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Frontiers of Biogeography, 13(2)

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et al.

2021

DOI

10.21425/F5FBG49487

Frontiers of Biogeography 2021, 13.2, e49487

RESEARCH ARTICLE

Frontiers of Biogeography
the scientific journal of
the International Biogeography Society

Revealing receiver bias in the communication of mapped biodiversity patterns

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Abstract

Researchers often communicate knowledge about biodiversity, especially information about where species are likely to be found, through maps. However, readers do not necessarily interpret such maps in the way the authors intend. We assessed undergraduate students' interpretations of mapped biodiversity data with a mixed-method approach: a survey instrument was developed using writing and focus groups, then delivered to students enrolled in introductory biology courses at the University of Florida in the United States. Surveyed participants (N = 195) were presented with sets of maps for the Palamedes Swallowtail butterfly, *Papilio palamedes,* with three data visualization methods: point occurrences, expert-assessed range, and correlative distribution model results (distributional models were shown at high and low resolutions). Map interpretations were assessed by asking participants to rate the likelihood of finding a Palamedes Swallowtail at various point on each map and how confident they were in the information the map presented. They were also asked which map type they would most likely use to find a Palamedes Swallowtail. For distributional model maps, the effect of resolution on interpretation was assessed by asking participants to rate the perceived accuracy of each map, as well as their confidence in the data being presented. Participants most trusted in data provided via point maps compared to range and distributional model maps, and trusted point maps most among the three map types. For distribution maps, participants felt more certain in data presented to them via higher-resolution maps and interpreted them as being more accurate. This preference was especially pronounced for participants studying Science, Technology, Engineering, and Mathematics (STEM) fields compared to their non-STEM peers. Our findings suggest biodiversity researchers need to carefully consider symbol choice and resolution when transmitting information about species distributions.

Highlights

- The manner of presentation of mapped biodiversity data to non-expert audiences can have a profound impact on their understanding of the data itself.
- This mixed-methods study provides both quantitative and qualitative insights into undergraduate students' interpretations of mapped biodiversity data.
- Participants found point maps to be easier to understand and felt they were more reliable for determining where a species might be found compared to range or suitability maps.
- Participants appeared to be using aesthetic cues in their judgements of map accuracy, interpreting high-resolution maps as being more accurate due to beliefs that those maps were of "higher quality" and based on more data.
- Students majoring in Science, Technology, Engineering and Mathematics fields were more likely to incorrectly interpret high-resolution maps as being more accurate.
- Maps need to be crafted to be useful to their end audiences, and so must consider science communication principles: a reliance on the presentation of fact alone without regard to user preferences, biases, and understanding can lead to misinterpretations.

Keywords: biodiversity data, biogeographical map, data interpretation, mapped data, mixed methods, science communication, science education, visual communication

e-ISSN: 1948-6596 https://escholarship.org/uc/fb doi:10.21425/F5FBG49487

Introduction

Biogeographers often use maps of species distributions as basic units of data and analysis, but maps are also key elements of data visualization that can convey complex messages based on a symbolic translation of reality (McInerney et al. 2014). Effective communication through maps is rooted not only in the accuracy and precision of mapped data (e.g. Rocchini et al. 2011), but in the user's ability to interpret these symbols as data with spatial relationships. Their dual purpose as tool-and-symbol means that effective use comes from not only from the map itself, but also user preferences, potential implicit biases, and the task they are seeking to complete with the map (MacEachren 2004, de Mendonça & Delazari 2011).

Maps are a common way of communicating biodiversity information. For example, natural history field guides compile information on distributions of species of plants and animals into range maps. Historically, these maps were hand-drawn by experts, but were imprecise and scale-dependent in terms of their ability to translate to where a given species might be found (Hurlbert & Jetz 2007). However, the historically unprecedented amount of species occurrence data now available permits researchers to model species distributions at spatial resolutions finer than expert-drawn maps. Still, more spatially-precise maps may have limited accuracy, as their precision is often based on mathematical interpolation instead of finer-scale data (Fick & Hijmans 2017). Beyond even these data-driven concerns, however, the *use* of the map must also be considered. Even if the data underlying the map were completely accurate, to be truly effective, the map's "connotations" must still be correct - the mapped data should align as best as possible with the expectations and preferences of those who will use the map (MacEachren 2004).

Effective communication via maps becomes particularly difficult when experts attempt to create maps intended for different end-users (Riemann et al. 2018). Expert and lay audiences do not interpret mapped data in the same way (Ooms et al. 2012, Wakabayashi 2013, Albert et al. 2016). Given species distribution maps' ubiquity in university-level scholastic biology, undergraduate students are a particularly important map use stakeholder group. While work has been done examining the usability of maps for undergraduate students (Wakabayashi 2013, Albert et al. 2016, Nusrat et al. 2018), there is at present little research examining these students' preferences concerning mapped data—especially for biodiversity phenomena—and how those preferences influence their interpretations. This is of particular importance for model-based maps, such as models of species distribution or hotspots of biodiversity, which come with assumptions that must be intuited by their users. Herein, we present a multi-stage qualitative and quantitative study of undergraduate students' interactions with biodiversity visualizations, particularly their preferences and interpretations when using biodiversity maps. While we have framed our study primarily around species distribution models, these results can be generalized to other problem spaces where researchers must communicate the results of spatial models. Such design considerations are increasingly important as we work to design maps that pique interest, not just to "go viral" as part of phatic discourse (Varis & Blommaert 2015, Robinson 2019), but to communicate relevant and understandable messages to achieve desired learning outcomes and societal engagement.

Particularly, we identified and investigated the degree to which undergraduate students inferred certainty and accuracy from different forms of symbolic representation of biogeographic data. We also interrogated students' preferences regarding mapped information as a proxy for messaging receptiveness. Finally, we assessed whether these students were able to distinguish between precision, the variance within measurements independent of their relationship to the true value, and accuracy, the distance between measurements and the true value (Walther & Moore 2005), in mapped data and which they thought was more important when mapping biodiversity data (see Table 1 for hypotheses, tests, and result summaries).

Materials & Methods

This study used a mixed-method approach to assess students' understanding of mapped biodiversity data. While the main aim of the study was to quantitatively measure map understanding and interpretation, qualitative methods were used in the creation of the instrument, as has been recommended for survey creation (Crocker & Algina 1986, Fink 2003, Fowler Jr 2013). In addition, qualitative data were used to enrich and inform the quantitative survey data.

Maps depicting empirical biodiversity data were created and used as stimuli for this study. To assist in the creation of a survey instrument based on these maps and to also collect rich data concerning map interpretations and preferences, these stimuli were first used in a set of writing groups. Insights from the writing groups were further explored in a series of focus groups. Prominent themes and discussion points were then incorporated into a web-based survey for quantitative assessment.

Formative Research

Map creation: We mapped empirical data from a study on butterfly biodiversity (Owens et al. 2017) using QGIS (version 2.18; qgis.org). Here we briefly summarize the methods used to generate the data--details can be found in Owens et al. 2017. The point map (Fig. 1A) shows occurrences of *Papilio palamedes*, the Palamedes Swallowtail butterfly. Georeferenced occurrence data were downloaded from the Global Biodiversity Information Facility (GBIF; gbif.org/), Red Mudial de Información sobre Biodiversidad (REMIB; conabio.gob.mx/remib_ingles/doctos/remib_ing.html), and from the social media photograph sharing website Flickr (flickr.com); occurrences were filtered for data quality and duplicate records were removed. Clean occurrences were integrated with environmental data

Table 1. Quantitative hypothesis testing using survey results. Survey participants (N = 195) were selected using a convenience sample of undergraduate students enrolled in introductory Biology courses at the University of Florida. Bolded results indicate statistical significance ($p < 0.05$).

Hypothesis	Test	Result
$H0_{1A}$: Participants do not trust the information presented in a point map more than a range map.	Two Tailed Paired Wilcoxon; One Tailed Paired Wilcoxon follow-up	**Participants trust point maps more than range maps (n = 193).**
$H0_{1B}$: Participants do not trust a range map more than a suitability map.	Two Tailed Paired Wilcoxon; One Tailed Paired Wilcoxon follow-up	**Participants trust suitability maps more than range maps (n = 193).**
$H0_{1C}$: Participants do not trust a point map more than a suitability map.	Two Tailed Paired Wilcoxon; One Tailed Paired Wilcoxon follow-up	**Participants trust point maps more than suitability maps (n = 195).**
$H0_{2}$: Participants have no preference in the resolution of a mapped raster.	Two Tailed Unpaired Wilcoxon; One Tailed Unpaired Wilcoxon follow-up	**Participants prefer high-resolution maps to low resolution maps (n = 195).**
$H0_{3}$: Participants do not interpret high-resolution maps as being more accurate than low-resolution maps.	Two Tailed Unpaired Wilcoxon; One Tailed Unpaired Wilcoxon follow-up	**Participants interpret high-resolution maps as being more accurate than low-resolution maps (n = 194).**
$H0_{4}$: Participants do not prefer accuracy to precision.	Two Tailed Unpaired Wilcoxon; One Tailed Unpaired Wilcoxon follow-up	Participants do not prefer accuracy to precision (n = 194).
$H0_{5}$: There is no significant difference in responses between Science, Technology, Engineering, and Mathematics (STEM) and non-STEM participants.	Kruskal-Wallace	One significant difference: **STEM participants were significantly more confident in high-resolution maps than non-STEM participants (n = 194).**

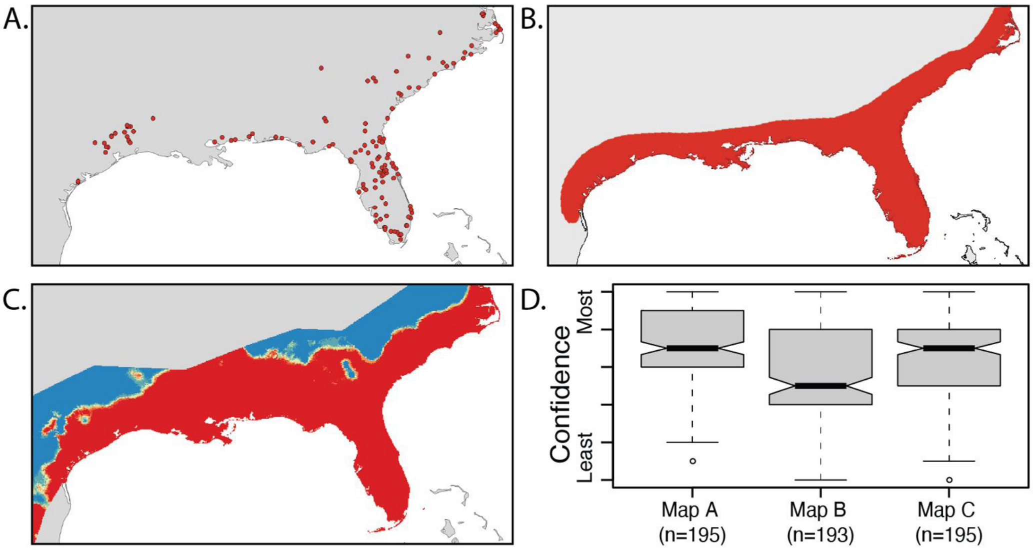

Figure 1. Maps of Palamedes swallowtail occurrences and survey results. A. Observations of Palamedes Swallowtails (Owens et al. 2017; downloaded from biodiversity databases GBIF and REMIB, and social media site Flickr). B. Expert-drawn range map of Palamedes swallowtail. C. Correlative distribution model based on occurrences (Owens et al. 2017) and WorldClim climate dataset (version 1.4; Hijmans et al. 2005); warmer colors indicate higher climatic suitability for Palamedes swallowtail. See Methods for more details. Interpretive features such as scale bars and keys were intentionally not included, as the goal was to assess students' inferences based on mapped visual cues alone. D. Boxplots of web survey responses showing respondents' confidence in different map types. The hollow circles represent statistical outliers.

from the WorldClim dataset (version 1.4; Hijmans et al. 2005) at a 2.5 arc-minute resolution using the correlative distributional modeling algorithm Maxent (Phillips et al. 2006). The resulting distributional model was presented as the mapped distributional model (Fig. 1C). Models were also projected at 30 arc-seconds and 10 arc-minutes using the same algorithm settings as for the 2.5 arc-minute model (Fig. 2A-B). The range map (Fig. 1B) based on the distributional model was drawn in Photoshop (version 20.0.4; Adobe, adobe.com/products/photoshop.html).

Participants: For all stages of this study, participants were recruited using a convenience sample of undergraduate students at the University of Florida in the United States. A convenience sample is a type of nonprobability sample, where subjects are directly recruited based on availability and access (undergraduate students enrolled in specific biology classes, as done in this study) as opposed to being randomly sampled from a population (all undergraduate students enrolled at a university; Battaglia 2008). A recruitment message was delivered in-person to attendees of introductory biology courses, both for majors and non-majors, as well as via course-based listservs. Anyone currently enrolled as an undergraduate student and over the age of 18 was eligible to participate in the study.

Writing groups: To understand what aspects of a biodiversity map might be important to guide understanding for students, three writing groups were held, each using the same group of three study participants. During the three writing group sessions, participants were shown the biodiversity maps created for this study and given booklets with writing prompts for each map. A member of the study team moderated the sessions, and a second took notes. The moderator guided participants through writing prompts, asking for written responses and open discussion about their thoughts, reactions, interpretations, and opinions of each map, and how they arrived at their answers. Sessions lasted between 46 and 120 minutes. Sessions were audio recorded and transcribed, and writing booklets and notes were digitized for analysis. Writing group map materials and worksheets are included in Supplementary Material, Appendix S1.

Focus groups: Focus groups were held to assess if the map interpretations and opinions expressed in the writing groups were consistent in a larger sample of students and were thus appropriate to measure quantitatively. A series of focus groups, with a total of 33 participants, were shown the same biodiversity maps as in the writing groups and asked a similar set of questions concerning each map. One member of the study team moderated the sessions, and a second took notes. Sessions lasted between 41 and 47 minutes and audio was recorded and transcribed for analysis. Focus group map materials and moderator guide are provided in Appendix S2.

Qualitative analysis: We used qualitative textual analysis (Hsieh & Shannon 2005, Creswell & Poth 2018) to analyze writing group workbooks and transcripts, focus group moderator notes and transcripts, and open-ended responses to survey items. Materials were open-coded, an inductive process through which textual data are aggregated into categories that are allowed to emerge from the data itself. The first author, who is trained in qualitative methods, read through all collected textual materials at each stage of the study several times to become familiar with the data. After this process, the materials were coded line by line for explicit references to map features that informed participants' attitudes and interpretations of the mapped data in order to understand their map

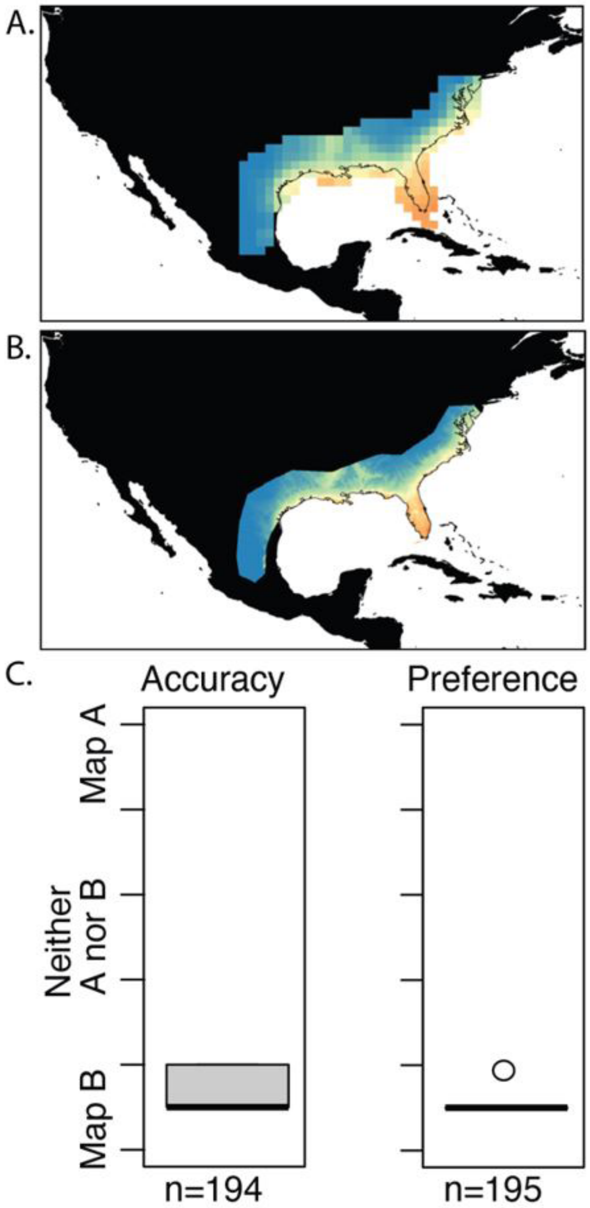

Figure 2. High- and low-resolution distribution model maps of Palamedes swallowtails and survey results. Warmer colors indicate higher climatic suitability. A. 10 arc-minute resolution. B. 30 arc-second resolution. C. Boxplots of web survey responses showing respondents' assessment of accuracy and preferences for Maps A and B. The hollow circle represents a statistical outlier.

use. This process was also used to understand why participants responded to certain map features in the ways that they did, as participants were asked to explain their reasoning directly and the open-coding process is designed to allow discussion themes to be generated inductively from the data itself. Analysis was sequential and guided subsequent study stages; writing group response analysis influenced focus group material creation, and both writing and focus group analyses informed survey instrument creation. After this process was completed for each stage, map aspects and themes were presented to the entire study team for discussion and refinement before the next stage of the study was implemented.

Survey

Web survey: The web-based survey was designed to gather information on participants' interpretations, opinions, and thoughts of mapped biodiversity data using multiple choice, scale, and open-ended questions. Visual prompts included the maps that were used during writing and focus groups. The survey instrument is provided in Appendix S3.

Map measures: All participants (N = 195) were shown the same series of maps and answered a bank of similar questions about each one. Map interpretations were assessed by asking participants their perceived likelihood of finding a Palamedes swallowtail butterfly at different designated points, using a scale of 1 (very unlikely) to 10 (likely). In addition, participants were asked to indicate their overall confidence in the information presented on the map, using a scale of 1 (very uncertain) to 10 (very certain). After each set of interpretation and confidence measures, participants were asked to discuss their answers through open-ended prompts. Participants were also asked to indicate their preferences for use among the different map types. Finally, participants were asked to provide confidence ratings for maps at different levels of accuracy and precision to test their practical applications of these definitions.

Demographic measures: Participants were asked to provide basic demographics, including: gender, age, race, and ethnicity. In addition, participants were asked to indicate whether their declared course of study was a Science, Technology, Engineering, and Mathematics (STEM) field.

Quantitative analysis: We quantitatively analyzed web survey data to test five hypotheses, summarized in Table 1. Survey data and codebook are provided in Appendices S4 and S5 respectively. Analyses were done using the open-source statistical computing environment R (version 3.5.0; R Core Team, Rproject.org/); code is located in Appendix S6). To quantitatively assess participant responses to a single question on a scale of 1 to 10, a two-tailed Wilcoxon signed-rank test with a continuity correction was performed (as data were not normally-distributed) to assess whether responses differed from an ambivalent response (5 on the response scale); in cases where responses differed significantly from 5, one-tailed Wilcoxon rank sum tests with a continuity correction were performed to ascertain if responses were significantly greater or less than 5. In cases where two scale responses were compared, paired two-tailed Wilcoxon signed-rank and rank sum tests were performed. Finally, to assess whether there were significant differences in responses between participants in STEM versus non-STEM majors, we performed Kruskal-Wallace tests for all numeric responses. These tests are summarized in Table 1. Responses were also visualized as boxplots (Figs. 1-3) using the base R graphics package (R Core Team, Rproject.org/). Boxplot hinges are defined as the first and third quartile of values, whiskers are 1.5 times the interquartile range, outliers are values that fall outside 1.5 times the interquartile range. Notches show values +/-1.58 times the interquartile range divided by the square root of the sample size; these notches approximate a 95% confidence interval for the median response value.

Results and Discussion

The results of each hypothesis test are below, with discussion of results immediately following.

$H0_1$: Participants do not express more trust in data presented via point maps, range maps, nor suitability maps.

Participants most trusted the data presented in the point map, followed by the suitability map and then the range map--all of these differences were statistically significant (Table 1, Fig. 1). In addition to trusting the information presented on the point map, the majority of survey participants also indicated that they thought

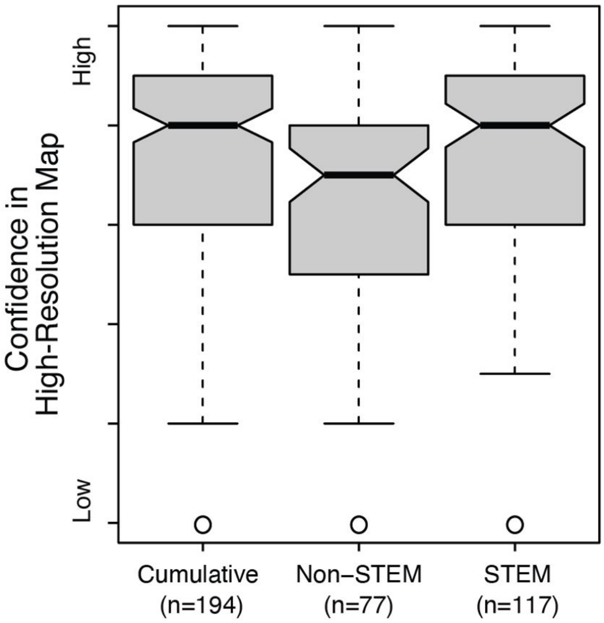

Figure 3. Boxplot of web survey responses showing difference in level of confidence in high-resolution distribution model map between Science, Technology, Engineering, and Mathematics (STEM) and non-STEM respondents. Hollow circles represent statistical outliers.

that the point map was the most effective at showing where one was likely to find a particular species (n = 107, 54.9%). The suitability map was the second most common choice (n = 72, 36.9%). Participants derived their trust in the data presented on the point-based map from the interpretation that the points represented actual species sightings. Participants also felt that the point map was easiest to use among the three map types, as it did not require comparison to a color scale. Furthermore, according to participants, the discrete nature of points as contained units of data also made the point maps more interpretable, as the density of sightings in a particular area could be readily assessed.

However, even those who trusted the point map did note a lack of specificity. In particular, several participants who were confident that points on the map indicated a direct sighting noted there was no mention on the map itself of the number of observations that each point represented. This led to some calling the map "vague," or noting it could not be used to answer certain kinds of questions.

In contrast, the broad, saturated area displayed in the range map was difficult for participants to understand. While some did note that a range may be a better representation for organisms that do not stay in one place, it did not make it easier to use the map to determine if the species could be found in a particular area. This was especially true for border areas (i.e. areas at the transition from presence to absence), which many participants were unsure how to interpret.

Many participants felt that the suitability map was effective at showing where swallowtails could be found, even though they most trusted the point map. Explanations echoed the issues that were previously discussed with the point map: it seemed unnatural to some to tie the presence of an organism to a specific point on a map, making the data presentation of the suitability map more "realistic."

$H0_2$: Participants have no preference in the spatial resolution of a species distribution model.

Participants significantly preferred the high-resolution map to the low-resolution map (Fig. 2). Though some participants were able to correctly identify the lower-resolution map as more accurate, the presence of pixilation was enough to make that map feel less usable, as typified by a survey participant: "Although [the low-resolution map] is probably more accurate because there isn't a clear border for climate regions, [the high-resolution map] is much [easier] to read and interpret." The pixilation and jaggedness present in the low-resolution map were difficult for participants to interpret and had a major impact on how the data being presented was viewed:

> "[Low-resolution pixilation] would bother me a lot, because usually, if I see some piece of paper that has data on it, it's probably printed. I would think that the printer just printed it badly. Then I wouldn't know what exact locations and so I don't know what exactly the colors represent." (Focus group participant)

> "In geography, nothing is cut up or jagged like [the low-resolution map]; [the high-resolution map] is more blended together and makes more logical sense. For example, rain isn't just strong in one 1mm x 1mm square, but flows from one area to the next." (Survey participant)

> "I think people in our generation, we don't really see that much stuff that's that pixelated, you know? We haven't seen stuff like that in a while and it just makes it—I feel like it just makes it look older and less accurate, like old technology." (Focus group participant)

$H0_3$: Participants do not interpret high-resolution maps as being more accurate than low-resolution maps.

A significant number of participants interpreted the high-resolution map as being more accurate than the low-resolution map (Fig. 2). Participants ascribed the smooth color transitions and geographic delineations of the high-resolution map to what they would expect of a "higher quality" map based on more data: "The jaggedness of [the low-resolution map] gives the impression of having less specific data to work with, or mapping the data in such a manner that it is not specific in comparison to [the high-resolution map's] details," (Survey participant).

Many participants did not understand why "suitable" pixels in the low-resolution map extended offshore (Fig. 2A), and interpreted the map as erroneously predicting where the species might be found:

> "One of the immediate things I notice is how the data goes off of the state of Florida. I don't know much about butterflies, but I feel like they wouldn't have travelled that far off of the land. There's not a ton of substantial land in the areas that it goes off of. You have the Keys and everything, but it's just like it's not that much land." (Focus group participant)

Some participants did note that the low-resolution map might be displaying more uncertainty and thus be more accurate, with "blurry" boundaries being more realistic. Still, this wasn't always viewed as a positive aspect of the map. According to one survey participant, "I think a lot of people don't like uncertainty." Accurate maps could be harder to understand, despite being more correct.

$H0_4$: Participants do not prefer accuracy to precision.

Participants were asked to rate how important they felt the balance between accuracy (i.e. truth of measurement) and precision (i.e. refinement of measurement) was in the communication of scientific information generally, and also whether they felt that accuracy or precision was more important when it came to the display of data on distribution maps specifically. Survey respondents indicated a conflicting viewpoint: they had a balanced view of the importance of accuracy vs. precision in mapped data generally, but also indicated a strong preference for distribution maps to be accurate rather than precise (n = 151, 77.4%). Their open responses reflected this preference, with the majority of respondents stating they want their map data to be "correct" and "factual," though a few did prefer precise maps:

> "...If we attempted to create all maps out of accuracy, 1) there is no way we could possibly accurately track all data, as species data is constantly changing and 2) all maps would be very vague and lack detail. Since the whole purpose of maps is to understand trends and process information, I believe that precision in maps is what is most important." (Survey participant)

Interestingly, focus group open responses differed from those provided by survey participants. Focus group participants emphasized map *use* compared to their survey counterparts (precise maps for a textbook, and accurate maps for researchers, for example), adhering more closely to the idea of a balanced view:

> "I feel like I would rather have—be looking at [a precise map] if someone were trying to explain an abstract topic to me, or just give me a general quick education about a topic. I feel like I would rather look at that graph. If I had to interpret actual numbers, or something from a graph, I'd rather see [an accurate map], because the squares make me feel like I can stay within the different colors, and pick the colors, and I'd be able to get information quicker from that than trying to figure out where exactly on the spectrum in [the precise map] it would be." (Focus group participant)

$H0_5$:There is no significant difference in responses between STEM and non-STEM participants.

Quantitative analysis of survey data recovered only one significant difference in responses between STEM and non-STEM participants: participants majoring in STEM fields were more trusting of data presented in high-resolution maps than their non-STEM counterparts (Fig. 3). This was counter to our expectations, as discernment between precision and accuracy are core competencies of critical thinking (Paul & Elder 2007), which, in turn, is foundational to science education. However, it is also possible that students with intended non-STEM educational arcs have been prepared to think critically about precise but inaccurate maps through addressing other educational core competencies. Regardless, this phenomenon is intriguing and merits further study to understand the extent of its persistence, and the likely source of this bias.

Conclusion

Mapped biodiversity data are commonplace in textbooks, field guides, natural history museum exhibits, and via data journalism – all of which are now frequently delivered digitally. These maps are often critical for visual storytelling about not only distributions of organisms, but loss of biodiversity over space or time. They thus play an increasingly critical role in explaining key issues such as the magnitude of the current extinctions happening globally.

Our survey results highlight the potential disconnect between intended and received messaging via mapped biodiversity data. Despite the shortcomings of the convenience sample design, we found clear patterns in how participants interpreted mapped data. Specifically, the more precise the symbol (points versus models versus ranges; high-resolution versus low-resolution) the more confident participants were in their interpretations of the data. Displaying uncertainty in mapped data is not a new problem and has been a subject of research for more than 20 years (e.g. Pang et al. 1997). There have been extensive studies into the visual conveyance of uncertainty and the ways that users interpret those visualizations (MacEachren et al. 2012). However, there is disagreement concerning which visualization styles are readily interpretable by nonexperts (Padilla et al. 2015), and there is likely not a one-size-fits-all visualization solution. Instead, we as researchers must be intentional about how maps are presented in order to encourage our audiences to think critically about the information we are presenting.

Our findings emphasize the need for those that wish to communicate biodiversity information with maps to carefully consider the symbolism they employ. This is particularly salient in a discussion of mapped data, as maps are tools that exist not only to advance science *education*, but also as instances of science *communication*. Unlike science education, which provides instruction and training in science facts and methods, science communication focuses more on the contextualization of data for different audiences – it aims to provide meaning and utility for scientific findings in the context of peoples' everyday lives (Fischhoff 2013).

From a communication perspective, it is important to understand that "useful" is a concept primarily defined not by those that craft the messages, but by the intended recipients. What is considered most useful by experts – generally facts – rarely matches the needs of non-experts. A reliance on and belief in the sufficiency of sheer fact to convey *useful* information to audiences is referred to as the "deficit model" of communication. Within the deficit model, any issues that arise in understanding scientific issues stem from simply not knowing the facts behind those issues. Because science fact is by definition well-established, experts then need only explain those facts to non-experts to make the science understood. While the deficit model is simple, common, and attractive, it also does not work. There is a significant body of research demonstrating that non-expert audiences use much more than science facts to understand, interpret and respond to science messages, including personal beliefs, attitudes, knowledge and skillsets, as well as message characteristics such as source and aesthetics (Sturgis & Allum 2004; National Academies of Sciences, Engineering, and Medicine 2017).

Our findings may be an example of this phenomenon. That students misinterpret high-resolution mapping as being more accurate is likely not a direct failure of education on those topics. Indeed, our participants were generally quite able to define the formal concepts of accuracy and precision correctly. Issues arose, then, not from absence of fact, but due to participants placing more importance on the presentation of the data itself. Educators (and anyone wishing to communicate visual data to any kind of non-expert audience) would have little reason to assume that this would happen, especially when the facts of accuracy and precision are taught as part of compulsory education in the United States. The disconnect between fact and perceived usefulness only becomes apparent when you take a deeper look into message assimilation.

Our work highlights the importance of understanding *how* an audience is understanding a message so that the education surrounding it can be refined to target misconceptions or incorrect interpretations. This understanding will allow educators to not only impart necessary fact to their students, but to also help them be savvier consumers of data. Specifically, visual communication of mapped data should be an essential part of any curriculum that includes visualizing and interpreting visualized statistical data. We recommend that educators integrate aesthetic ramifications of concepts like accuracy and precision when discussing such visualized data, moving beyond definitions and into effective contextualization for students. Using even contrived mapped examples as we have done here can make it clear that, practically, accurate data might *look* quite displeasing, with greater amounts of pixilation, or appear “blurred,” or have oddly-demarcated boundaries, but that that is expected and correct.

The findings presented here provide insight into student map use, but further analysis examining the dimensions of the themes that emerged from our results could provide a deeper understanding of students’ map interpretations. This in turn may provide insight into other lines of inquiry, such as why students in STEM majors would be more likely to place their confidence in high-resolution maps. Additional data collection and quantitative work in this area is also necessary. This study used a convenience sample of undergraduate students from introductory biology courses. While this has allowed us to uncover useful and meaningful insights into these students’ map use and interpretations, it is not a representative sample and the findings should not be generalized to all students. A larger survey including a representative sample of students across all levels of familiarity with biodiversity maps will be needed to see broader trends in map use, and to understand if and how personal demographic factors beyond STEM specialization play a role in these trends. This work is ultimately essential for understanding not only how students perceive and interact with mapped biodiversity and biogeographic data, but also the more general public assimilates biodiversity messaging. Ultimately, these lessons will serve to demonstrate how to design clear, meaningful maps that make an impact on societal engagement with science.

Acknowledgements

Funding for this project was provided by the University of Florida Biodiversity and Informatics Institutes. Jamie Gillooly, Nicole Gerlach, and Andrew Hill were kind enough to support our endeavors via their roles as instructors in University of Florida Biology courses. Approval for the human subjects research protocol used in this study was granted by the University of Florida Institutional Review Board, under study number IRB201701686.

Supplementary Material

The following materials are available as part of the online article from https://escholarship.org/uc/fb

Appendix S1. Writing group map materials and worksheets.

Appendix S2. Focus group map materials and moderator guide.

Appendix S3. Survey instrument.

Appendix S4. Survey data.

Appendix S5. Survey data codebook.

Appendix S6. R code and statistical analysis of survey data.

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Submitted: 16 August 2020
First decision: 2 October 2020
Accepted: 27 January 2021

Edited by Richard Ladle and Robert J. Whittaker