Visualization in Ecology.
State of Practice: How Ecologists use Visualizations in Publications: Journal Survey.

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INTRODUCTION

Availability of large and varied datasets provides continued opportunities and challenges for scientists dealing with new types of problems. Technical innovations developed by computer science and engineering research provide not only the hardware (sensor tools, processing capability of computers), but also the software, for dealing with such problems (D. A. Keim, Kohlhammer, Ellis, & Mansmann, 2010). Using technology, researchers learn, observe, and come to conclusions differently than they might have before, and new practices emerge with technical innovation, especially with the deluge of data available for analysis. Some observers have labeled this the eScience paradigm (Hey, Tansley, & Tolle, 2009) and suggested it may lead to the end of theory, where data mining will be just as important as hypothesis testing (Anderson, 2008). The amount of data collected by sensors is outpacing the ability of scientists to crunch it, so will scientists be able to increase their understanding and use of that data? Will innovation lead to insight into contemporary problems? Data visualization and visual analytics can help make sense of complex systems and large amounts of data (Thomas & Cook, 2006). Visualization deeply compresses data and exploits the ability of human vision to detect patterns quickly in the data.

The Grand Challenges of environmental science, including biodiversity and ecosystems, hydrologic forecasting, infectious diseases, and land use dynamics (NRC, 2001) involve multiple spatial and temporal scales with complex, highly distributed and heterogeneous data, but how are scientists currently using visualization to reach insight into these complex data? A review of the state of current practice in ecological visualization focusing on visualizations contained in key academic journals and at major conferences produced the following findings: visualizations published in various media, including journals and a conference primarily consisted of 2D graphs; however, a small set of computer generated visualizations that include advanced features were found. A systematic comparison of features of the more sophisticated visualization might also help define characteristics the potential of certain visualization better-suited to assist scientists in analyzing complex ecological problems.

This paper includes the methods for evaluating the current practice in ecological visualization, findings, and a brief discussion. While we identify promising areas of research in our conclusions to this paper, we mainly focus on reporting the current practice in ecological visualization. A companion paper on the state of the art in ecological visualization is forthcoming and will expand upon topics found in the discussion. The paper is organized as follows: we first describe our sample and methods for analysis of visualization use in ecological publications, i.e., which journals and subfields, what data were collected for each figure in each article, and how the figures were categorized. We present our findings, then analyze and discuss implications of our findings as they relate to describing current practice in ecological visualization.

Understanding Current Practice

Data challenges are particularly problematic in ecological research: “Unlike science such as physics or astronomy, in which detectors are shared, in ecological science data are generated by a wide variety of groups using a wide variety of sampling, or simulation methodologies and data standards” (Hunt, Baldocchi, and Van Ingen in Hey et al., 2009: 23). One challenge to researchers in ecology is the potential mismatch of their data sources, or data variety, as well as differing methods for collecting, cleaning, testing, or generating and modeling data throughout the pipeline. Big data are characterized by the following 3Vs: volume, velocity, and variety (Hey, Tansley, & Tolle, 2009). The 3Vs can be described as such: Not only are there vast amounts of data (volumes) continually being collected quickly and dynamically (velocity), but a variety of datasets are becoming available for use by anyone who may have the means to analyze them (variety).That said, “Big data marks the beginning of a major transformation...just as the telescope enabled us to comprehend the universe and the microscope allowed us to understand germs, the new techniques for collecting and analyzing huge bodies of data will help us make sense of our world in ways we are just starting to appreciate” (Mayer-Schönberger & Cukier, 2013) –add page 17. Researchers are often not limited by data, but rather by their ability to make sense of the data.

Scientific visualization is the transformation of data into visual output, such as in the form of a graph or digital elevation map. It is said to increase the ability of scientific researchers to see patterns and trends in data by compressing it into a quick and highly interpretable form (D. Keim et al., 2008; D. Keim, Qu, & Ma, 2013; Kohlhammer, Keim, Pohl, Santucci, & Andrienko, 2011). Visualization makes use of human ability to sense patterns and anomalies very easily through sight, thus producing insight, separating visual signal from noise in data. Scientists typically use a range of interactive software over the course of a research project prior to publication, and many scientists create visualizations that might benefit from innovative tools.

In order to understand the visualization practices of a wide-range of ecological sub-disciplines, we evaluated a sample of journals and a conference. The journals represent a broad number of subfields of ecological research. We did not evaluate general science journals such as *Science* and *Nature,* but rather journals limited to ecology subfields. Additionally, we did not evaluate journals in other fields such as medicine or computer science.

Table 1: Journals included in the visualization survey. Impact factors and descriptions from web sites were accessed December, 2014.

Journal	Impact Factor	Publisher	Abbreviated Description from the Journals’ Website
Agricultural and Forest Meteorology ("Agricultural and Forest Meteorology ", July-December 2011)	3.984	Elsevier	“...inter-relationship between meteorology, agriculture, forestry, and natural ecosystems. Emphasis is on basic and applied scientific research relevant to practical problems in the field of plant and soil sciences, ecology and biogeochemistry as affected by weather as well as climate variability and change.”
("Atmospheric Environment," July-December, 2011) http://www.journals.elsevier.com/atmospheric-environment	3.062	Elsevier	“...air pollution and its societal impacts. The journal publishes papers on the consequences of natural and human-induced perturbations to the earth's atmospheres, including processes involving chemistry and physics of the atmosphere as well as subjects related to human health, welfare, climate change, and environmental policy.”

("Boundary Layer Meteorology," July-December 2011)http://link.springer.com/journal/10546	2.525	Springer	"... agriculture and forestry, air pollution, air-sea interaction, hydrology, micrometeorology, the planetary boundary layer, surface processes, mesoscale meteorology, numerical modelling of the lower atmosphere, remote sensing, and urban meteorology."
("Canadian Journal of Forest Research," July-December, 2011) http://www.nrcresearchpress.com/journal/cjfr	1.657	Canadian Science Publishing	"...forest sciences, including biometrics, conservation, disturbances, ecology, economics, entomology, genetics, hydrology, management, nutrient cycling, pathology, physiology, remote sensing, silviculture, social sciences, soils, stand dynamics, and wood science, all in relation to the understanding or management of ecosystem services."
("Ecology," July-December, 2011) http://esajournals.onlinelibrary.wiley.com/hub/journal/10.1002/(ISSN)1939-9170/	5	Ecological Society of America	"...a broad array of research that includes a rapidly expanding envelope of subject matter, techniques, approaches, and concepts: paleoecology through present-day phenomena; evolutionary, population, physiological, community, and ecosystem ecology, as well as biogeochemistry; inclusive of descriptive, comparative, experimental, mathematical, statistical, and interdisciplinary approaches."
("Ecosystems," July-December, 2011)http://link.springer.com/journal/10021	3.531	Springer	"The study and management of ecosystems represent the most dynamic field of contemporary ecology. Ecosystem research bridges fundamental ecology and environmental ecology and environmental problem-solving, and spans boundaries of scale, discipline and perspective."
("Journal of Hydrology," July-December, 2011) http://www.journals.elsevier.com/journal-of-hydrology	2.693	Elsevier	"...publishes original research papers and comprehensive reviews in all the subfields of the hydrological sciences including water based management and policy issues that impact on economics and society."
("Water Resources Research," July-December, 2011) http://agupubs.onlinelibrary.wiley.com/agu/journal/10.1002/(ISSN)1944-7973/	3.709	American Geophysical Union (Wiley)	"... original research in the natural and social sciences of water. It emphasizes the role of physical, chemical, biological, and ecological processes in water resources research and management, including social, policy, and public health implications."

Ecological subfields represented by the selected journals include hydrology, eco-hydrology, micro-meteorology, biogeochemistry, biological and ecological engineering, and ecosystem ecology (Table 1) and include*, Agriculture and Forest Meteorology, Atmospheric Environment, Boundary Layer Meteorology, Canadian Journal of Forest Research,* and *Ecology, Ecosystems, Journal of Hydrology, and Journal of Water Resources Research.* To show the range of topics covered by the journals and amount of times articles are cited, we include an abbreviated description of the journal (Table 1) from the journal's web site, the publisher, and the impact factor, which "the average number of times articles from the journal published in the past two years have been cited in the *Journal Citation Reports* year" (http://admin-apps.webofknowledge.com/JCR/help/h_impfact.htm). For example, the 5.0 Impact Factor for *Ecology* means that, on average, journal articles were cited five times per year over the previous two years.

METHODS

We conducted an analysis of visualization from (1) a purposive sample of academic journals (Table 1) from July-December, 2011 (n=1,142 articles, n=24,881 visualizations); (2) an analysis of a representative sample of conference presentations (n=173 presentations; n=3,898 visualizations) from an annual ecological conference; and a follow-up analysis of a representative sample of journal visualizations from July-December 2015 (n=133 articles; n=2832 visualizations). The 2015 survey was conducted to determine whether the distribution of visualization types from the 2011 survey had changed significantly over time. To build the 2015 sample so that it would be comparable with the 2011 survey, we totaled the number of articles for each journal reviewed in 2011 and the number of visualizations found over that six-month period. Next, based on the total number of visualizations, we identified the required sample size necessary to reach a 95% confidence level with a +/- 5% margin of error in the sample. Once we determined the sample size needed based on total visualizations, we determined the average number of visualizations per article in the six-month period. We used the number of visualizations per article to determine how many articles would be necessary to view in order to reach our required number of visualizations. Finally, for each journal, we generated a random sample of articles from each journal using the random number generator in Excel.

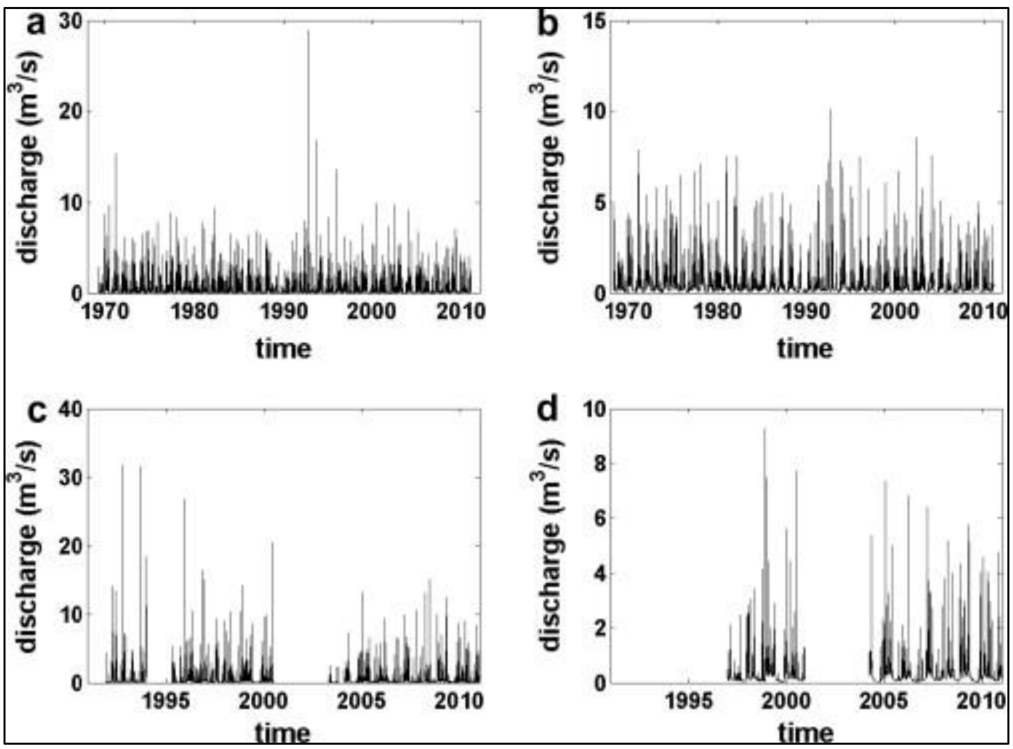


Figure 1: Two dimensional graphs, like the one pictured above, were the most highly used visualization type across the entire sample. This figure found in the *Journal of Hydrology* contains a total of four 2D graphs (Labat, Masbou, Beaulieu, & Mangin, 2011).

Information collected about each figure included use of scale, caption-description included with each figure, use of labeling, use of color, and visualization type based on all types of visualization we were seeing in the journals (e.g. graph, map, photo, chart, illustration, computer graphic; see Figure 1). For each figure, we recorded the type and frequency of visualization depicted. Figures could include more than one type of visualization. Computer-generated visualizations (n=280, 2011 sample; n=45, 2015) were tagged as “visualizations of interest” and set aside for later discussion. Other data were collected about each journal, such as impact factor, costs for publishing, information about the online presence of the journal (e.g., whether the journal publishes multi-media content, whether the journal is open-access), and the ecological sub-discipline of the journal.

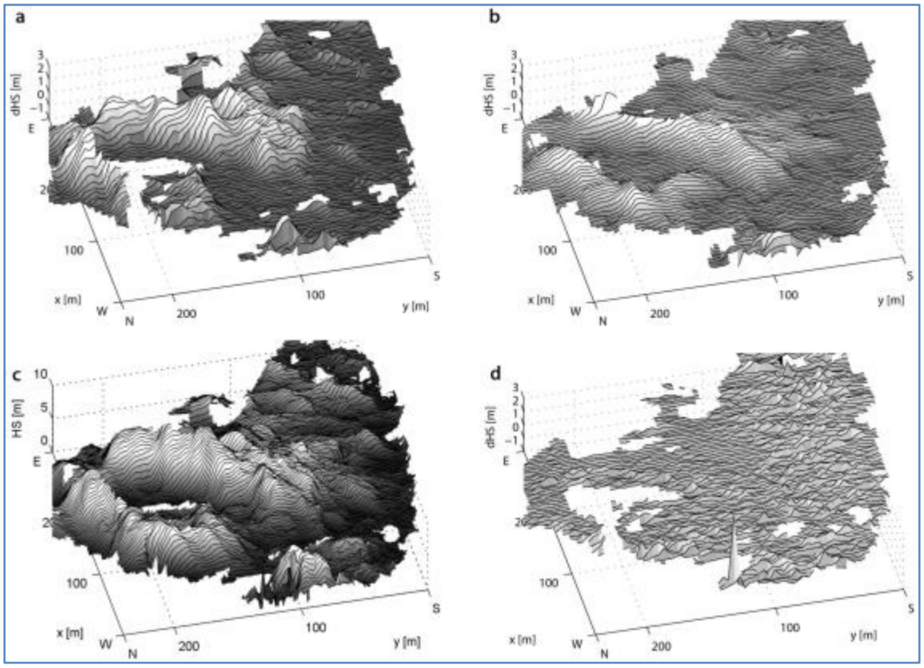


Figure 2: Visualization of interest, such as the figure pictured above, were tagged and further discussed by the research group. This visualization of interest from Schirmer and Lahning (2011) was tagged because it contained a 3D representation, compared multiple representations of possible or actual realities, and compared two or more models over time

We also reviewed a random sample of conference presentations (n=173 presentations; n=3,898 visualizations) at the 2012 Ecological Society of America (ESA) annual meeting. These visualizations were evaluated using an abbreviated survey form (i.e., count of different visualization types; note whether to follow-up; and note if any exceeded the visualization of interest criteria developed during the journal survey). We hypothesized that the use of Microsoft Powerpoint and multimedia during presentations might produce exceptional examples of interactive visualization, helping define the state of current practice in ecological visualization.

FINDINGS

By far the most-used visualization across the samples was the 2D graph, followed by maps (Table 2). Two dimensional visualization often included the use of multiple, miniature graphs in one figure (e.g., Figure 1). Many visualizations of interest that we flagged incorporated simple, 2D graphs as miniatures accompanying other visualization types, such as time-series or animation.

Table 2: Frequencies by percent of types of visualizations found in journal figures and conference presentations.

	Visualization types, 2011 journal (n=1,142 articles;	Visualization types, 2012 ESA conference (n=173 presentations;	Visualization types, 2015 journal (n=133 articles; n=2932 visualizations)

	n=24,881 visualizations)	n=3,898 visualizations)	
Graphs	~77%	40%	80%
Maps	~11%	11%	12%
Charts	*	4%	1%
Photos	~2%	31%	3%
Illustrations	~6%	9%	2%
Computer Graphics of Natural Phenomena	~4%	5%	1%

We found that conference presentations used a fewer percentage of graphs (40%) than research journal articles, but a higher percentage of photos (Table 2). This result makes sense, especially considering the use of slides during presentations, as well as the personal storytelling and verbal explanations using visual aids such as photographs that accompany conference presentations. In the 2015 samples, the overall percentages for visualization type were comparable to the 2011 sample collection. The increase in visualizations categorized as graphs in 2015 (80%) compared to 2011 (77%) was within the +/-5% margin of error. A lower percentage, also within the margin of error, of computer generated graphics of natural phenomena (VOI) were tagged in the 2015 sample (1%) than the 2011 sample (~4%).

As mentioned earlier, we tagged computer generated graphics of natural phenomena for further analysis, calling these figures visualization of interest (VOI). We created a gallery of VOI and identified the characteristics of these VOI that made these visualization novel or stand out. Through this process, we determined that VOIs included most frequently three or more of the following: 3D representations; an attempt to show multiple time or spatial scales; portrayal of natural phenomena; color carrying information; comparison of two models or times, or multiple representations of possible or actual realities; comparison of modeled and actual phenomena with difference shown as an extruded volume; and computer simulations of what a person would see when looking at phenomena.

Table 3: Visualizations of interest (VOI) by journal (represents data from July-December, 2011).

	2011			**2015**		
Journal	# of articles	Articles w/VOI	% VOI/article	# of articles	Articles w/VOI	% VOI/article
Agricultural and Forest Meteorology	68	4	5.88%	12	2	16.67%
Atmospheric Environment	302	11	3.64%	12	0	0%
Boundary Layer Meteorology	56	4	7.14%	12	1	8.33%
Canadian Journal of Forest Research	80	7	8.75%	23	0	0%
Ecology	94	2	2.13%	27	1	3.70%
Ecosystems	48	9	18.75%	17	0	0%
Journal of Hydrology	239	25	10.46%	11	0	0%
Water Resources Research	255	51	29%	12	3	25%

Water Resources Research had, by far, more tagged visualizations of interest than any other journal in both 2011 and 2015—by number and by percent (Table 3). There may be a number of reasons for this difference. One might hypothesize that a certain field, hydrology, is more advanced in their use of visualization for research, or that water is easier to visualize in a concrete way than other ecological phenomena. And, some fields have historically used certain types of visualizations that become common or "best" practice; for example, researchers in micrometeorology tend to use scatter plots to display their data, rather than what we identified as a visualization of interest. These reasons aside, questions about whether VOI are somehow better or more effective or are representative of the state of current practice in ecological visualization than other types of visualization remain unexplored.

ANALYSIS

Two dimensional graphs are the most often used visualization across the sample. In order to understand what might be driving this predominance of 2D graphs and other questions about the state of current practice in ecological visualization, we looked at relationships between the journal, its impact factor[1], ecological subfield, intended audience, and the types of visualization published in the 2011 sample. For example, in order to explore whether certain journals used a more diverse set of visualization type, we evaluated the ratio of 2D graphs to other types of visualizations—such as maps and photos—for each journal. A low graph ratio signifies lower graph use and higher diversity of visualization types in a journal (i.e., scientists had chosen to use a wider range of visualization types). Table 4 summarizes information about the eight journals evaluated in the state of current practice survey.

Table 4: A low graph rating means a high diversity of visualization were used. Table shows journal restrictions, such as color cost and whether multimedia visualization is encouraged or specifically requested in the author submission instructions (journal web sites accessed December, 2014).

Journal & Impact Factor	Graph rating	Color Cost?	Multimedia Encouraged?	Journal Publisher	Audience	Ranking (# of VOI)
Agricultural and Forestry Management 3.984	4.3	Can choose (for print)	Yes: interactive plots and data	Elsevier	Meteorology	6
Atmospheric Environment 3.062	2.4	Can choose (for print)	Yes: interactive plots and data	Elsevier	Meteorology	5
Boundary Layer Meteorology 2.525	7.7	Yes	Yes, multimedia, video files, graphics	Springer	Meteorology	7

[1] It should be noted that the impact factor of the journal was collected in December 2014; however, the sample of journal articles was taken from July-December, 2011.

Canadian Journal of Forestry 1.657	5.1	No cost	Yes: encouraged; not .exe files; multimedia and data	Canadian Science Publishing	Forestry	3 high VOI
Ecology 5.000	2.4	No cost	Not specified	Ecological Society of America	Mainstream	8
Ecosystems 3.531	1.9	No cost	Not specified	Springer	Ecology (general)	2 high VOI
Journal of Hydrology 2.693	1.7	$350/figure	Yes: supplemental online	Elsevier	Hydrology	4
Water Resources Research 3.709	2.2	Can choose (for print)	Yes: interactive plots and data	Wiley (AGU)	Hydrology	1 most VOI

The top three types of journals using the highest diversity of visualization types were hydrology and general ecology. Also, the top three journals using high diversity of visualization types are produced by three different publishers, which vary in whether they charge for color use and whether they encourage multimedia and interactive displays in their instructions to authors.

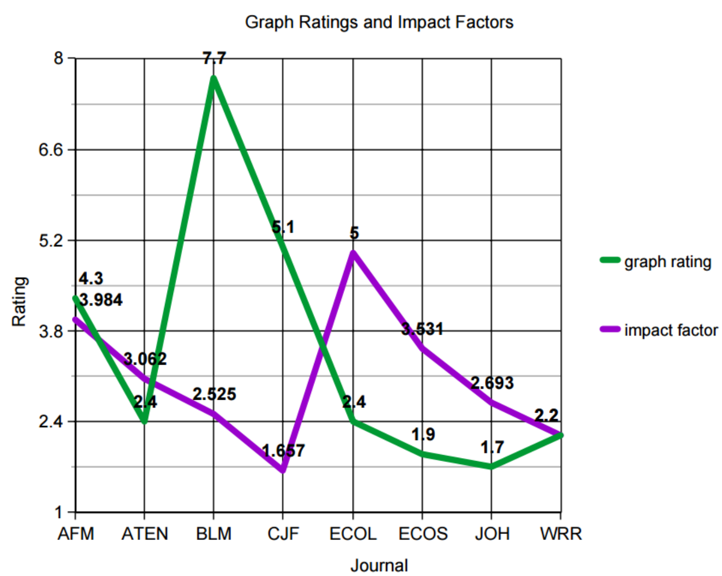


Figure 3: A low graph rating means a low use of graphs in relation to all other types of visualization used (high diversity of visualization type) in the 2011 sample. The highest use of graphs in relation to all other types of visualizations are in the two journals with the lowest impact factors, as seen in *Canadian Journal of Forestry* and *Boundary Layer Meteorology*.

Figure 3 plots the graph ratio for the 2011 sample. The journals where publications contain a higher amount of graphs compared to all other visualization types (*Canadian Journal of Forestry and Boundary Layer Meteorology)* seem to also have a lower impact factor rating; whereas, the journal with the highest impact factor *(Ecology*) has a low graph rating (high diversity of visualization), but not the lowest. *Ecology* had a higher ratio of graphs to all other visualizations than other journals with lower impact factor ratings, meaning that impact factor and diversity of visualization types used may not be related.

Freedom to Publish

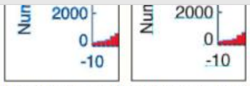
Do certain journals encourage or solicit a wider variety or diverse set of visualization? For example, do they make it easy or cheap to print color figures, support authors in preparing their articles for print, or solicit authors to include data sets and multimedia material such as found in an animation or movie? In order explore this question we collected the following information from journal websites (accessed Dec 2014): (1) the cost of publishing color figures, and (2) the level of support and solicitation for multimedia figures.

Table 5: Use of graphs, the freedom to publish score, and the journal publisher.

Journal/Impact Factor	*Graph rating (ratio of graphs to all other visualizations chosen)*	*Freedom to Publish*	Journal Publisher
Water Resources Research 3.709	2.2	2	Wiley (AGU)
Ecosystems 3.531	1.9	1	Springer
Canadian Journal of Forest Research 1.657	5.1	0	Canadian Science Publishing
Journal of Hydrology 2.693	1.7	1	Elsevier
Atmospheric Environment 3.062	2.4	1	Elsevier
Agricultural and Forestry Management 3.984	4.3	1	Elsevier
Boundary Layer Meteorology 2.525	7.7	1	Springer
Ecology 5.000	2.4	0	Ecological Society of America

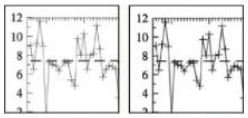
The *freedom to publish metric* was calculated by adding together: (1) whether there is a cost associated with publishing a color figure (1 = no cost, 0 = can choose, -1 = yes, a cost) and (2) whether a journal directly solicits multimedia content in the instructions for authors (0=not solicited, 1=directly solicited). The higher freedom-to-publish metric indicates low restrictions and costs for publishing visualization and high encouragement to include multi-media content as posted on journal web sites in December 2014.

In addition to lowering barriers to publish visualization of interest, *Water Resources Research* offers illustrated instructions for authors for publishing figures as seen below in Figure 5. Instructions for authors to include multimedia material and tips on graphics might be one way to increase publication of novel visualization, as well as give ideas to scientists about options for presenting data. Elsevier Publishing, which hosts three of the journals from this study *(Journal of Hydrology, Atmospheric Environment, and Agriculture and Forest Meteorology),* also offers assistance for creating figures and illustrations, which they term “art.”



(left) Outlined text and (right) Nonoutlined text

- All lines must be at least 0.5 point (i.e., do not use hairline rules)



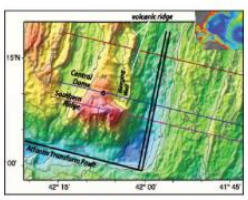
A figure using (left) hairline lines and (right) the correct 0.5 point lines.

Raster Art: This format is best for photography, halftones, shading, texture, patterns, or gradation blends. The image quality of a raster based file is determined by resolution (PPI). When saving or exporting as a .tif or .jpg, please follow these criteria.

- .tifs and .jpgs must be saved with resolution between 300 and 600 ppi at final print size.
- Color should be in RGB mode.
- For .tifs, use LZW compression (if available). For .jpgs, use high or maximum quality.

A raster-based file is ideal for reproducing photographic images, halftones, shading, texture, patterns, or blends.

Combination Art: To reduce the file size of complex vector art, or to combine and label raster-based art, a figure file can combine vector elements with raster. This means that complex or photographic portions of a figure come from a raster file while the type and line art are added using a vector editing program (such as Illustrator or Powerpoint.) When opening a raster file in a vector editing program, use the "open" or "import" commands.



An example of combination art that combines a raster background with vector lines and type.

Figure 5: Detail from the instructions for authors page of *Water Resources Research* journal, managed by the American Geophysical Union (Wiley Publisher; accessed January, 2015).

No other publisher refers to visualization as art. Springer, the other major journal publisher of articles reviewed for this analysis, has very little in the way of guidance for figures that might be used in publication. That said there seems to be no clear trend in the data that might show the effect of Elsevier's support for "art." Also, while the instructions for publishing figures such as found in Elsevier and on the AGU web site *(i.e., Water Resources Research Journal),* there does not seem to be a connection between the article submission process and the use of visualization in publications. One might hypothesize that, over time, these websites will publish articles differently than they do now, and—perhaps—even the structure of articles and supporting visualizations will change due to the publishing of datasets and interactive models, so others can reconstruct and test the findings on their own.

DISCUSSION

With regards to our findings, the predominance of graphs seems likely to continue in published manuscripts, as graphs are familiar and useful for quickly showing relationships between variables and expressing magnitude; however, just as was found in the visualizations of interest, computer-generated visualization design will likely enable scientists to incorporate both graphs and a diversity of visualization types in their figures in order to represent more variables and attributes found in the data (e.g., spatial information visualized as a map with magnitude represented through a graph, categorical data represented through color, and change over time represented through multiple time series graphs). Eventually, live visual analytics of figures, where the data and visualization can be manipulated, will change how findings are published. Whether visualization of interest will make communication of findings more "effective" has yet to be tested.

Relationship between the Freedom to Publish and the Use of Graphs

Figure 6 shows the relationship between freedom to publish metric and the graph ratio. There seems to be no consistent relationship between these two metrics—meaning, low use of graphs in relation to all other visualization types is not necessarily related to fewer barriers to publishing visualization. In other words, it may not be the journal's rules for submissions that are affecting the high use of 2D graphs. To be sure, calculating a metric for evaluating how easy it is for scientists to publish more technically advanced material, their data sets, or an interactive model is difficult to do.

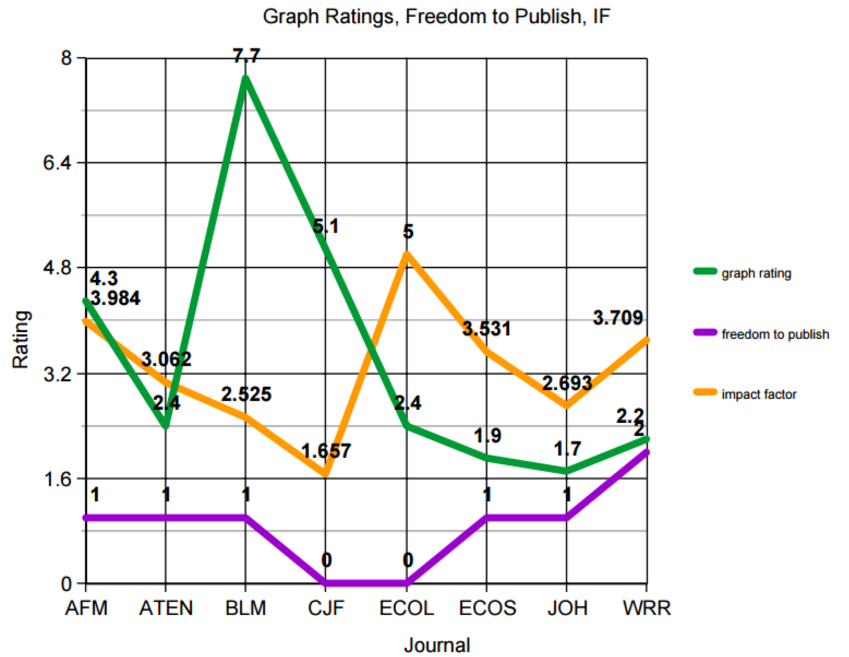


Figure 6: There is no clear trend in the high use of graphs to all other visualizations in journals where there is a cost to publish in color and where no direct solicitation for multimedia content is called for (i.e., low freedom to publish).

Other variables that might affect the freedom to publish a diversity of visualization types used in figures are formatting restrictions by the journal publishers and the increasing use of multi-media displays for interactivity with datasets, so that the visualization type is influenced not by the ecological discipline, but rather by other formatting and media influences dependent on the publisher of the journal. While some publishers encouraged more sophisticated visualizations (e.g., multimedia material) in their online publications, there is no direct connection between the trends in visualization use and the freedom to publish new types of visualization. While the various publishers offer help, such as the case with Elsevier offering assistance with “art work,” we question whether the process seems overcomplicated, posing barrier for scientists who might be encouraged to experiment (Table 6).

Table 6: Detail from Elsevier’s web site on the formats for graphics (Accessed December, 2014).

Types of "artwork"	Abbreviated description
Line art - EPS (vector based)	...complementary to raster graphics (images as an array of pixels, like photographs)
Line art - TIFF (bitmap)	...commonly used for graphs and charts. Information contained in black and white line art images is purely black and white with no tints or gradations present in the image.
Grayscale images in TIFF/JPEG format	...are distinct from black-and-white images, which in the context of computer imaging are images with only two colors, black and white. Grayscale images have many shades of gray in between.
RGB images in TIFF/JPEG format	...RGB images are made of three color channels (Red, Green, Blue). An 8-bit per pixel RGB image has 256 possible values for each channel, which means it has over 16 million possible color values. RGB images with 8 bits per channel are sometimes called 24-bit images (8 bits x 3 channels = 24 bits of data for each pixel).
Combination Art - TIFF/JPEG format	...This is an image type that is a combination of both a halftone (gray or/and color) and line art elements: combination artwork.
Combination Art - EPS format	When vector based images also contain images, such as photographs, or line art images, this is called combination artwork (hybrid vector images

One reason why there is inconsistency among journals may be that not all publishing is entirely online—some journals continue to develop material that will need to be accessible both in print and online. Scientists and publishers might struggle to accommodate both the requirements the static and the dynamic page. It seems that with the ubiquity of technology that print versions of articles are becoming less common in research institutions, and online access to material is the norm. This change from print to online media is relatively new, and the transition makes predicting what might change for the process of publishing in the next decade difficult. Some researchers project that new technologies will make old functionality more efficient, as well as create new functionality that could not have been captured prior to dynamic display (Cope & Phillips, 2014). Additionally, many researchers download articles – this may be more difficult do to if the article contains a multimedia VOI and requires more bandwidth. Downloading dynamic material onto the static page unlinks dynamic and static content. That said, it seems likely that the trend of dynamic and multimedia visualization will continue and eventually manifest itself in online publications, not only because there will be a demand for it, but because the medium for making such dynamic visualization available to others will spur this development. Through a longitudinal study of publication web sites, one might be able to chart the changing nature of visualization use in scientific research and communication.

Finally, the emergence of online media poses implications not only for preparing materials for publication, but also for the general process of science. One such implication seems to be greater accessibility to others' findings and data. For example, animating another researcher's online model and manipulating it using live visual analytics is easier than viewing a static journal page where the animation is visualized as a series of miniature graphs or maps followed by a caption. This ability to interact with visualization online seems to increase accessibility. Journals are encouraging the publication of multimedia material and datasets, and it seems that access to others' data and models will likely increase the need for more interactive and sophisticated visualization; however, it is too soon to assess the implications of this accessibility to the process of science and whether scientists and others will find it useful or time-consuming to design and develop related visualization. Finally, we found no clear relationship between the impact factor of a journal and the types of visualization being used, leading us to question whether scientists who are concerned about the impact of their work need to change how they represent their work visually. That said, until tools and visualizers become standardized, we would recommend scientists who are publishing data-driven visualization to acknowledge the tools and the source of their visualization. Also, the extent to which sophisticated and diverse visualization enables research ecologists to conduct good science should be considered.

LIMITATIONS

While it might be tempting to present our findings as representative of the state of current practice in ecological visualization, we strongly suspect that the use of visualization in ecological journals and possibly as presented at research conferences lags significantly behind actual current practice. Our reasons for believing this are: (1) We found during conference presentations that researchers were experimenting with data visualization, including attempts at animated models during live presentations, leading us to question whether ecologists are using more sophisticated visualization in their research than is found in academic journals. (2) Our own observations of an admittedly small cohort of ecology researchers indicates that many ecologists use more sophisticated visualization in their own work, as they seek to gain insight into their data.

With more time and resources, this study might have expanded the data collection to include visualization from a broader sample of the research process—such as through querying scientists about visualization use for forming hypothesis or validating data. For example, despite the increasing prevalence of visualization techniques on the Web, we are often looking at tables of numbers, best-fit curves, or other analytic results rather than being able to use visual means to interact with the complex scientific data over the course of the research cycle. Many visualization tools that are available to scientists do not allow live linking, and are therefore not represented even in the most innovative publication outlet. Additionally, once the visualization is created, it is no longer tied to the data, so that it becomes an immutable information product—as the data changes, the visualization is no longer up to date (Fox and Hendler, 2011). Related acts of visual analysis and visualization output at different stages in the research process are impossible to measure or understand with our current sampling technique.

CONCLUSION

This study displays a systematic way of evaluating the state of current practice of ecological visualization, representing thousands of visualizations and tracking features of these visualizations. We identified visualizations typically used by ecologists and provide a baseline for tracking status and trends in ecological visualization. Findings and analysis hypothesize whether certain subfields of ecology are using visualization differently, and whether the impact factor, and other aspects of the various journals and publishers, affected the types of visualization chosen. Factors such as cost to publish color, direct solicitation of multimedia content, and subject matter were considered with regards to diversity of visualization used and presence of visualization of interest. Also, the survey of presentations at the ESA conference was conducted in order to understand whether the live visualization experience produced a different set of predominant visualization types than a journal. We found that, while presentations made use of more photographs, it was difficult to detect much difference between the two mediums. We revisited this research by completing a smaller representative sample of journal articles and visualizations and could not detect a change towards a higher number of diverse visualizations being used or more effective use of visualizations. ///

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