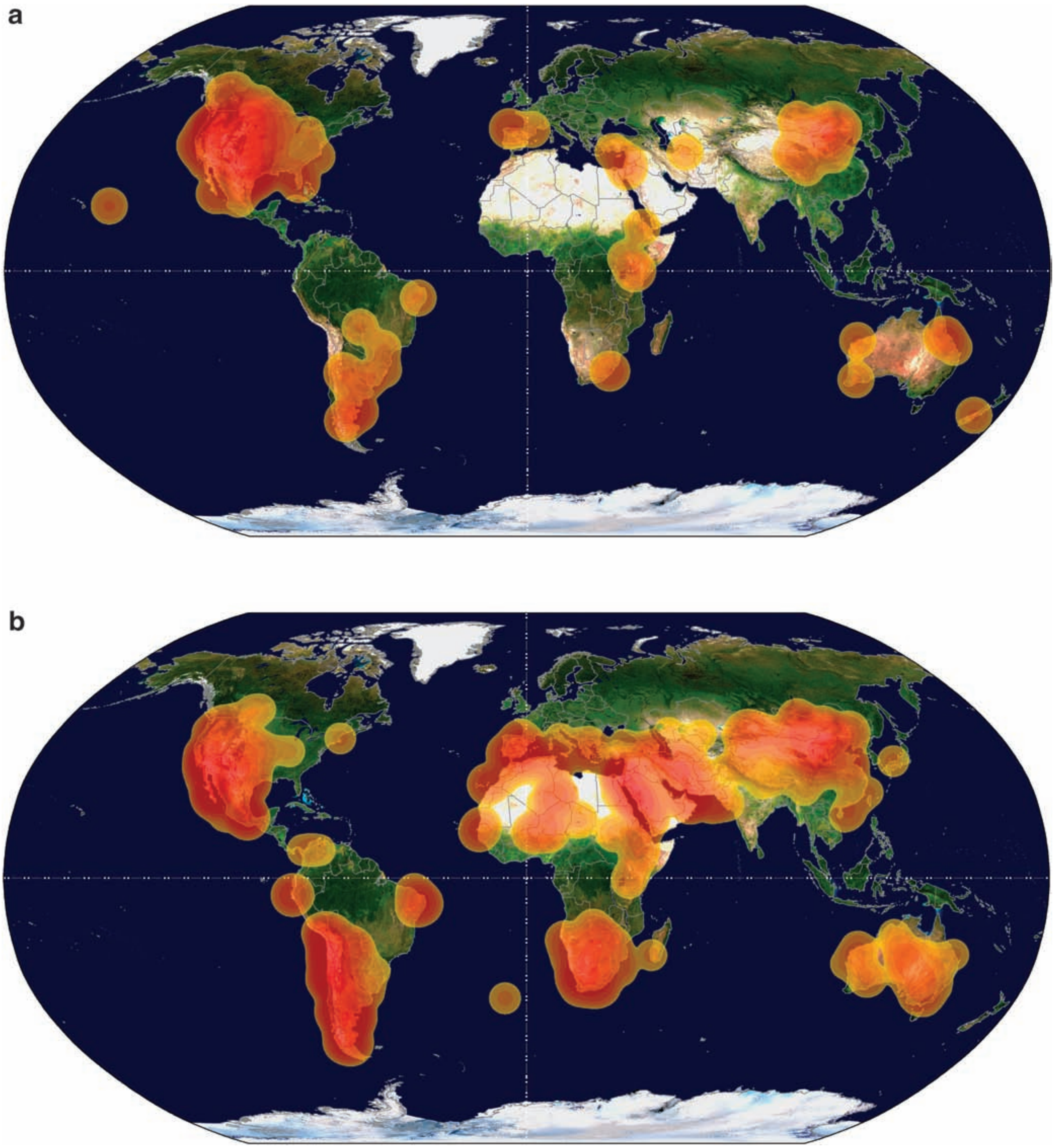


Figure 3. Examples of the geographic concentration of research published in two journals with similar topical focus: (a) **Rangeland Ecology and Management** *(articles from 2005 to 2011) and (b)* **The Journal of Arid Environments** *(articles from 2006 to 2011).*

to provide standardized geographic information in their publications and with their publically shared metadata.

Although improving the quality and availability of location information for studies in the future is crucial, there are significant technical hurdles that must also be overcome to enable the full representation of existing ecological knowledge.

First, existing studies that include only place names must be annotated with geographic coordinates. The frequency

Box 1. Recommendations for implementing geosemantic searching in ecological sciences.

Standardize the coordinate system, format, and precision of reported geographic locations in journal articles.

Require authors to report geographic coordinates for submitted manuscripts unless they are prevented from doing so by privacy concerns.

Validate reported coordinates at a manuscript's submission: For example, are the coordinates valid and in the correct format?

Provide tools for authors to verify the accuracy of locations: Is the study in the right place?

Include explicit location information in standard document metadata (e.g., Dublin Core Metadata Initiative; *http://dublincore.org*).

Develop and implement robust geosemantic tools for searching for ecological literature.

Collect study-area locations (either geographic coordinates or place names) from already-published articles or make holdings available to third parties to extract location information.

Make location information for published studies available to searching from third-party applications (e.g., Google Scholar, the Web of Science).

Implement methods for extracting general study-area locations (e.g., place names, approximate locations) from past field studies and associating them with geographic coordinates.

of coordinate reporting for studies has increased over time, but reporting of place names is still common. Prior to the widespread use of geographic information system (GIS) and GPS technologies, place names were the *de facto* means of describing the location of a study area. Automated annotation of place names with geographic coordinates is possible, but many natural resource studies take place in remote areas away from places with commonly recognized names, resulting in poor precision in the absence of some level of manual quality control. Therefore, older studies may have less accessible location information than those published more recently. Regardless, to fully represent available ecological knowledge, referencing based on place names must be implemented as precisely as is possible, with the lower spatial data quality of these studies made clear to users.

A second challenge is how to spatially represent the studies themselves. In many studies, a single point coordinate is reported. Although this is convenient for roughly locating the study area, it does not communicate the study's inference area and can compromise the ability to assign contextual attributes. Conversely, studies in which bounding boxes are reported (e.g., between 36°43′S–36°54′S and 143°59′E–144°03′E), linear features, or other complex polygon shapes present different challenges. Bounding boxes are difficult to represent, because they often contain areas that were not part of the study. Also of concern is how to represent study areas for broadscale research (e.g., the Columbia River Basin) alongside local-scale studies and broadscale studies that include more intensive experimental or observational locations. Ideally, study areas would be defined through spatial data layers, such as using polygons entered using GIS software. We recognize that the need to protect privacy, sensitive areas, and rare or endangered species may lead to occasions on which publishing a study location is not possible. In this case, the location could be obscured or generalized (see Chapman and Grafton 2008). Alternatively, describing the context of a study with ecological attributes (e.g., elevation, climate, soil, slope, aspect), controlled vocabularies, and classifications (e.g., AGROVOC keywords [*www.fao.org/agrovoc*], soil taxonomy) and ontologies (Michener 2006, Madin et al. 2008) could partially substitute for geographic referencing.

These challenges are not unique to georeferencing literature sources. The taxonomic community has faced both of these challenges in the process of digitizing specimen collections and has developed location and uncertainty reporting standards, tools (e.g., *www.museum.tulane.edu/geolocate*), and georeferencing best practices (Chapman and Wieczorek 2006). Much of this work could be directly applied to georeferencing ecological literature.

Large-scale efforts are needed to georeference previously published studies. The rise of Web-based citation managers, such as Zotero (*www.zotero.org*) and Mendeley (*www.mendeley.com*), that encourage users to share their reference collections through social networks may be a powerful way to crowdsource the Herculean task of georeferencing already-published works. Given how extensive ecological literature is, however, systems to automate the mapping of published studies must be developed. We encourage researchers and programmers to use the data set developed for the JournalMap Web site (available at *www.journalmap.org/downloads*) to begin to develop tools for mining location information from published studies. However, the challenge in georeferencing ecological literature extends beyond automating the assignment of coordinates to place names and reformatting reported coordinates. The biggest challenge to the automation of literature georeferencing may be identifying location information within an article in the first place. As a test case for identifying and mining location information from published studies, we compiled a set of 20 articles that represent diverse location reporting forms (also available at *www.journalmap.org/downloads*). All of these exemplars are open-access articles and have been annotated with descriptions of their location reporting style.

Despite the current limitations, it is clear that providing even a single location at the center of each published study would dramatically increase the value of the ecological literature for natural resource managers and policymakers and would improve the ability of ecologists to leverage existing studies. High-quality geographic data would promote the development of robust knowledge discovery tools for the ecological sciences, expanding the relevance of ecological studies across disciplines to address important ecological challenges.

Acknowledgments

We would like to thank Jacob A. Karl, Ellinor J. Karl, and Robin Metz for their work in collecting coordinate locations for the published studies used in this article. The JournalMap Web application was designed and developed by Ty Montgomery, Ryan Shaw, Matthew Lawhead, Scott Miller, and David Smith of The Other Firm (*www.theotherfirm.com*). ECE and WGL were supported by the National Science Foundation Division of Computer and Network Systems award no. 115210 as part of the GLOBE project (*http://globe.umbc.edu*).

References cited

Adler PB, Milchunas DG, Sala OE, Burke IC, Lauenroth WK. 2005. Plant traits and ecosystem grazing effects: Comparison of U.S. sagebrush steppe and Patagonian steppe. Ecological Applications 15: 774–792.

Arnqvist G, Wooster D. 1995. Meta-analysis: Synthesizing research findings in ecology and evolution. Trends in Ecology and Evolution 10: 236–240.

Bautista Cabello J, Emparanza JI, Ansuategi E. 2006. Improving literature searches. Geographic filters, methodology filters. Two different algorithms, two different applications. Revista Española de Cardiología 59: 1221–1224.

Börner K. 2010. Atlas of Science: Visualizing What We Know. MIT Press.

Browning DM, Duniway MC, Laliberte AS, Rango A. 2012. Hierarchical analysis of vegetation dynamics over 71 years: Soil–rainfall interactions in a Chihuahuan desert ecosystem. Ecological Applications 22: 909–926.

Chan LM. 2007. Cataloging and Classification: An Introduction, 3rd ed. Scarecrow Press.

Chapman AD, Grafton O. 2008. Guide to Best Practices for Generalising Sensitive Species Occurrence Data. Global Biodiversity Information Facility.

Chapman AD, Wieczorek J, eds. 2006. Guide to Best Practices for Georeferencing. Global Biodiversity Information Facility.

Duniway MC, Herrick JE, Monger HC. 2007. The high water-holding capacity of petrocalcic horizons. Soil Science Society of America Journal 71: 812–819.

———. 2010. Spatial and temporal variability of plant-available water in calcium carbonate-cemented soils and consequences for arid ecosystem resilience. Oecologia 163: 215–226.

Ellis EC, Ramankutty N. 2008. Putting people in the map: Anthropogenic biomes of the world. Frontiers in Ecology and the Environment 6: 439–447.

Evans JA, Foster JG. 2011. Metaknowledge. Science 331: 721–725.

Fisher R, Radford BT, Knowlton N, Brainard RE, Michaelis FB, Caley MJ. 2011. Global mismatch between research effort and conservation needs of tropical coral reefs. Conservation Letters 4: 64–72.

Herrick JE, Sarukhán J. 2007. A strategy for ecology in an era of globalization. Frontiers in Ecology and the Environment 5: 172–181.

Hughes TP, Baird AH, Dinsdale EA, Harriott VJ, Moltschaniwskyj NA, Pratchett MS, Tanner JE, Willis BL. 2002. Detecting regional variation using meta-analysis and large-scale sampling: Latitudinal patterns in recruitment. Ecology 83: 436–451.

Jetz W, McPherson JM, Guralnick RP. 2012. Integrating biodiversity distribution knowledge: Toward a global map of life. Trends in Ecology and Evolution 27: 151–159.

Kadmon R, Farber O, Danin A. 2004. Effect of roadside bias on the accuracy of predictive maps produced by bioclimatic models. Ecological Applications 14: 401–413.

Knorr Cetina K. 1999. Epistemic Cultures: How the Sciences Make Knowledge. Harvard University Press.

Lawton JH. 1999. Are there general laws in ecology? Oikos 84: 177–192.

Lomolino MV, Channell R. 1995. Splendid isolation: Patterns of geographic range collapse in endangered mammals. Journal of Mammalogy 76: 335–347.

Madin JS, Bowers S, Schildhauer MP, Jones MB. 2008. Advancing ecological research with ontologies. Trends in Ecology and Evolution 23: 159–168.

Martin LJ, Blossey B, Ellis E. 2012. Mapping where ecologists work: Biases in the global distribution of terrestrial ecological observations. Frontiers in Ecology and the Environment 10: 195–201.

Michener WK. 2006. Meta-information concepts for ecological data management. Ecological Informatics 1: 3–7.

Monger HC, Bestelmeyer BT. 2006. The soil-geomorphic template and biotic change in arid and semi-arid ecosystems. Journal of Arid Environments 65: 207–218.

[NIMA] National Imagery and Mapping Agency. 1997. Department of Defense World Geodetic System 1984: Its Definition and Relationships with Local Geodetic Systems, 3rd ed. NIMA. Technical Report no. TR8350.2.

O'Neill RV, DeAngelis DL, Waide JB, Allen TFH. 1986. A Hierarchical Concept of Ecosystems. Princeton University Press.

Paruelo JM, Jobbágy EG, Sala OE, Lauenroth WK, Burke IC. 1998. Functional and structural convergence of temperate grassland and shrubland ecosystems. Ecological Applications 8: 194–206.

Peters DPC. 2010. Accessible ecology: Synthesis of the long, deep, and broad. Trends in Ecology and Evolution 25: 592–601.

Peters DPC, Pielke RA Sr, Bestelmeyer BT, Allen CD, Munson-McGee S, Havstad KM. 2004. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. Proceedings of the National Academy of Sciences 101: 15130–15135.

Peters DPC, Belnap J, Ludwig JA, Collins SL, Paruelo J, Hoffman MT, Havstad KM. 2012. How to be general, yet specific: The conundrum of rangeland science in the 21st century. Rangeland Ecology and Management 65: 613–622.

Shapiro JT, Báldi A. 2012. Lost locations and the (ir)repeatability of ecological studies. Frontiers in Ecology and the Environment 10: 235–236.

Turner MG, Gardner RH, O'Neill RV. 2001. Landscape Ecology in Theory and Practice: Pattern and Process. Springer.

Urban DL, O'Neill RV, Shugart HH Jr. 1987. Landscape ecology. BioScience 37: 119–127.

Valderas JM, Mendivil J, Parada A, Losada-Yáñez M, Alonso J. 2006. Development of a geographic filter for PubMed to identify studies performed in Spain. Revista Española de Cardiología 59: 1244–1251.

Van Vliet N, et al. 2012. Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: A global assessment. Global Environmental Change 22: 418–429.

Wallis PJ, Nally RM, Langford J. 2011. Mapping local-scale ecological research to aid management at landscape scales. Geographical Research 49: 203–216.

Wilson JRU, Procheș Ș, Braschler B, Dixon ES, Richardson DM. 2007. The (bio)diversity of science reflects the interests of society. Frontiers in Ecology and the Environment 5: 409–414.

Wu J. 1999. Hierarchy and scaling: Extrapolating information along a scaling ladder. Canadian Journal of Remote Sensing 25: 367–380.

Zimmerman A. 2007. Not by metadata alone: The use of diverse forms of knowledge to locate data for reuse. International Journal on Digital Libraries 7: 5–16.

Jason W. Karl (jkarl@nmsu.edu) is a research ecologist and Jeffrey E. Herrick is a soil scientist with the US Department of Agriculture Agricultural Research Service's Jornada Experimental Range, in Las Cruces, New Mexico. Robert S. Unnasch is the director of science for the Idaho Chapter of The Nature Conservancy in Boise, Idaho. Jeffrey K. Gillan is a college assistant professor with the Jornada Experimental Range at New Mexico State University, in Las Cruces. Erle C. Ellis is an associate professor in the Department of Geography and Environmental Systems and Wayne G. Lutters is an associate professor in the Department of Information Systems at the University of Maryland, Baltimore County, in Baltimore. Laura J. Martin is a National Science Foundation graduate fellow with the Department of Natural Resources at Cornell University, in Ithaca, New York.