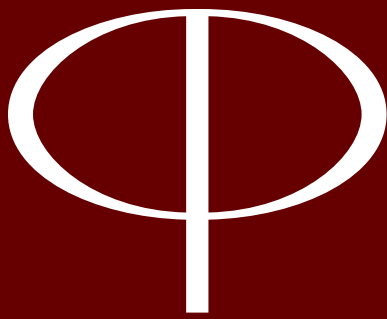


Cartographic Perspectives

The Journal of **nacis**

Number 78, 2014





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Cartographic Perspectives

The Journal of **nacis**

ISSN 1048-9053

www.nacis.org | @nacis_cp

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ABOUT THE COVER: "Many Rivers" by Matthew Cusick. Image courtesy of the artist and Pavel Zoubok Gallery. See page 82 for more.

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LETTER FROM THE PRESIDENT

Greetings to all NACIS Members and *Cartographic Perspectives* Readers,

These are exciting times for NACIS. We had a successful and well-attended Annual Meeting in Pittsburgh in October 2014, board committees and members continue to push forward new initiatives, and *Cartographic Perspectives* continues to be a respected, widely-read, and informative platform for publishing cartographic content.

As organizer for the Pittsburgh meeting, I know there were great talks and presentations for Practical Cartography Day, Geographic Data Collections Day, and for the main NACIS conference. I only wish I could have been present at more of them! I would like to offer a big thank you to all who attended and participated. It was a lively gathering for talking about maps, making new friends, and renewing contacts in the mapping community.

Our opening and keynote presentations at the Pittsburgh meeting gave added insight to the city and of the theme of the conference. In his talk, “Taking the Measure of the Topographical City,” Martin Aurand, of Carnegie Mellon University, discussed the unique physical position of the city of Pittsburgh at the forks of the Ohio River. Anne Kelley Knowles and two of her students from Middlebury College presented a thought-provoking talk titled, “Do Maps Really Tell Stories? The Problem of Narrative Time in Cartography.” The conference theme of *Time and Cartography* was further explored in several sessions during the conference with presentations on “Treating Time in Atlases,” “Why are Timelines Maps?,” “Spatial-Temporal Displays of Daily Climate Data,” and “1 Minute to 100,000 Years: Mapping The Out of Eden Walk Project.”

Well-established features such as the Map Gallery, the Student Map and Poster Contest, and Geo-Dweeb Geopardy were all successful parts of the conference. We were also happy to welcome a new event: the NACIS Fun Run.

The current Vice President, Amy Griffin, and VP-Elect, Anthony Robinson, are busy preparing for the next meeting, in Minneapolis, and welcome any and all ideas for participation. The theme is *Mapping Interactions*. The 2015 Call for Participation is provided at the end of this issue of *Cartographic Perspectives* and is posted at nacis.org. Abstracts are due by May 31, 2015.

The NACIS Board has been active in its work of running the Society and preparing for the future. I would like to thank the Board members for their time and dedication. I would also like to extend a special thanks to the Executive Office for all their help over the past year: Executive Director Tanya Buckingham, Director of Operations Daniel Huffman, and Business Manager Susan Peschel. In this all-volunteer organization, we are indebted to those who step up to help.

If you are ready to give back to the NACIS community, please let me know. You can help in many ways large and small, you will get to know your colleagues better, and you will gain a sense of satisfaction from helping to maintain our group of mapping enthusiasts.

I hope that you have time to delve into this issue of *CP*. Martin Lukas' article on using maps to reconstruct environmental change is a valuable contribution to better understanding a method of historical research and analysis. And we can all benefit from the valuable insights provided by the knowledgeable team of cartographic authors in the article "A Process for Keeping Pace with Evolving Web Mapping Technologies."

Section editors have provided many more items for your perusal: a collection review, cutting edge digital techniques, a practical cartography tool, and book reviews. The rich content of the current issue is a testament to the effectiveness of our Society's open access journal and to the hard work of the *CP* Editor. Enjoy!

Alex Tait

NACIS President, 2014–2015

Cartographic Reconstruction of Historical Environmental Change

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Historical maps provide large potential for research into historical environmental change. However, the limited availability and accuracy of early cartographic material restricts the analytical time scale of inquiry and poses methodological challenges. An important consideration in this context is the question: at minimum, how accurate must historical maps be in order to be used for which kind of analysis. This question is addressed here, based on the example of a combined analysis of historical maps and satellite images that aimed at reconstructing shoreline aggradation in the Segara Anakan lagoon on the south coast of Java. I present a practical methodological approach to analyzing historical spatial information which has varying degrees of accuracy. In the example presented, this approach links an accuracy assessment of selected historical maps of the region with a lagoon shoreline change analysis. As indicators for the maps' analytical suitability and the reliability of results, I propose ratios between environmental change rates and quantitative map accuracy measures, as well as combined uncertainty measures. The empirical example demonstrates that in case of large magnitudes of environmental change an analysis of even fairly inaccurate historical maps can provide results with surprisingly low levels of uncertainty. However, large magnitudes of environmental change can also constrain the analysis of historical maps. Quantitative analyses of the accuracy and the contents of historical maps should be accompanied by a qualitative appraisal taking into account carto-bibliographic information and the various dimensions of map accuracy. The maps of change presented in this paper may support further inquiry into the dynamics and drivers of environmental change in the Segara Anakan lagoon region.

KEYWORDS: historical maps; historical cartography; map reliability; map accuracy; planimetric accuracy; historical environmental change; shoreline reconstruction; coastal sedimentation; Segara Anakan lagoon; Java; Indonesia

INTRODUCTION

HISTORICAL MAPS ARE OFTEN the only source of historical spatial information. The digitization and reproduction of archival material has tremendously enhanced the accessibility of historical maps, while GIS has made accuracy assessment, correction, and analysis possible and efficient. This in turn facilitates the linking of historical maps with recent spatial information, providing larger potential than ever for research into environmental histories. Historical maps, often embedded in GIS, have proven valuable for the analysis of land use / cover changes (Haase et al. 2007), coastal features (Crowell, Leatherman, and Buckley 1991; Jabaloy-Sanchez et al. 2010; Levin 2006; Monmonier 2008), settlement processes (Levin, Kark, and Galilee 2010), agricultural histories (Pearson and Collier 1998), soil degradation (Brookfield 1999), salt

marsh losses (Bromberg and Bertness 2005), and river meanders (Słowik 2013). Historical maps can help to verify, concretize, or dismantle narratives about past environmental changes and political events (e.g., Brookfield 1999; Pearson 2005).

Knowledge about past environmental changes is crucial for a realistic understanding of contemporary environmental issues, because current conditions and processes are partly an outcome of long-term developments, and the nature and pace of current dynamics can only be realistically evaluated against the backdrop of past developments. In this context, our choice of analytical time scales is an important consideration, since it may influence our results and conclusions (Batterbury and Bebbington 1999;



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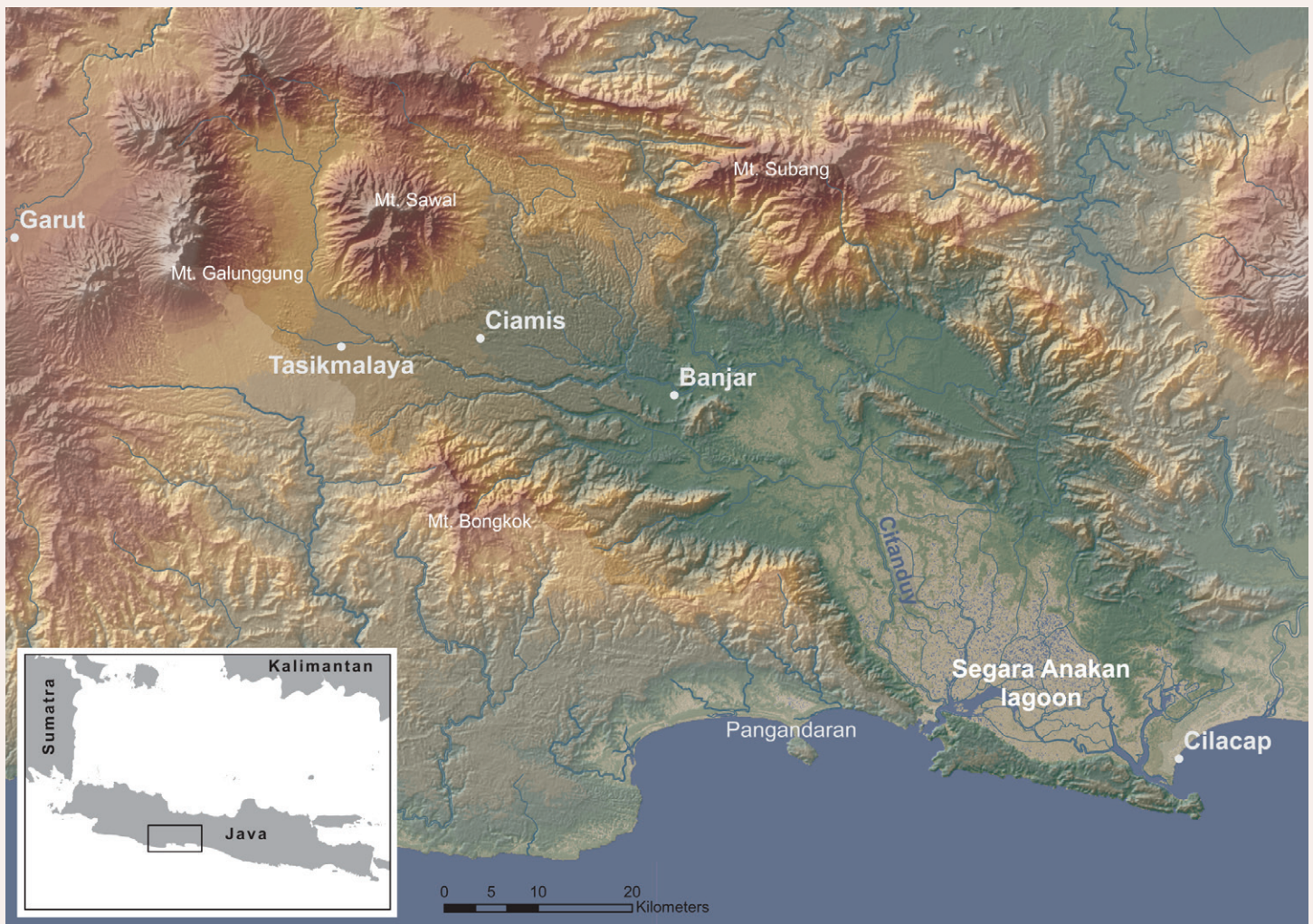


Figure 1. Location of the Segara Anakan lagoon and its catchment area on the south coast of Java.

Chapman and Driver 1996). For a realistic understanding of anthropogenic drivers, it is particularly interesting and meaningful to incorporate times of transition from mainly nature-dominated to human-dominated landscapes (Batterbury and Bebbington 1999; Messerli et al. 2000).

However, the further we expand our analytical time scale into the past, the more our inquiry is constrained by the limited availability and accuracy of historical cartographic material. While contemporary remotely sensed material provides very precise and accurate images of almost the entire world at resolutions of a few meters or less, historical topographic maps from the nineteenth or early twentieth century may be marked by inaccuracies of tens or hundreds of meters, and earlier charts may only depict a small range of selected topographic features and include completely uncharted territories. In this context, careful evaluation of the cartographic material's reliability is crucial. This should include a thorough exploration of the history

of mapping of the target region, the gathering of knowledge about mapmakers and mapmaking processes, and a careful examination of the maps' accuracy (Levin 2006; Jenny 2006). One important question at this juncture is: how accurate does the cartographic material need to be, at minimum, in order to be used for which kind of analysis?

I address this question here, based on the example of a combined analysis of historical maps and satellite images which aimed at reconstructing shoreline aggradation in the Segara Anakan lagoon on the south coast of Java. I present some of the valuable but largely underutilized historical cartographic material of the region and an assessment of its accuracy. Linking map accuracy with the results of the shoreline change analysis, I propose ratios between environmental change rates and quantitative map accuracy measures, as well as combined uncertainty measures as indicators for the maps' analytical suitability and the reliability of results.

RATIONALE AND CONTEXT: THE SHRINKING SEGARA ANAKAN LAGOON —

THE RESEARCH PRESENTED HERE aimed at contributing to an improved understanding of environmental changes in the Segara Anakan lagoon. This shallow coastal lagoon on Java's south coast (Figure 1) has been heavily impacted by riverine sediments. Rapid aggradation is said to have contributed to a vicious cycle of diminishing marine resources, environmental degradation and poverty (Bird, Soegiarto, and Soegiarto 1980; Dudley 2000; Olive 1997; White, Martosubroto, and Sadorra 1989; Yuwono et al. 2007; Purba 1991).

Despite a long record of research and political interventions in the area, knowledge of the historical dynamics and drivers of sedimentation remains limited, and related discussions have been dominated by political discourses (Lukas 2013; 2014). While these discourses have focused on upland agriculture, other drivers of sedimentation have been neglected (*ibid.*). Knowledge of the temporal dynamics of lagoon sedimentation may contribute to exploring its various drivers. In this context, the research presented here aimed at reconstructing lagoon shoreline aggradation, with an analytical time scale expanding as far back as the availability and accuracy of historical cartographic material allowed. The results—a delineation of historical shorelines—illustrate the rapid pace of transformation and provide a rough, albeit only two-dimensional, picture of the temporal dynamics of lagoon sedimentation. The maps

of change presented below may support further research into the environmental history of this area.

Historical shoreline reconstructions of the Segara Anakan lagoon already exist (Schaafsma 1926; Hadisumarno 1964; Hadisumarno 1979; ASEAN/US CRMP 1992; PRC-ECI 1987; Soewondho 1984; ECI 1994; Tejakusuma 2006). However, these analyses only cover the twentieth century and lack adequate documentation of data sources, methods, and map accuracy. In addition, their results are partly erroneous. For example, Hadisumarno (1964; 1979) did not pay attention to the time gap between the dates of surveys and map publication. The dramatic increase in his annual aggradation rates for the lagoon's eastern shoreline from 5m for the period 1900–1940 to 54m for the period 1940–1946, which he interpreted as a result of “deforestation within the river catchment area of Citandui during the Japanese occupation,” (49) in fact largely resulted from his neglecting the fact that the maps from the 1940s were based on surveys already carried out in the 1920s. The same error appears in the shoreline change maps subsequently included in various project documents (ASEAN/US CRMP 1992; PRC-ECI 1987; Soewondho 1984; ECI 1994). A well-documented shoreline change analysis is contained in the findings of a land use change analysis by Ardli and Wolff (2008; 2009), but it only covers the period from the 1970s onwards.

ACCURACY OF THE HISTORICAL MAPS OF JAVA'S SOUTH COAST —

THE ERRORS IN PREVIOUS shoreline change analyses underline the importance of obtaining background information about mapmakers and mapmaking processes before using the content of the cartographic material for analysis. Systematically gathering as complete an account of historical maps of an area as possible, ordering them in a temporal sequence, connecting them with information on the processes of their making, and analyzing their accuracy supports the selection of the most suitable material, with as small a temporal resolution and as large a temporal scale as possible, and helps to realistically assess the varying reliability of the material.

OVERVIEW OF THE MATERIAL

As a basis of the research presented here, more than 50 different historical maps and map series produced between

the sixteenth and twentieth century were gathered from various libraries and archives worldwide. An overview of this material along with information about mapmakers and mapmaking processes is provided in Lukas (*forthcoming*). Accordingly, the earliest known maps of the Segara Anakan lagoon or parts thereof go back to cartographic expeditions undertaken on behalf of the United (Dutch) East India Company in 1698, 1711, and 1739 (Schilder 1981; Schilder 1978; Knaap et al. 2007). The manuscript sea charts drawn during these voyages remained the only original cartographic documentation of the lagoon until the early nineteenth century. One of them is depicted in Figure 2. The first fairly detailed maps of the entire lagoon were produced in 1809 by Jan Theunis Busscher (Figure 3) and in 1813–15 as part of the first systematic topographic large-scale mapping of Java (Figure 4). Additional increasingly detailed maps were produced

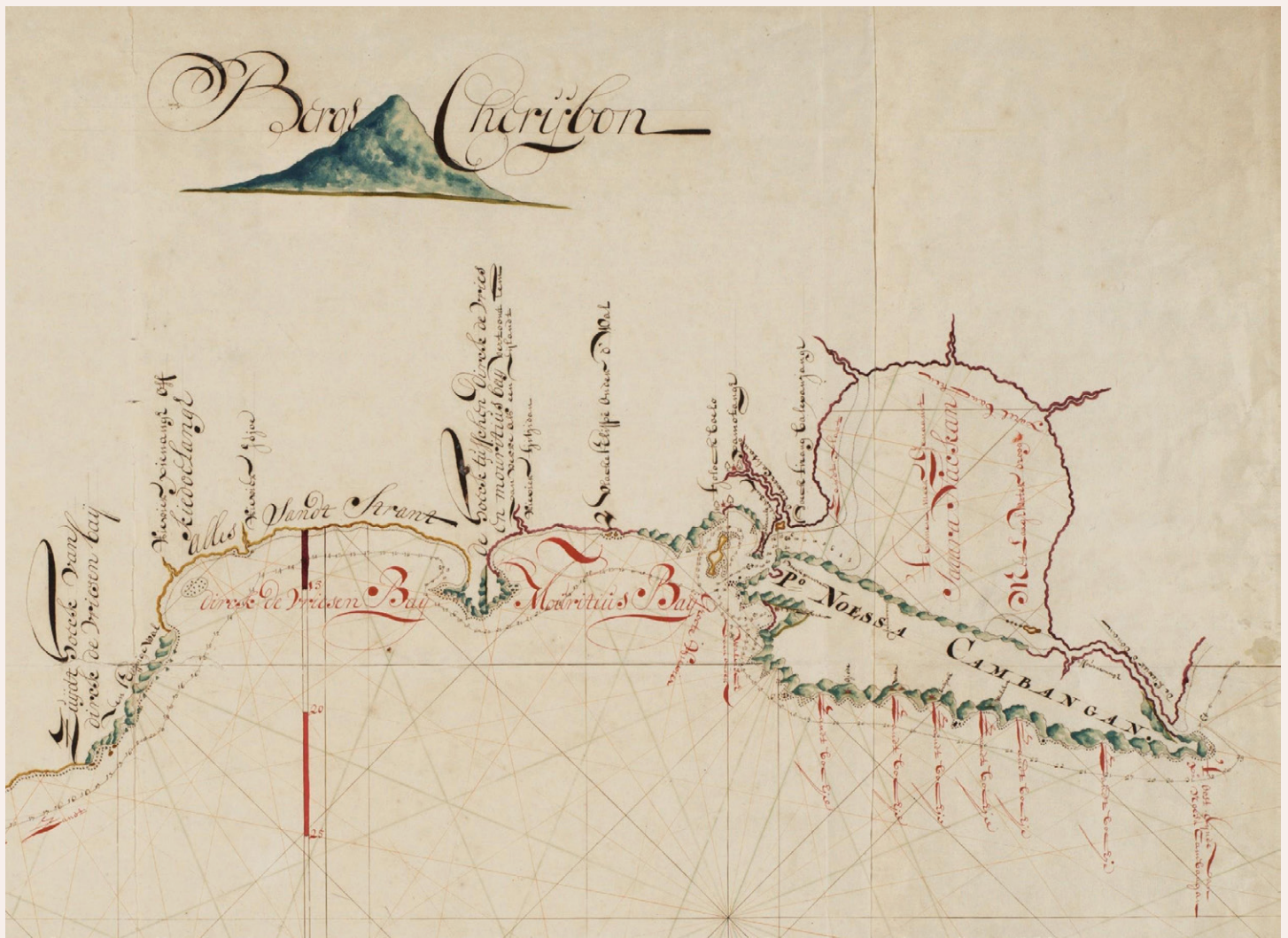


Figure 2. This section of the manuscript sea chart drawn by Cornelius Coops in 1698 is the earliest known map of the Segara Anakan lagoon. Original scale: approx. 1:140,000. Retrieved from the Netherlands National Archives in The Hague.



Figure 3. Map of the Segara Anakan lagoon, drawn by Jan Theunis Busscher in 1809. Original scale: 1:76,000. Retrieved from the Netherlands National Archives in The Hague.



Figure 4. Section of Sheet 20 of the Kaart der Preanger Regentschappen en Crawang, based on surveys carried out between 1813 and 1815. Original scale: 1:114,000. Retrieved from the Netherlands National Archives in The Hague.



Figure 5. Section of the Topographische Kaart van de Residentie Banjoemaas, based on surveys carried out between 1857 and 1860. Original scale: 1:100,000. Retrieved from the Netherlands Royal Tropical Institute (KIT). The red points represent the ground control points used for georectification.



Figure 6. Topographic map of Java, Residency Banjoemas, produced by the Topographical Service in the Netherlands East Indies (TDNI), based on surveys carried out between 1897 and 1901. Compilation of sections of map sheets III, IV, VII, and VIII. Original scale: 1:100,000. Retrieved from KIT.



Figure 7. Topographic map of Java, Middle and West Java, produced by TDNI, mainly based on surveys carried out between 1924 and 1926. Compilation of sections of map sheets 42/XLI D, 43/XLI C, 43/XLI D, 42/XLII B, 43/XLII A, 43/XLI D. Original scale: 1:50,000. Retrieved from KIT.

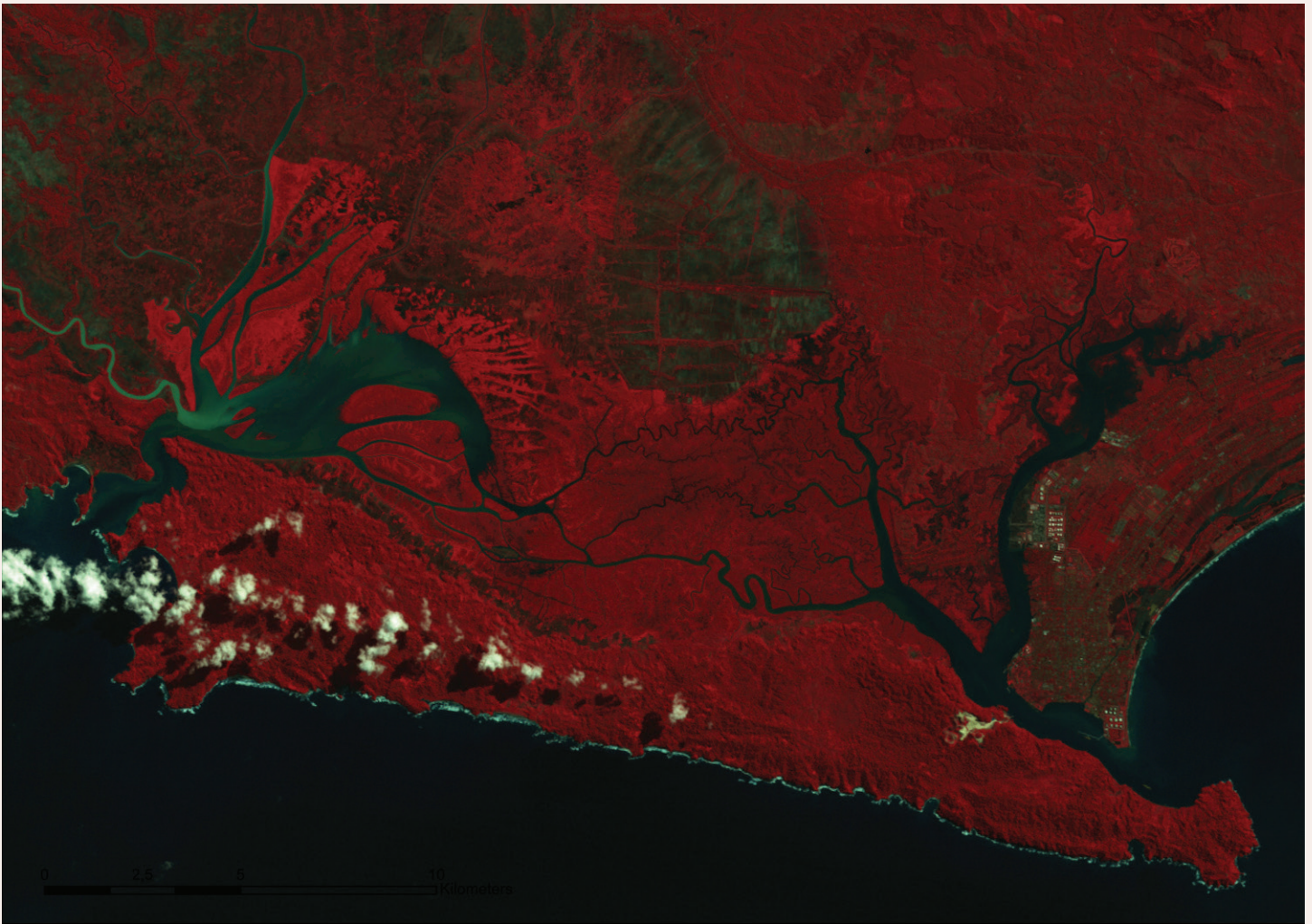


Figure 8. Section of a Landsat image depicting the Segara Anakan lagoon in 1993. Landsat TM, resolution: 30m, date of acquisition: 23.05.1993. Retrieved from BTIC Dataport, Indonesia.

as part of subsequent topographic surveys in 1857–60, 1901–04 and 1924–26 (Figures 5–7). A map series produced by the US Army between 1939 and 1944 did not provide new topographic information, but was based on the previous topographic maps. Following several decades without any update of the cartographic knowledge of this area, a Corona satellite image from 1962 is the next temporal layer of lagoon shoreline information that could be found (available from the US Geological Survey). From the 1970s, Landsat images provide an easily accessible basis for analyzing environmental changes in most parts of the world, including the Segara Anakan lagoon (also available from the USGS). And since the 1980–90s, remotely sensed data from various satellite missions offer analytical possibilities that, with regard to temporal and spatial resolution and accuracy, completely outshine those provided by early topographic maps from the nineteenth

century, not to mention the early manuscript sea charts from the seventeenth and eighteenth century.

A brief glance at the historical cartographic material outlined above unsurprisingly indicates that the reliability of the material continuously declines the further we go back in time. Yet if the temporal scale of our analysis is to cover more than only the past few decades—and to truly understand today’s environmental dynamics often requires looking further back—we need to combine the analysis of satellite images with the analysis of clearly less accurate early topographic maps. An important consideration in this context is the question where the extent of map inaccuracy delimits the temporal scale of a historical cartographic analysis. The next two sections outline the dimensions of map accuracy and present an accuracy analysis of selected historical maps of the Segara Anakan lagoon region.

DIMENSIONS OF MAP ACCURACY

The accuracy of historical maps is affected by factors like topographic knowledge, the methods of surveying, map drawing, and reproduction as well as paper deformation processes, such as shrinking or stretching (Jenny and Hurni 2011). The contribution of each of these factors can often not be determined (Jenny 2006). Following Laxton (1976), Blakemore and Harley (1980), Levin et al. (2006; 2010), and Jenny and Hurni (2011), accuracy assessment can comprise four dimensions: (1) *topographic accuracy*, referring to the quantity and quality of information about landscape features; (2) *chronometric accuracy*, referring to the dating of the map and the information therein; (3) *geodetic accuracy* (or *coordinate grid accuracy*), referring to the positioning of the map in the coordinate system; and (4) *planimetric accuracy* (or *feature or geometric accuracy*), referring to the positions, distances, areas, and angles of features on the map as compared to those in reality.

1. The *topographic accuracy* of the maps of Java's south coast continuously increased over time, with the early manuscript sea charts of the seventeenth and eighteenth century only depicting a few major bays and capes and at best showing a rough outline of (parts of) the Segara Anakan lagoon (see Figure 2), and the topographic maps from 1860, 1901–1904 and 1924–26 depicting shorelines and various other topographic features with increasing completeness (see Figures 5–7).
2. The errors in earlier historical cartographic analyses of the Segara Anakan lagoon caused by ignoring the time gaps between survey dates and the maps' publication dates demonstrate the importance of assessing the *chronometric accuracy* of the material. Dating the information contained in historical maps may require knowledge of mapmakers and mapmaking processes. Access to this information has greatly improved with the digitization and reproduction of archival material in recent years. The surveying and publication dates of the maps depicted in Figures 2–7 are provided in Table 1. Based on this, the shoreline data that were extracted from the maps and that are presented below are consequently dated in line with the year of topographic data collection rather than the year of map publication.

3. Assessing the *geodetic accuracy* of the maps presented is rather problematic, since in most cases no coordinates and gridlines are depicted, and map projections are unknown. This is often the case with historical maps (Jenny and Hurni 2011). Many of the earlier maps of Java from the seventeenth and eighteenth century were not yet based on conformal projections, even though the conformal Mercator projection had been introduced as early as around 1570 (Schilder et al. 2006, 22). Geodetic inaccuracy can lead to errors in the positioning of features. However, such errors are often of minor importance in relation to planimetric inaccuracies (Jenny and Hurni 2011; Locke and Wyckoff 1993). This can be assumed to be particularly true in case of the research presented here, given the small size of the study area, the comparably large scale of the maps and the location close to the equator. The non-existence of any systematic single-directed deviation in the maps presented, as indicated by the displacement vectors, which visualize positional errors after georectification, confirms that potential geodetic inaccuracy is of minor importance.
4. The *planimetric accuracy* can be quantified by comparing the locations of features on historical maps with their "true" locations on more accurate, recent topographic maps, on remotely sensed images, or as measured in the field using GPS (Levin, Kark, and Galilee 2010). By comparing the positions of at least four such locations with the help of tools included in programs such as ArcGIS or MapAnalyst, the Root Mean Square Error (RMSE) can, in the case of negligibly small geodetic inaccuracies, be determined as the median planimetric location error. It can be given in millimeters at map scale or in meters at real world scale. With MapAnalyst, the extent and spatial variation of this error can be visualized in the form of distortion grids or displacement vectors (Jenny 2006; Jenny and Hurni 2011). The planimetric accuracy of historical maps differs greatly depending on the period and the region, but also on the scale of the maps. An example of very early maps with exceptionally high levels of planimetric accuracy are those drawn of the region around Dresden, Germany by M. Öder in the late sixteenth century. With mean planimetric errors of only about 100m at real world scale, they are perhaps the most

accurate maps of their time worldwide (Bönisch 1967). Levin, Kark, and Galilee (2010), to mention one more example out of a larger number of similar studies, determined mean errors between 71m and 780m at real world scale for historical maps of Palestine produced between 1880 and 1946 at scales between 1:20,000 and 1:250,000, and errors at a magnitude of several kilometers for maps produced earlier.

QUANTITATIVE PLANIMETRIC ACCURACY ASSESSMENT

For the maps depicted in Figures 2–7 and the Corona image, median planimetric errors were determined by comparing point locations identified on the historical material against those on recent topographic maps, applying the following steps:

The maps were scanned, if not acquired in digital form. In case of the maps from 1857/60 and 1897/1901, the single map sheets were aligned manually to form one file. In case of the map from 1924/26, the single map sheets were processed separately. Using ArcGIS, the maps were then georectified according to the most recent topographic maps: Peta Rupabumi, 1:25,000, produced by BAKOSURTANAL in 1997–98, based on surveys in 1993–94 (8 map sheets). Georectification, by aligning map features to their real world position, brings the historical maps into coincidence or at least a best geometric fit with recent maps and satellite images within one common coordinate grid system. At the same time it provides the RMSE as a quantitative measure of the original map's accuracy. In line with the recent topographic maps, UTM Zone 49S (WGS 1984) was used as a common coordinate grid system. Georectification requires a minimum of four control points. Depending on the map and its topographic accuracy, between 11 and 31 control points were selected on each of the historical maps and aligned with their actual geographical position by linking them with their equivalent on the recent topographic maps (see Table 1). The considerable magnitude of environmental change, i.e. of sedimentation, river regulations, and settlement development (see Figures 2–8), limited the number and constrained equal distribution of control points, particularly in the northern part of the lagoon and the adjacent land areas. This rendered an assessment of spatial variations in map accuracy, as was done by Levin (2006), unfeasible. Most ground control points were identified based on

topographic features, such as river intersections, bays, and capes (see Figure 5). Based on the control points, 1st, 2nd, and 3rd order polynomial transformations were performed. The resulting RMSE represent the residual error after transformation: the differences between the position of the control points after georectification and their actual geographic location. In addition to small methodological inaccuracies related to scanning resolution, the selection of control points, and possible—but negligible—geodetic inaccuracies, the RMSE in case of the maps analyzed can be assumed to mainly reflect the historical maps' planimetric accuracy.

Table 1 provides an overview of the historical maps analyzed and presents the results of the quantitative accuracy assessment. Not surprisingly, the later the maps were created, the higher their planimetric accuracy.

The earliest maps that were drawn as part of the charting expeditions between 1698 and 1739 are barely accurate enough to be georectified. Their limited topographic accuracy, resulting in a lack of suitable control points, and the collinearity of the few control points that could be identified constrained georectification and the determination of any mean planimetric errors by the means described above. The median error of 1510.5m (1st order polynomial transformation) for Coops' map can therefore not be compared with the results for any other maps. Due to their limited topographic and planimetric accuracy, these early sea charts could not be used for a quantitative analysis of shoreline changes. However, qualitative interpretation of these maps may provide information supporting the exploration of possible longer-term shoreline developments at times prior to the production of the earliest more accurate and quantitatively analyzable maps (see Lukas [forthcoming]).

The considerable difference between the median errors received for J. T. Busscher's map and the *Kaart der Preanger Regentschappen*, both of which were produced within the first two decades of the nineteenth century, demonstrates the usefulness of a quantitative planimetric accuracy assessment. Visual comparison of the two maps (Figures 3 and 4) and their comparison with the Residency map from 1857 (Figure 5) suggest that Busscher mapped the eastern shoreline of the lagoon's open water surface area with a higher level of topographic accuracy than the producers of the *Kaart der Preanger Regentschappen*, which simply depicts the eastern shoreline as a straight line, indicating

Map Title or Description; Surveyor or Editor; Scale	Year of Production / Publication	Year(s) of Topographic Data Collection	Library, Archive, and/or Source of Reproduction	Number of Ground Control Points	Median Error (\approx Median Planimetric Error) at Real World Scale, Per Polynomial Transformation (m)			Suitability for Analysis of Historical Environmental Change
					1 st Order	2 nd Order	3 rd Order	
Manuscript maps of charting expeditions by Cornelius Coops, Albert van Petten, and Paulus Paulusz; map scales between approx. 1:120,000 and 1:500,000	1698, 1711, 1739	1698, 1711, 1739	Netherlands National Archives in The Hague, see Schilder (1981) and Knaap et al. (2007)	8	(1510.5)	728.4	not applicable	For qualitative analysis only
<i>De Baay Segara-Anakkang of de Kinder Zee Met het daarvoor gelegene Eiland Noessa-Kambang, gelegen aan Java's Zuider Zee Strand</i> ; by Jan Theunis Busscher; 1:76,000	1809	1809	Netherlands National Archives in The Hague	11	1460.9	915.0	not applicable	For qualitative analysis only
<i>Kaart der Preanger, Regentschappen en Cawang, gecoppieerd naar die van den Heer Beeftjes door J. T. Bik</i> ; 1:114,000	1817	1813–1815	Netherlands National Archives in The Hague, see Knaap et al. (2007)	11	582.3	297.4	112.0	For qualitative analysis only
<i>Topographische Kaart van de Residentie Banjoemaas</i> (Map Sheets I and II); under the direction of the Kolonel Direktor der Genie W.C. von Schierbrand by the Kapitein der Infanterie W. Beijerink; 1:100,000	1860	1857–1860	KIT; Sächsische Landesbibliothek, Staats- und Universitätsbibliothek Dresden	26	192.0	158.3	127.0	Suitable for quantitative analysis
Topographical map of Java, Residency Banjoemas (Map Sheets III, IV, VII, and VIII); TDNI, Land tax survey brigades; 1:100,000	1901–1904	1897–1901	KIT	31	87.1	60.3	46.0	Suitable for quantitative analysis
Topographical map of Java, Middle (and West), Map Sheets 42/XII D, 43/XII C, 43/XII D, 42/XIII B, 43/XIII A, 43/XII D); TDNI, Land tax revision brigades; 1:50,000	1925–29 (Sheet 42/XIII B: 1942), reprints from 1938–42	1924–1926	KIT	13	51.1	34.5	27.3	Suitable for quantitative analysis

Table 1. Results of an accuracy assessment for selected historical maps of the Segara Anakan lagoon.

a lack of topographic knowledge. However, the result of the quantitative analysis shows that Busscher's map is clearly generally less accurate than the *Kaart der Preanger Regentschappen* (see Table 1), and this is important to consider when using the maps' contents for analysis.

The median errors obtained (see Table 1) are very large as compared to modern maps or satellite images, but they are comparable to the results obtained by other scholars for historical maps. Taking into account the different map scales and years of production, the median errors obtained for the maps produced between 1813/15 and 1924/26 are in a similar order of magnitude as those of the historical maps of Palestine analyzed by Levin et al. (Levin, Kark, and Galilee 2010; Levin 2006), the historical maps of North Carolina analyzed by Lloyd and Gilmartin (1987), and the historical maps of England that Bromberg and Bertness (2005) used to analyze salt marsh losses. In comparison extremely accurate are the Saxon Mile Sheets from 1780–84 for which Walz (2008) achieved a mean spatial accuracy of only 24m, and the nautical chart of the

Adra River delta in southeast Spain from 1855 for which Jabaloy-Sanchez et al. (2010) found an RMSE of 11.5m.

Preparing a systematic overview of the historical maps of an area including related carto-bibliographic information (see Lukas [forthcoming]) and results of an accuracy assessment (Table 1) provides a solid basis for a cartographic analysis of historical environmental change. However, based on this information and the quantitative accuracy measures alone, the question posed at the beginning—*how accurate the cartographic material needs to be at minimum in order to be used for which kind of analysis*—cannot be conclusively answered yet. As was noted by Levin (2006) and as will be demonstrated below, the analytical suitability of historical maps also depends on the magnitude of the environmental changes to be investigated; in other words the maps' reliability depends on both their accuracy and their utilization. Therefore the next section presents the methods and results of the shoreline change analysis carried out, before the following section returns to the question of map accuracy.

RECONSTRUCTING THE LAGOON'S HISTORICAL WATER SURFACE AREA

ANALYSIS OF SHORELINE VARIABILITY and related methodological challenges has been a growing research field in the past two decades (see, for example, Boak and Turner [2005], Crowell, Leatherman, and Buckley [1991], Moore [2000], and Monmonier [2008]). Knowledge of past shoreline changes can be relevant for various contemporary management issues, including ecological, legal, regulatory, and engineering questions. In case of ocean shorelines, the accurate detection of the land-water boundary is constrained by its great fluctuating variability over various time scales, caused by waves, currents, tides, and temporally variable accumulation and erosion processes. Therefore, identification and mapping of contemporary shorelines, let alone their historical reconstruction, remains a methodological challenge.

In the case of the Segara Anakan lagoon, fluctuating variability is largely confined to the influence of tides and is thus less problematic than in case of open ocean shorelines. Yet the fuzzy, barely visible character of the land-water boundary within the mangrove forest areas potentially introduces uncertainty. However, since aggradation has consistently been accompanied by the expansion of mangroves or other vegetation, the most practical and fairly accurate

approach is to define the water surface area of the lagoon as the area that is covered by water at high tide but that is not vegetated. This area is demarcated from the sea by the two tidal channels and comprises the lower reaches of the tributary rivers. It also includes the entire channel network in the eastern part of the lagoon and the areas of the pile villages, which existed within the open water surface area until the first half of the twentieth century and which are depicted in the respective maps (see Figures 4–7).

Based on the quantitative accuracy assessment of the historical maps presented in Table 1 and a qualitative area-specific comparison of these maps, the historical maps from 1857–60, 1897–1901, and 1924/26 were selected as a solid basis for the shoreline change analysis. The quantitative accuracy assessment also suggests including the map from 1813/15. However, qualitative comparison and overlay of this map with the more recent maps indicates its limited accuracy particularly in the areas affected by shoreline changes—areas where the limited topographic accuracy of the map and the environmental changes themselves did not allow for the identification of suitable control points. The unrealistically straight line that represents the eastern shoreline in this map (see Figure 4, compared

with the maps from 1809 and 1857–60, shown in Figures 3 and 5) indicates the mapmakers' limited knowledge of this part of the lagoon and hence low levels of topographic accuracy in this section of the map.

In addition to the historical maps, one section of a Corona Satellite Image, taken in 1962 and scanned with a resolution of 1,800 dpi, was georectified on the basis of the recent topographic maps, using a 2nd order polynomial transformation, with an RMSE of 14.1m. In addition, a number of satellite images taken between 1973 and 2013 (see Table 2) were georectified with negligibly small RMSEs, if not acquired in pre-processed form.

On the basis of the three historical maps (3rd order polynomial transformation) and the satellite images, the historical course of the Segara Anakan lagoon's shorelines was

Type of Data	Date of Acquisition	Spatial Resolution
Corona, FTV-1126, Mission No. 9034	17.05.1962	140m
Landsat MSS	01.08.1973	79m
Landsat MSS	21.06.1983	79m
Landsat TM	23.05.1993	30m
Landsat ETM+	03.03.2013	30m

Table 2. Satellite images used for shoreline reconstruction in combination with the historical maps (The Landsat TM image was acquired from BTIC Dataport, Indonesia; all other images were acquired from USGS).

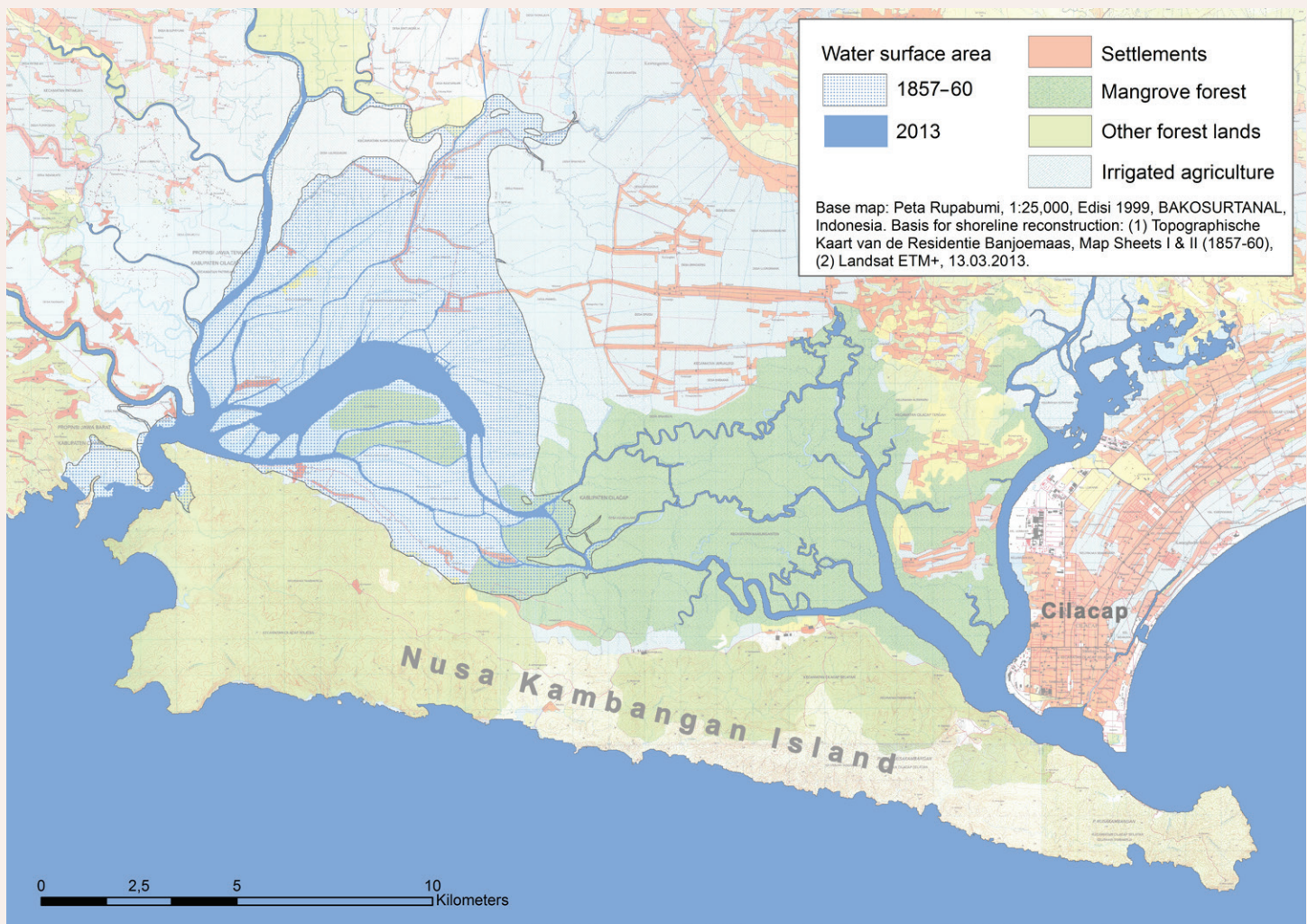


Figure 9. Change in the water surface area of the Segara Anakan lagoon between 1857/60 and 2013. Most of the silted-up area is presently covered by (partly degraded) mangroves and shrubs, (partly abandoned) aquaculture ponds, agricultural fields, and settlements [c.f. Ardli and Wolff [2009]].

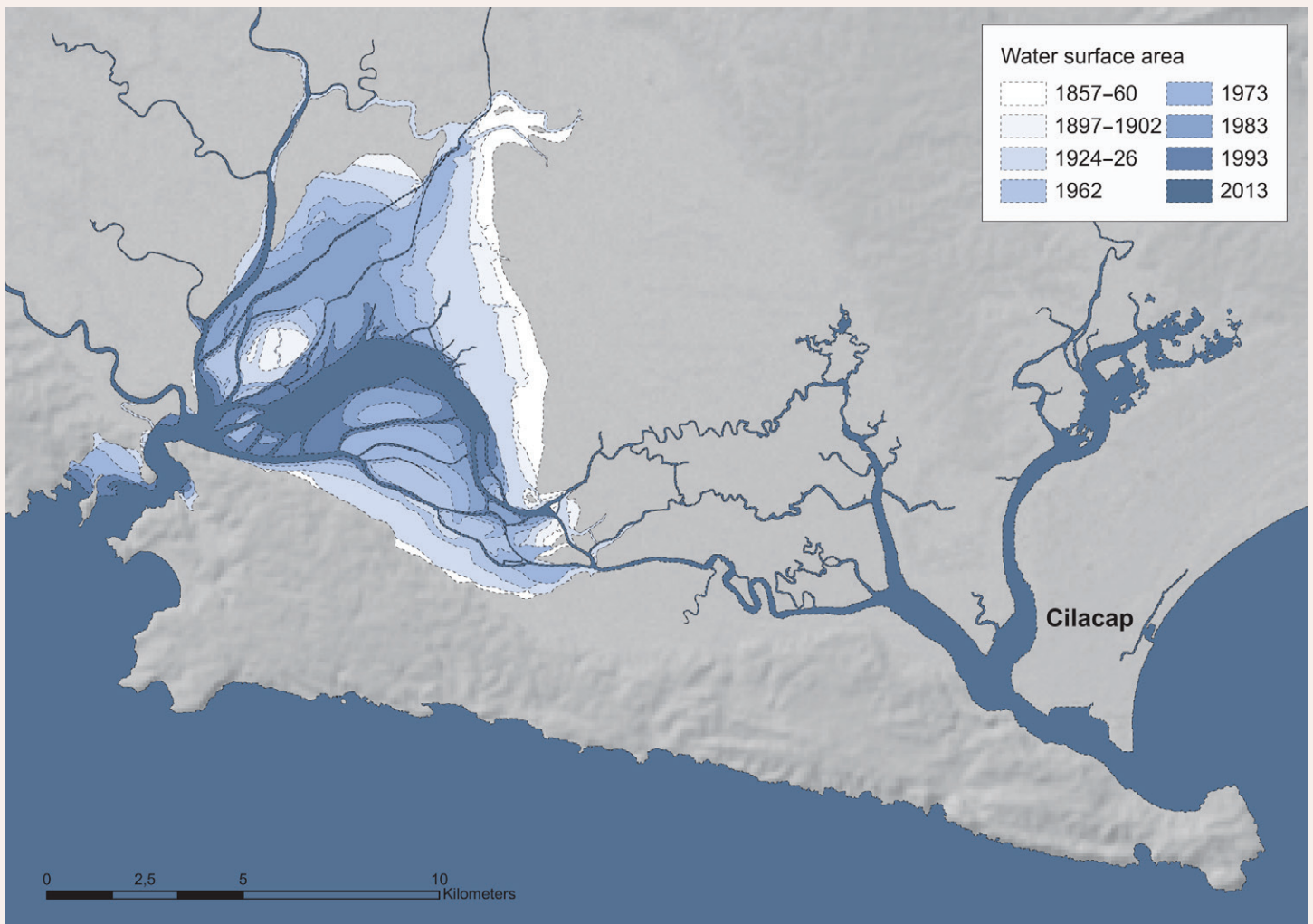


Figure 10. The reconstructed historical lagoon shorelines illustrate the siltation process between 1857/60 and 2013. Base map: SRTM (Shuttle Radar Topography Mission), available from the USGS. Reconstructed shorelines based on maps and satellite images listed in Tables 1 and 2.

manually delineated. Figures 9 and 10 present the results. They depict the dramatic decline in the lagoon’s water surface area, providing a two-dimensional picture of lagoon sedimentation between 1857/60 and 2013. Shoreline aggradation accelerated between 1857/60 and the late 1980s or early 1990s and slowed down thereafter. The latter is partly related to lagoon dredging in the early 2000s (ADB 2006), but might also reflect the possibility of approaching a state where the proportion of riverine sediment input that is *not* deposited in the lagoon but carried out into the ocean increases in line with the shrinking of the water body.

Critically questioning these results, one could argue that it is uncertain whether the makers of the historical maps followed a similar approach in defining the lagoon’s shorelines as has been used in analyzing their maps. Some of

the historical maps indicate that water depths were already fairly low in parts of the lagoon. For example, Busscher’s map from 1809 (Figure 4) delineates deeper channels from the surrounding shallower water areas, using different signatures. It could be argued that the differences in the course of shorelines and in the number and size of islands situated within the lagoon on the various historical maps do not indicate physical changes, but result from different approaches of different mapmakers in delineating shorelines. However, a number of considerations clearly support the conclusion that the major differences between the maps do reflect real physical changes (i.e., aggradation): (1) certain islands, such as those at the south-eastern edge of the open water surface area, were consistently drawn by all map makers with increasing sizes over time; (2) other islands, such as those in the western part of the lagoon, were not depicted on earlier maps but were later

drawn by all mapmakers with increasing sizes over time; (3) the northern and eastern shorelines of the lagoon were over time depicted further and further to the south and west respectively, while the location of other (also vegetated) shoreline sections that were not affected by sedimentation (e.g., within the eastern channel network) did not vary between map makers and over time; and (4) the early spatiotemporal trends observed on the time sequence of historical maps continued during the period covered by remotely sensed data.

However, a major limitation of this historical cartographic analysis of aggradation is its confinement to the water surface area, while changes in water depth remain unknown. An analysis of the latter would require a time series of historical depth soundings with a high spatial resolution,

which does not exist. In addition, changes of the lagoon's water surface area and even of its volume cannot be directly translated into temporal changes of riverine sediment input, since the proportion of sediments that is deposited in the lagoon and not transported out to the ocean must have changed over time. Nevertheless, given the large magnitude of change in aggradation rates, it seems plausible to assume that the historical cartographic reconstruction of the water surface area presented here provides at least a rough picture of the temporal dynamics of riverine sediment input, albeit not with proportionality. In a next step, a time sequence of the various potential drivers of sedimentation or information from sediment core analyses could be combined with the maps of change presented here.

LINKING MAP ACCURACY WITH ENVIRONMENTAL CHANGE RATES

FINALLY, THE RESULTS of the shoreline change analysis presented in Figures 9 and 10 should be linked with the quantitative map accuracy measures. This is part of the necessary critical reflection on the methodological approach used and, at the same time, brings us back to the question posed at the beginning: *how accurate does historical cartographic material need to be at minimum in order to be used for which kind of analysis?* The “required” or “minimum” accuracy level of historical maps for analyzing environmental changes depends considerably on the kind and magnitude of the changes to be analyzed. Table 3 links the median planimetric errors of the historical maps used with the rates of shoreline change detected. It shows that the rates of shoreline change were so extraordinarily high that they clearly exceed the magnitude of potential uncertainty introduced by map inaccuracies and the analytical process.

Ratios between the rates of the environmental changes to be analyzed and planimetric map accuracy may serve as a general quantitative indicator for the analytical suitability of historical maps. The ratio r is determined as follows:

$$r = \frac{s}{\Delta x_{1,2}}$$

where s is the total shoreline change rate during the respective period and $\Delta x_{1,2}$ the median planimetric errors of the respective maps (Map 1, 2) at real world scale.

In the research presented here, the ratios r calculated for the different shoreline sections and maps indicate that the shoreline change rates detected were in almost all cases between 6.5 and 106.4 times higher than the median planimetric errors of the respective maps (see Table 3). Such high ratios between environmental change rates and map inaccuracy clearly indicate the historical maps' suitability for detecting environmental changes with potential errors that are acceptably small for most purposes. In the case of the map from 1857/60 (when overlaid with the map from 1897/1901), the ratios between environmental change rate and median planimetric error of 2.4–6.4, depending on the shoreline section, indicate higher levels of uncertainty, but also show that the changes detected still clearly exceed the levels of potential inaccuracy. When analyzing a time-sequential series of maps to detect spatial changes continuously directed in one single direction (as in the research presented here), comparably low ratios between environmental change rates and map inaccuracy may usually still be acceptable, while analysis of fluctuating environmental changes may require higher levels of planimetric map accuracy.

While the ratios proposed above provide a practical and easy to calculate indicator for the suitability of historical maps for particular analytical purposes, the reliability of the actual results from cartographic analyses may be quantified using combined uncertainty measures. As environmental change rates are usually based on information from

Period	Total Shoreline Change Rate (s in m)		Annual Shoreline Change Rate (s _a in m)		Median Planimetric Error at Real World Scale (in m)		Ratio r Between Rate of Shoreline Change and Median Planimetric Error				Digitization-operator Error		Combined Uncertainty of Shoreline Change Rates (Δy in m)	Combined Uncertainty of Shoreline Change Rates (Δy/s)	
	Northern Shoreline	Eastern Shoreline	Northern shoreline	Eastern shoreline	Map / Image 1 (Δx ₁)	Map / Image 2 (Δx ₂)	Northern Shoreline	Eastern Shoreline	Map / Image 1	Map / Image 2	Map / Image 1 (Δd ₁ in m at real world scale)	Map / Image 2 (Δd ₂ in m at real world scale)			
1857/60–1897/1901	no major change	300–815	n.a.	7.5–20.4	127.0	46.0	n.a.	2.4–6.4	6.5–17.7	n.a.	35.0	35.0	143.9	n.a.	17.7%–48.0%
1897/1901–1924/26	400	300–450	15.4	11.5–17.3	46.0	27.3	8.7	14.7	11.0–16.5	8.7	35.0	17.5	66.3	16.6%	14.7–22.1%
1924/26–1962	500–800	500–1500	13.5–21.6	13.5–40.5	27.3	14.1	18.3–29.3	35.5–65.7	35.5–106.4	18.3–29.3	17.5	37.0	51.2	6.4%–10.2%	3.4%–10.2%
1857/60–2013*	3,200–4,800	n.a.	20.8–31.2	n.a.	127.0	5.6*	25.2–37.8	571.4–857.1	n.a.	n.a.	35.0	8.0	132.1	2.8%–4.1%	n.a.
1897/1901–2013*	3,200–4,400	n.a.	28.1–38.6	n.a.	46.0	5.6*	69.6–95.6	571.4–785.7	n.a.	n.a.	35.0	8.0	58.6	1.3%–1.8%	n.a.

Table 3. Linking the magnitudes of environmental change with map accuracy measures to evaluate the reliability of results.
*For the Landsat ETM+ image (03.03.2013), the total RMSE, based on the GSP residual report by the USGS, has been used.

two different maps or images, their uncertainty Δy can be derived from the respective maps' planimetric errors Δx_1 and Δx_2 , applying the law of propagation of uncertainty:

$$\Delta y = \sqrt{\Delta x_1^2 + \Delta x_2^2}$$

In addition, a digitization-operator error has been incorporated in determining the uncertainty of shoreline change rates (based on Crowell, Leatherman, and Buckley 1991; M.-Muslim, Foody, and Atkinson 2007). In case of the historical maps, digitization and operator errors are estimated at 0.25mm each at map scale (following Crowell, Leatherman, and Buckley [1991]), resulting in a combined digitization-operator error $\Delta d_{1,2}$ of 0.35mm at map scale:

$$\Delta d_{1,2} = \sqrt{0.25mm^2 + 0.25mm^2}$$

Table 3 lists the ground distance equivalent of the digitization-operator error based on the individual map scales. In case of the aerial photographs and satellite images, estimates of the positional accuracy of the shorelines detected are based on M.-Muslim, Foody, and Atkinson (2007), who determined shoreline prediction accuracies depending on the spatial resolution of the satellite images of 3.16–4.25m in case of a resolution of 16m and 5.73–8.67m in case of a resolution of 32m. Based on these results and assuming a near-proportional relationship between resolution and positional accuracies determined, positional accuracies of 8m in case of the Landsat ETM+ image from 2013 (30m spatial resolution) and of 37m in case of the Corona image from 1962 (140m spatial resolution) were used.

Thus, based on the respective maps' planimetric errors Δx_1 and Δx_2 and the respective digitization-operator errors Δd_1 and Δd_2 , the combined uncertainty is determined as follows:

$$\Delta y = \sqrt{\Delta x_1^2 + \Delta x_2^2 + \Delta d_1^2 + \Delta d_2^2}$$

The combined uncertainty measures can be expressed in absolute (Δy) or relative ($\Delta y/s$ as a percentage of the shoreline change rate) terms. As shown in Table 3, the shoreline change rates detected for the period 1857/60–1897/1901 are marked by uncertainties of 17.7–48.0%, depending on the shoreline section, while the shoreline change rates detected for the period 1924/26–1962 are marked by uncertainty levels of only 3.4–10.2%.

The lower two rows of Table 3 clearly illustrate the dependence of the “required” or “minimum” levels of map accuracy on the rates of the environmental changes to be analyzed. When analyzing shoreline change rates for the entire period from 1857/60 to 2013, even the use of the comparably inaccurate map from 1857/60 yields results that are marked by uncertainty levels of only 2.8–4.1%, because the shoreline change rates for this period exceed the map inaccuracy measure by a factor of 25–38.

The number of studies that have directly linked environmental change rates with quantitative map accuracy measures is relatively limited to date. While some cartographers' work is completely devoted to the analysis of map accuracy (e.g., Jenny and Hurni [2011], Jenny [2006], Bönisch [1967], Nell [2009]), other scholars who used historical maps for analyzing environmental changes did partly not link their results with map accuracy measures, though they provided georectification errors (e.g. Khromova et al. [2006], Jabaloy-Sanchez et al. [2010], Bromberg, and Bertness [2005]). A comparison of the georectification errors provided by the authors with the environmental change rates detected shows, in case of the study of salt marsh losses by Bromberg and Bertness (2005), that environmental change rates clearly exceeded potential errors introduced by planimetric map accuracy. In fact, since many of the analyzed salt marshes were completely lost, planimetric map accuracy seems less relevant than topographic accuracy. In case of the study of Jabaloy-Sanchez et al. (2010), who reconstructed coastline changes in the Adra River Delta, the georectification result (RMSE of 11.5m for a map from 1855 and 237.3m for a map from 1873/76) combined with the shoreline change rate they detected for this period (16m per year, thus about 288m in total from 1855 to 1873) yields ratios between environmental change rate and RMSE of 25.0 for the map from 1855, but of only 1.2 for the map from 1873. The latter indicates high uncertainty of results. Also Tanaka et al. (2007), who analyzed coastline changes in the Miyagi and Fukushima Prefectures in Japan, did not link their quantitative map accuracy measures with the coastline changes identified. Their georectification results (RMSE <40m) and their shoreline change rates of about 220–550m between 1801 and 1904, as depicted in a map, yield ratios between environmental change rate and map accuracy measures of at least 5.6–14.1.

The work of Levin (2006) is one of the few studies that directly links map accuracy and environmental change

rates. His dune movement rates of 3.98–6.32m/year and his maximum data resolution error (which in addition to the RMSE comprises a survey, digitization, and feature-boundary error) of 2.96m/year yield a ratio of 1.3–2.1, indicating relatively high levels of uncertainty. Also Salerno et al. (2008) compared environmental change rates with map accuracy. They analyzed surface area variations of glaciers in Nepal, comparing maps from the 1950s and the early 1990s. Linking their areal errors of 0.1 to 3.6km² for individual glaciers with the surface differences of 0.1 to 6.1km² detected for the respective glaciers, the ratios between environmental change rates and analytical accuracy varied between 0.6 and 10.0. That is, in one case ($r = 0.6$) the uncertainty measure exceeded the glacier change rate detected.

The quantitative measures proposed above support the appraisal of the historical maps' suitability for analyzing

environmental changes. Yet, in some cases, and this particularly applies to maps with higher levels of inaccuracy, quantitative measures alone might not be sufficient to assess the maps' suitability for analysis. The example of the *Kaart der Preanger Regentschappen en Crawang* from 1813/15 illustrates this. While the RMSEs obtained for this map are somewhat comparable to those obtained for the map from 1857/60, qualitative comparison and overlay of this map with more recent maps show its comparatively low level of reliability, particularly in areas where the limited topographic accuracy combined with shoreline changes did not allow for the identification of ground control points. Also the contradicting comparison of topographic and planimetric accuracy between the map from 1813/15 and the map by J. T. Busscher from 1809 noted above supports the argument that quantitative accuracy measures should be combined with a qualitative, sometimes area-specific, appraisal of the other dimensions of accuracy.

CONCLUSION

THE CASE OF THE shrinking Segara Anakan lagoon presented in this paper illustrates the large, to date clearly underutilized, potential of the historical cartographic material of Southeast Asia for analyzing spatial-temporal patterns of historical environmental changes. In the case presented, a combined analysis of historical maps and recent satellite images is the most obvious, most feasible, and—in terms of spatial coverage and resolution—also the most complete approach to analyze historical shoreline dynamics. However, the limited availability and accuracy of early historical cartographic material limits the temporal scale of analysis, poses methodological challenges, and introduces uncertainty.

The shoreline change analysis presented demonstrates that the question of how accurate historical cartographic material needs to be at minimum in order to be used for quantitatively reconstructing historical environmental changes considerably depends on the kind and magnitude of the dynamics to be analyzed. On the one hand, large magnitudes of environmental change potentially constrain the accuracy analysis and rectification of historical maps due to the resulting lack of suitable control points. On the other hand, the larger the magnitude of the environmental changes to be analyzed, the higher the levels of planimetric map inaccuracy that are acceptable.

Hence, determining ratios between environmental change rates and median planimetric map accuracy is crucial to assess a map's suitability for quantitative analysis. This should be combined with a qualitative appraisal of the maps, taking into account carto-bibliographic information and the various dimensions of map accuracy. In the case presented here, ratios between environmental change rates and median planimetric errors of mostly between 6.5 and >100 clearly indicate the maps' suitability for quantitative analysis. In case of analyzing continuous, single-directed environmental changes using a time-sequential series of maps, lower ratios between environmental change rates and planimetric map accuracy may be acceptable than in case of fluctuating changes.

Combined uncertainty measures, derived from the planimetric accuracies of the maps or images used and the environmental change rates detected, indicate the reliability of the results from cartographic analyses. In the case presented here, the uncertainty of the shoreline change rates detected for the historical time spans vary between 3 and 48%, depending on the period (i.e. the maps used) and the shoreline section. In the case of large magnitudes of environmental change, the use of even fairly inaccurate historical maps with planimetric accuracy levels of, for example 127m, in combination with recent satellite images, can

provide surprisingly precise environmental change rates, with uncertainty levels of only 1–4%.

Last but not least, the results of the shoreline change analysis—the maps of change presented here—may be

regarded as one milestone towards a better understanding of environmental changes in the Segara Anakan lagoon region and support further inquiry into the long-term dynamics and drivers of lagoon transformation.

ACKNOWLEDGEMENTS

I would like to thank Michael Flitner and Kathleen Schwerdtner Máñez Costa for the discussions which contributed to the initiation of this research; Ferjan Ormeling for his comments regarding the history of mapping in the Segara Anakan region; Manfred Buchroithner for his information and contacts; and Jill Heyde as well as three anonymous reviewers for their feedback on the manuscript. Thanks also go to Elger Heere, John W. Hessler, Vladimiro Valerio, Chris Fleet, Daniel N. Pagano, and all who contributed valuable comments to my questions about map accuracy via the email list MapHist. The research was carried out by the author when he was affiliated with

the Leibniz Center for Tropical Marine Ecology Bremen GmbH (ZMT). It was part of the research programme SPICE II (Science for the Protection of Indonesian Coastal Marine Ecosystems) and funded by the German Federal Ministry of Education and Research (Grant No. 08F0391A). The author was also supported by the Bremen International Graduate School for Marine Sciences (GLOMAR), which is funded by the German Research Foundation (DFG) within the frame of the Excellence Initiative by the German federal and state governments to promote science and research at German universities.

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A Process for Keeping Pace with Evolving Web Mapping Technologies

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The current pace of technological innovation in web mapping offers new opportunities and creates new challenges for web cartographers. The continual development of new technological solutions produces a fundamental tension: the more flexible and expansive web mapping options become, the more difficult it is to maintain fluency in the teaching and application of these technologies. We addressed this tension by completing a three-stage, empirical process for understanding how best to learn and implement contemporary web mapping technologies. To narrow our investigation, we focused upon education at the university level, rather than a professional production environment, and upon open source client-side web mapping technologies, rather than complementary server-side or cloud-based technologies. The process comprised three studies: (1) a competitive analysis study of contemporary web mapping technologies, (2) a needs assessment survey of web map designers/developers regarding past experiences with these technologies, and (3) a diary study charting the implementation of a subset of potentially viable technologies, as identified through the first two studies. The process successfully achieved the practical goal of identifying a candidate set of web mapping technologies for teaching web mapping, and also revealed broader insights into web map design and education generally as well as ways to cope with evolving web mapping technologies.

KEYWORDS: web mapping; UI/UX design; open web standards; interactive cartography; cartographic education; D3; Leaflet; Google Maps API; OpenLayers

INTRODUCTION

THE CURRENT PACE of innovation in web cartography is spectacular, with new releases of or substantial updates to web mapping technologies occurring almost daily (Haklay et al. 2008; Harrower 2008). However, the ever-evolving nature of web mapping technologies results in a fundamental tension for cartographers. On one hand, the increasing flexibility and interoperability of web mapping technologies create new opportunities for cartographers; we can do more now than ever. On the other hand, as technology evolves, so does the solution space from which cartographers can draw; it is growing ever more difficult to establish and maintain one's bearings within this increasingly complex array of technologies. In the following, the term *web mapping technologies* is used broadly to describe

the compilation of APIs, frameworks, libraries, services, etc., that altogether enable the creation and dissemination of web maps (Kraak and Brown 2001; Peterson 2003).

The research reported here is motivated specifically by (at the time of this writing) a broad transition in client-side web mapping away from standalone, proprietary technologies (e.g., Adobe Flash) and towards open technologies that leverage the HTML, CSS, SVG, and XML web standards (the Open Web Platform) and the JavaScript programming language. As a result, professional cartographers have needed to update their skillsets in response to shifting client requests, while educators have needed to rethink their approach to teaching on the Open Web



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Platform. To this end, our research was designed to generate initial insight into the following four questions, ranging from practical questions approaching the current technological landscape to longer-term conceptual questions working towards a deeper understanding of web cartography:

1. What technologies currently are available for web mapping and how do they vary?
2. What are the important characteristics of web maps that should inform the selection of web mapping technologies?
3. How should web mapping be taught in higher education?
4. How can we better cope with continued evolution in web mapping technologies?

To address these research questions, we designed and executed a repeatable process following the discount, convergent approach recommended in the fields of usability engineering and user-centered design (Buttenfield 1999). The process was completed in three stages: (1) an initial competitive analysis study of contemporary web mapping technologies to evaluate said technologies according to

their relative strengths and weaknesses, (2) a needs assessment survey with web map designers and developers to solicit past experiences with and existing opinions of contemporary web mapping technologies, and (3) a diary study charting the design and development of prototype applications implemented with a selected subset of candidate web mapping technologies deemed potentially viable. The process itself was calibrated to address educational and learning objectives for beginning users, rather than all professional web mapping contexts, and to address open source, client-side technologies built on the Open Web Platform, rather than proprietary server-side or cloud-based technologies. However, the three-stage process is offered as a generic approach to keeping pace with evolving web mapping technologies than can be applied in both industry and government contexts, as well as repurposed for other forms of mapping technology.

We proceed with four additional sections. In the following section, we introduce important concepts related to historical and contemporary web cartography. We then describe parameters of each of the studies included in the three-stage process. We report the results of each study in the fourth section. We reflect on the meaning of these results with regards to our four research questions and offer concluding remarks in the fifth and final section.

BACKGROUND

ARGUABLY, WEB MAPPING IS as old as the web itself, a technological innovation that often is dated to 1991, with the public release of the World Wide Web, or 1993, with the launch of the first browser supporting a graphical user interface (Peterson 2008). The actual progression of technological developments required for the web as we know it today has a much longer history coinciding with the history of computing (Leiner et al. 1997; Leiner et al. 2009). The use of the term ‘web’ is intentionally distinct from the terms ‘Internet’ or ‘World Wide Web.’ The *Internet* refers to the series of interconnected computer networks facilitating the transfer of files, while the *World Wide Web (WWW)* refers to the corpus of interconnected documents shared over the Internet in a web browser (Tsou 2011); such a technical characterization of the Internet and WWW solely as a file or document sharing mechanism is commonly described as *Web 1.0*. In contrast, the term *web* is used today to describe the Internet as a platform upon

which otherwise disparate data and services are integrated for customized use (O’Reilly 2007); the characterization of the Internet as a virtual space with activities occurring within it is described as *Web 2.0*.¹

The design and use of web maps has evolved profoundly from the early days of the Internet (for a comprehensive review, see Donohue 2014). Following a Web 1.0 model, early attempts to disseminate maps online primarily were limited to digitally scanned, static maps (Cartwright 2008). Today, web maps commonly are *adaptive* in response to the use and user context (e.g., Reichenbacher 2003; Friedmannová et al. 2006), *interactive* to respond to user requests (e.g., Andrienko and Andrienko 1999; Roth 2013b), *mobile*, indicating the user’s location on the

1. The distinction between Web 1.0 and Web 2.0 is more about how the Internet is used, and not necessarily the technologies needed to support these uses.

map as they move through the depicted area (e.g., Clarke 2004; Meng et al. 2005), *multiscale* to view the world at every geographic location and extent (e.g., Brewer and Buttenfield 2007; Roth et al. 2011), and/or updated in *real time* to respond to geographic events and processes as they unfold (e.g., Boulos and Burden 2007; Goldsberry 2007). The suite of Web 2.0 tools and techniques facilitating design and development of online, dynamic maps collectively are described as *web mapping technologies* and the corpus of geographic information (and associated maps of these information) contributed online through web mapping technologies collectively is described as the *GeoWeb* (Leclerc et al. 2001; Haklay et al. 2008). While there are a growing number of important and timely treatments of the latter topic—particularly with regards to the social and ethical implications of volunteered contributions to the GeoWeb (e.g., Goodchild 2007; Crampton 2009; Elwood 2010; Harvey 2012; Wilson 2012; Sack 2013)—this research treats challenges related to the former: adapting to ever-evolving web mapping technologies.

Contemporary web mapping technologies, and web technologies generally, can be organized into one of three broad categories: (1) *server-side technologies* used to index and query geographic information from a centralized source or, increasingly, distributed sources (e.g., the cloud), (2) *client-side technologies* used to render and manipulate web maps of these geographic information in the user's browser, and (3) *web services* or similar intermediary scripts used to relay information requests between the client and server (Roth et al. 2008). Careful design and development of all three technologies are essential architecturally for an effective web map. When it comes to web mapping, however, we contend that the cartographer may be separated from the GIS technician by an increased contribution to client-side technology, as it is the client implementation that includes design decisions regarding the map representation itself (choices of projection, generalization, symbolization, typography, etc.), the *user interface* (UI) provided for manipulating this map, and the overall *user experience* (UX) achieved with the web map. The following discussion therefore is constrained to client-side technology, given the overall motivation of this research on the transition in client-side technologies (see details below) and this increasingly important role of UI/UX designer for the cartographer. As stated in the introduction, we expect our proposed method to remain useful when applied for evaluation of server-side and cloud-based technologies as well (for a broad review, see Peterson 2014).

Until recently, a tension existed in client-side web mapping between technologies built upon *open web standards*, which can be interpreted natively by web browsers and viewed for reuse and extension, and technologies leveraging browser *plugins*, which require installation of an additional software component into the browser to run a stand-alone executable embedded in the webpage (Hu 2008). Starting with the former, the World Wide Web Consortium (*W3C*: www.w3.org) governs specification of the majority of these web standards, a suite referred to as the *Open Web Platform*. W3C client-side standards commonly leveraged in web mapping include:

- Hypertext Markup Language (*HTML*), providing the structure of a webpage and allowing for the organization, layout, and styling of its content, as well as the interconnection of webpages through hyperlinks.
- Extensible Markup Language (*XML*), a more flexible text-based markup language than HTML typically used as a data format for loading and manipulating information in the browser; proprietary variants of XML include Esri's ArcXML and Google's KML.
- Scalable Vector Graphics (*SVG*), an open variant of XML for defining and rendering vector shapes and text in the browser.
- Cascading Style Sheets (*CSS*), affording separation of content and styling in web design through definition of hierarchical and reusable style rules, which can be defined to account for varying viewing contexts, allowing the webpage design to be responsive to display devices.
- the Document Object Model (*DOM*), a platform-independent specification for creating and manipulating HTML and XML objects within the browser; the DOM enables manipulation of objects in the browser using *JavaScript*², a popular browser programming language used for defining client-side business logic, and the associated JavaScript Object Notation (*JSON*).

2. JavaScript was originally developed by Netscape and continues to be maintained as part of the open source Mozilla project, although is officially trademarked by Oracle. Although not a standard maintained by the W3C, JavaScript typically is considered part of the Open Web Platform.

While the earliest web maps made use of the first-generation versions of these open web standards (Peterson 2008), the use of plugin technologies with compiled scripts for web mapping grew in popularity in the late 1990s and into the early 2000s, in part due to their perceived performance and stability. Notable plugin solutions for web mapping included Tcl/Tk applications (e.g., Dykes 1996; Dykes 1997; MacEachren et al. 1999; Masters and Edsall 2000), enhanced QuickTime videos (e.g., Al-Kodmany 2001; Cammack 2003; Schwertley 2003), and Java applets (e.g., Herzog 2003; Tsou 2004; Hardisty and Robinson 2011). Flash Player was the most popular plugin for web mapping in the mid-to-late 2000s (Muehlenhaus 2013), which ran Shockwave Flash³ (*SWF*) executables produced first from Macromedia's Director (raster) or Flash (vector) authoring environments and later from Adobe's Flash, Flex, or Flash Catalyst authoring environments.⁴ At one point in time, 98% of all personal computing devices had Flash Player installed (Jenny et al. 2008). Web applications, maps or otherwise, relying on plugin client technologies commonly are described as *Rich Internet Applications* (Tsou 2011).

There were several important advantages to browser plugins that justified their popularity for web mapping at this time. First, plugin technologies afforded greater consistency across browsers and across platforms (if a plugin version was available for the platform). Cross-browser and cross-platform compatibility were particularly important during the 'browser wars' of 1990s (Peterson 2005), but remain frustrating aspects of client-side web map development today.⁵ Second, the Shockwave Flash format, and other plugin executables, compiled vector graphics into relatively small binary files, greatly expanding the potential for high-quality, vector-based web mapping at a time when open web standards like SVG were cumbersome to load, render, and manipulate due to bandwidth and hardware limitations (Hu 2008; Lienert et al. 2012). Finally, use of a plugin-based technology typically meant development in a single authoring environment using a single scripting language, allowing for greater ease in learning the web mapping technology and maintaining source code across projects. Comparatively, open web standards are considered to have a steeper learning curve for be-

ginners given the number of markup/scripting languages and file formats used across a single web mapping project (Woodruff 2011). In this regard, Adobe Flash was particularly kind to cartographers, as it allowed for tight integration with Adobe Illustrator and Photoshop (i.e., what cartographers already use: graphic design software) and afforded an inherently visual design environment (i.e., how cartographers already think: visually).

Despite their advantages, use of plugin-based technologies for web mapping waned in the late 2000s in favor of open web standards (Pulsifer et al. 2008), a transition that has been realized fully over the past several years. There were at least three drivers for this wholesale transition. First, the introduction of Google Maps in 2005 pioneered the use of AJAX for web mapping. Asynchronous JavaScript and XML, or *AJAX*, is an approach to using JavaScript and open web standards that allows for client-server communication without requiring a webpage refresh (Garrett 2005; Tsou 2005); such communication required plugin-based technology prior to the advent of AJAX. The use of AJAX in Google Maps and other web map services afforded continuous panning and zooming of map tiles that were pre-processed and loaded on-demand, giving rise to the now ubiquitous *slippy map* (Haklay et al. 2008; Haklay and Weber 2008). While rendering and serving custom tiles was prohibitively expensive until only recently (Peterson 2011), cartographers could create *mash-ups* of their own geographic information and tilesets from Google Maps and other commercial map services using a provided application programming interface (*API*), which exposes a subset of a proprietary map service's functionality for open use (Plewe 2007; Tsou 2011). At the time of this writing, most popular client-side web mapping APIs are provided in the JavaScript language and leverage open web standards.⁶

The second driver towards open web standards was the recent improvement of telecommunications bandwidth and hardware, and the associated increased consumption of maps on mobile devices such as smartphones and tablets, making continuous network connectivity more accessible (Meng et al. 2005). In April 2010, Apple Inc. announced that it would not support the Flash Player plugin on its iPhone and iPad mobile devices, citing increased openness, improvement of web standards, the interconnectedness

3. Later rebranded as 'Small Web Format.'

4. Adobe acquired Macromedia in 2005.

5. In particular, many web clients still rely on older versions of Internet Explorer, which did not comply with many open web standards until version 9.0.

6. Google Maps had separate APIs written for JavaScript and ActionScript, the scripting language used for Flash development. The Google Maps API for Flash was deprecated in 2011.

of reliability/security/performance, improved battery life, support for touchscreens, and the politics surrounding third-party control over app development as reasons for the move towards HTML5 (Jobs 2010). As a result, development of mobile maps using Flash Player waned to the point of extinction (Muehlenhaus 2013) at the same time that a vibrant research and development initiative emerged around responsive web design using the Open Web Platform (Gardner 2011). *Responsive web design* describes an approach to using open web standards that modifies the layout and styling of content according to the display device and user context (Marcotte 2010). Despite relevant work on the topic of adaptive cartography (Reichenbacher 2003), research and practice on *responsive cartographic design* remains in its infancy.

The third driver away from plugin-based technologies was the formation of open source interest groups across the web mapping community, such as the Open Geospatial Consortium (OGC; www.opengeospatial.org) and Open Source Geospatial Foundation (OSGeo; www.osgeo.org/home). The OGC was founded in 1994, just one year after formalization of the W3C, with the mission of promoting standards across the spectrum of geospatial technologies. Notable contributions of the OGC to web mapping include the web mapping services (WMS) and web feature services (WFS) technical specifications, which leverage

the SVG open web standard (Peterson 2012). While the OGC primarily focuses on standardization, OSGeo plays a broader role in the promotion and advancement of open source geospatial data, software, and tools. Among the most important outreach activities of OSGeo is the Free and Open Source Software for Geospatial (FOSS4G; foss4g.org) conference, meeting annually since 2006. Finally, there is an informal community of web map designers and developers—arguably numbering in the thousands if not tens of thousands—contributing to the missions of the OGC and OSGeo through the sharing and maintenance of source code, web map examples, and tutorials. Due in large part to the efforts of this open web mapping community, there are now a multitude of open source web mapping technologies that afford a sophistication in cartographic design previously only possible through use of proprietary plugin technologies (Pulsifer et al. 2008). These open source technologies offer the promise of rapid advancement due to the scale of developer collaboration and their ability to be creatively manipulated to suit specific application needs. Because of their current dynamism and increased relevance of open source on contemporary web map design, we have constrained the following treatment of client-side web mapping to open source technologies, reviewing several proprietary technologies for comparison only.

METHODS

WE DESIGNED AND EXECUTED a three-stage process in order to characterize and push our way into the current landscape of open source web mapping technologies. Design of the process followed the *convergent methods paradigm*, which prescribes administration of multiple, often qualitative methods (Buttenfield 1999). Each study then is conducted in a *discount* manner (e.g., leveraging secondary sources, recruiting only a small number of participants) to ascertain input and feedback quickly (Nielsen 1993). Reliability of the project as a whole is maintained through triangulation of insights generated across the studies.

There is a growing volume of research in the context of user-centered design that follows a discount, convergent approach to include target end users in the design and development of interactive maps and map-based visualizations (e.g., Slocum et al. 2003; Fuhrmann et al. 2005; Robinson et al. 2005). Here, we leverage a discount, convergent

process to understand the experience of web map designers and developers, rather than the ultimate users of these maps. We triangulated insights across three studies in total: (1) a competitive analysis of existing web mapping technologies, (2) a needs assessment survey with web map designers and developers, and (3) a diary study tracking the implementation of the same web map using a candidate subset of technologies identified from the first two studies. The following subsections describe the method design of each of the three studies included in the process.

COMPETITIVE ANALYSIS STUDY

We began the process by completing a competitive analysis of contemporary open source web mapping technologies. A *competitive analysis study* is a systematic, critical comparison of a suite of related tools or technologies based on their relative merits (Nielsen 1992). The competitive

analysis method is appropriate when evaluating new and emerging tools/technologies, in formative stages of evaluation, and in situations when there are a large number of competing technological alternatives. When the tools or technologies are compared according to established theoretical frameworks, a competitive analysis study is effectively a content analysis of secondary sources, common to archival research in social science (Roth et al. 2015). The competitive analysis represented the widest scoping stage in the process, as it assumed little or no existing knowledge of contemporary technologies and sought to characterize the complete solution space for open source web mapping. Even with existing knowledge, however, we recommend completing a new competitive analysis study at the start of each process cycle, given the pace of technological change in web mapping.

We collected the primary webpages (i.e., the secondary sources included in the content analysis) for open source web mapping technologies over a two-week period in the spring of 2012, making use of keyword searches, popular blogs, and social media for webpage collection. In total, thirty-five (n=35) web mapping technologies with some degree of openness were identified for the competitive analysis during this timeframe.⁷ Two project members then independently ‘coded’⁸ the technologies according to the supported *representation* techniques for graphically encoding information and the supported *interaction* techniques for building user interfaces around the representation. Representation techniques included support for different basemaps, vector overlays, and linked graphics/charts, as well as support for common thematic map types (Slocum et al. 2009). Interaction techniques included support of interaction operators, or generic kinds of interactive functionality available for manipulating maps and other visualizations (Roth 2012; Roth 2013a), as well as support for mobile and location-aware web maps. Twenty-seven (n=27) ‘codes’ were used in total between the representation and interaction categories; Table 1 lists and defines the representation and interaction codes used for the competitive analysis.

7. Over a dozen additional technologies have been released since the initial coding in the spring of 2012. In addition, several of the technologies evaluated have undergone significant changes and upgrades, and some have been deprecated.

8. ‘Code’ in this sense refers to a qualitative topic by which each web mapping technology is assessed, rather than in the sense of the ‘source code’ comprising these web mapping technologies that is manipulated and appended by the developer.

We instructed the project team coders to apply codes based solely on the documentation included in the collected webpages (i.e., what the webpage promised of the technology) without experimenting with the technology itself. We also instructed the coders to follow a four point ordinal scale in their coding: (1) supported, (2) known work-around, (3) requires hack, and (4) not possible, with the average score between the coders ultimately used for a reliable comparison across technologies. These coding instructions followed the discount, convergent approach in the process, producing a broad understanding of the solution space in the first stage of the process.

ONLINE NEEDS ASSESSMENT SURVEY

Following the competitive analysis study, we administered an online needs assessment survey with web map designers and developers. We included the survey as the second step in the overall process in order to acquire rapid feedback about technologies collected in the competitive analysis from designers and developers outside of the project team. The online survey acted as a *needs assessment study*, as the purpose of the survey was to elicit past experiences with the collected technologies as well as to identify future or currently unmet web mapping needs (Wiggins and French 1991). We chose the online survey format over interviews or focus groups given the discount, convergent approach to the overall process, enabling rapid feedback from a diverse set of designers/developers in a distributed manner.

Twenty-one (n=21) web map designers and developers participated in the online needs assessment survey in the spring of 2012. Participation was limited to individuals who either develop web maps as part of their work responsibilities or supervise individuals who develop web maps. Table 2 describes the frequency with which the participants used geographic information, made print maps, and developed web maps as part of their daily work.

We divided the survey question protocol into three sections: (1) current use of the web mapping technologies identified in the competitive analysis, (2) important qualities of web mapping technologies we should consider when selecting a technology, and (3) approaches to keeping pace with evolving web mapping technologies. The non-biographical portion of the survey included 12 questions in total, with four categories of Likert scale questions (each category including multiple Likert scales) and eight free

REPRESENTATION		
1	Map vs. Imagery	load different basemap tiles, such as road map, satellite imagery, etc.
2	Basemap Styling	adjust the styling of the basemap
3	Tile Rendering	generate and serve custom maps as tiles
4	Vector Overlays	draw and overlay additional vectors, including points, lines, and polygons
5	Choropleth	generate a choropleth map
6	Proportional Symbol	generate a proportional symbol map
7	Dot Density	generate a dot density map
8	Isoline/Surface	generate an isoline or surface map
9	Flow	generate a flow map
10	Cartogram	generate a cartogram
11	Bivariate/Multivariate	depict two or more statistical variables on the map
12	Animation	animate the map over a time series
13	Graphics/Charts	add additional information graphics or charts to the map
INTERACTION		
1	Arrange/Linked Views	manipulate the layout of the map and linked views
2	Reexpress	change the displayed map type
3	Sequence	generate an ordered set of related maps or change the map from the sequence that is shown
4	Resymbolize	change the design parameters of a map without changing the map type
5	Overlay/Toggle	adjust the feature types included in the map
6	Reproject	change the map projection
7	Pan	change the geographic center of the map
8	Zoom	change the scale or resolution of the map
9	Filter	alter the map to remove map features that do not meet one or a set of user-defined conditions/constraints
10	Search	alter the map to add/indicate a particular location or map feature of interest
11	Retrieve	request specific details about a map feature of interest
12	Calculate	derive new information about a map feature of interest
13	Mobile Support	support for viewing and interacting with the map on a mobile device
14	Location Aware	support for collecting and mapping information about the user's location

Table 1. The representation and interaction codes used to compare the collected suite of open web mapping technologies.

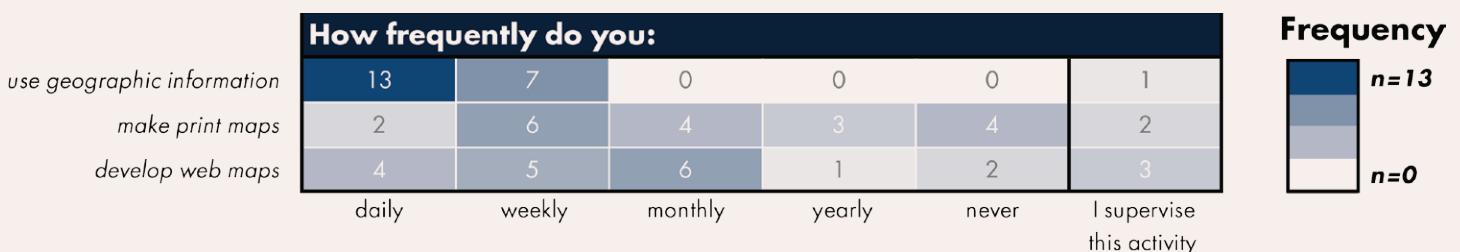


Table 2. The frequency with which participants in the online needs-assessment survey use geographic information, make print maps, and develop web maps as part of their daily work.

response. We designed the online needs assessment survey to take no longer than 15 minutes to complete.

DIARY STUDY

We combined insights from the competitive analysis study and online needs assessment survey to identify a final

subset of four candidate technologies that we suspected could meet the needs of a contemporary curriculum in web cartography. We then evaluated the four candidate technologies using a *diary study*, a variation of participant observation that requires participants to ‘self-observe’ as they complete an activity (Marsh and Haklay 2010). In the diary study, participants developed a case study web

map using one of the four candidate technologies and recorded their progress in an online journal. We selected a diary study for the third step in the process because it provided the deep development experience with a given technology needed to properly assess its advantages and limitations, but did so in a convergent, discount manner by relying on prior methods to reduce the total number of technologies under consideration. As described in the next section, we selected D3, the Google Maps API, Leaflet, and OpenLayers for inclusion in the diary study.

Four students representative of the targeted user group were recruited to complete an example web mapping scenario during the summer of 2012, each using a different candidate technology. A fifth student completed the same web mapping scenario with all four technologies to improve reliability across participants. As a result, there were eight (n=8) diaries total, two for each of the candidate technologies. We did not allow participants to integrate multiple technologies into their web map solutions, nor allow collaboration across participants, in order to identify the limitations of each technology in isolation. While the limitation on group work unrealistically constrains an important aspect of classroom learning, it was further justified by our interest in generating insight across the four research questions enumerated above, rather than focusing solely on the third research question (understanding how students best learn a new web mapping technology). All participants had taken one introductory course on cartographic design and one advanced course on web mapping, and thus were familiar with the requirements included in the web mapping scenario from a conceptual statement. Participants were required to complete lynda.com's video tutorials on HTML, CSS, and JavaScript before beginning the diary session, resulting in a one day engagement with the Open Web Platform before introduction to the assigned web mapping technology. No further training on the assigned web mapping technology was given, allowing us to identify important web resources (e.g., documentation, examples, forums, etc.) for each candidate technology, and to learn how beginners integrate such learning materials into their design and development workflows.

At the start of the diary study, we introduced participants to a web mapping scenario, presented as a hypothetical client request for a web map depicting energy consumption by country over the past 30 years and included a requirements document outlining the project scope. We provided the energy time series dataset to the participants as a CSV

file. As with the competitive analysis, requirements for the web mapping scenario were split between representation and interaction techniques. Representation requirements covered elements of effective design for classed choropleth and graduated symbol maps, including traditional cartographic design topics such as aesthetics, classification, typography, and visual hierarchy as well as emerging cartographic design topics enabled by digital media, such as animation, linked information graphics, and visual storytelling. The specific representation requirements included in the diary study deviated from the representation codes included in the competitive analysis due to the narrowed focus upon only two thematic map types. Interaction requirements were specific to the interaction operators included in the competitive analysis, and included one additional requirement for interface design aesthetics. Twenty-four (n=24) requirements in total were included in the web mapping scenario; Table 3 lists and defines the representation and interaction requirements used for the diary study.

We gave participants a total of 40 hours of development time to complete as many of the twenty-four requirements as possible, mimicking constraints of a standard work week. Given the lack of familiarity with the assigned technology, we did not expect participants to implement all requirements within the provided time period and instead instructed participants to implement what they considered to be 'easy' requirements before moving onto more difficult ones. Therefore, the requirements that ultimately were implemented by the participants indicate functionality that likely is natively supported by the technology, rather than functionality needing a work-around or hack.

We required participants to log a diary entry every hour across the 40-hour period. Within each diary entry, participants were asked to describe: (1) the requirement(s) they implemented in the past hour, (2) key frustrations or breakthroughs in the past hour, and (3) their current satisfaction with the web mapping technology drawing from a provided list of 125 emotions, derived from the list of moods available at github.com/hazbo/mood-swing2. Regarding the latter, we selected the larger list of moods—rather than more terse taxonomies of affective or emotional experiences (e.g., Plutchik 1980; Feldman-Barrett and Russell 1998)—to give participants greater flexibility and precision in describing their emotional state; the moods were coded according to their valence (positive, neutral, and negative) for subsequent analysis. It is

REPRESENTATION		
1	Classed Choropleth	generate a classed choropleth map
2	Graduated Symbol	generate a graduated symbol map
3	Animation	animate the map over the included time series
4	Typography	label map features following typographic conventions
5	Classification	use an equal interval classification scheme for both maps
6	Legend	dynamically redraw a map legend to match the displayed map type
7	Highlighting	include a highlighted variant of each map feature to indicate selection
8	Information Graphic	include a line graph showing the signature of the selected country in comparison to the United States and the median value for the year
9	Visual Hierarchy	style the basemap to produce a strong visual hierarchy
10	Storytelling	provide a title and supplementary text to introduce the map subject and purpose
11	Cartographic Design Aesthetics	customize the look and feel of the map itself to fit the scenario
INTERACTION		
1	Reexpress	change the displayed map type between classed choropleth and graduated symbol
2	Sequence	include standard VCR controls (play, stop, step, back) to control the animation
3	Resymbolize	change the number of classes used for the classed choropleth or graduate symbol map
4	Overlay/Toggle	toggle between a road map and aerial image for the basemap
5	Reproject	set the map projection to equal area for the classed choropleth map and conformal for the graduated symbol map
6	Pan	change the geographic center of the map
7	Zoom	change the scale and/or resolution of the map
8	Filter	filter the map according to the attribute range using a two-thumb slider
9	Search	search for a specific country
10	Retrieve	highlight a probed map feature and activate an associated information window with details about the feature
11	Calculate	dynamically calculate deviation of the map feature from median (i.e., percentile)
12	Link	coordinate retrieve on the map with the line graph to show the selected feature on both graphics
13	Interface Design Aesthetics	customize the look and feel of the interface to the map to fit the scenario

Table 3. *The representation and interaction requirements of the diary study.*

important to note that insight from the field of curriculum and instructional design suggests that students learn best when pushed towards the point of frustration, but without reaching this point (Bampton 2011). Thus, an

overwhelming positive valence may not reflect an optimal learning experience; however, an overwhelming negative valence likely does indicate a suboptimal learning experience.

RESULTS

COMPETITIVE ANALYSIS STUDY

RESULTS OF THE COMPETITIVE ANALYSIS study are illustrated in Table 4. In the matrix, the darkest blue shading indicates a representation or interaction technique that was coded as ‘supported’ by both coders and the white shading indicates a technique that was coded as ‘not possible’ by both coders.

When interpreted horizontally, the matrix summarizes the supported functionality for each of the 35 reviewed web mapping technologies. The competitive analysis revealed a basic distinction between specialist web mapping technologies designed to support a small subset of specific functions (e.g., Cloudmade Editor, Mapnik, Modest Maps) and multi-purpose web mapping technologies designed

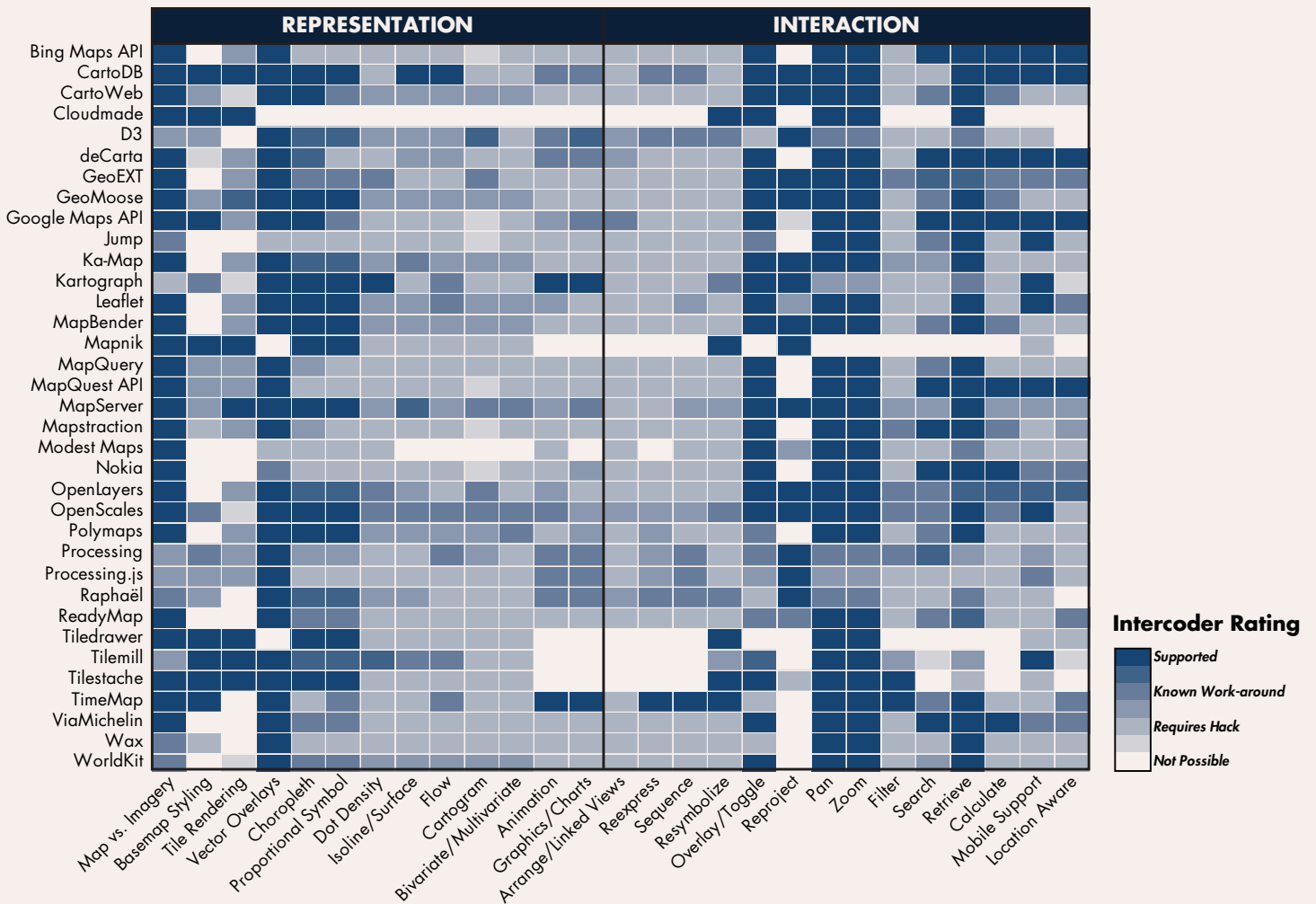


Table 4. Results of the competitive analysis study. Collection and coding was completed in the spring of 2012; therefore, the matrix is no longer complete nor accurate, although arguably it never can be, given the speed of technological advancements in web mapping. The matrix does provide a snapshot in time of web mapping technology that is useful for understanding general patterns and emerging trends in web map design.

to support numerous functions (e.g., CartoDB, D3, the Google Maps API, Leaflet, MapServer, OpenLayers/OpenScales). Individual technologies generally fell into one of the following categories: (1) *frameworks* (10/35; 28.6%) providing a full stack of client- and server-side technologies (e.g., GeoMoose, MapServer, Processing), (2) *open libraries* (14/35; 40.0%) supporting client-side map rendering (e.g., D3, Leaflet, OpenLayers), (3) *closed APIs* (6/35; 17.1%) exposing a subset of functionality for creation of web map mashups (e.g., the Bing Maps API, the Google Maps API, the MapQuest API), and (4) *tile rendering services* (5/35; 14.3%) facilitating the rendering and serving of basemap tiles (e.g., Cloudmade Editor, TileMill, TileStache). The large majority of the reviewed technologies (28/35; 80.0%) leveraged JavaScript as the base programming language, with four (4/35; 11.4%) exclusively leveraging CSS or the CartoCSS variant used for

tile rendering, one (1/35; 2.9%) leveraging Java, one (1/35; 2.9%) leveraging PHP, and one (1/35; 2.9%) leveraging ActionScript.

From the competitive analysis by technology, we identified open libraries implemented in JavaScript as the most suitable technological form for teaching web mapping in the context of higher education. Open libraries can be combined flexibly with other non-mapping JavaScript libraries (e.g., jQuery) and can be extended more easily to implement non-natively supported representation and interaction functionality, two advantages that open libraries hold over closed APIs. Full stack frameworks, while more powerful and feature-complete than open libraries, are less approachable for a single, semester-long course and require background on server-side databases outside the scope of a course on interactive cartography and geovisualization.

We instead recommend instruction of frameworks that integrate client- and server-side technologies in an advanced course on geocomputing and web GIS, taken towards the end of a program in cartography and GIS after students have been exposed to foundational concepts and skills. Finally, the opportunity to teach and practice interaction design is limited with tile rendering services in comparison to the other forms of technologies. As an auxiliary outcome of the competitive analysis, we now teach the TileMill tile rendering service as a laboratory exercise in an advanced graphic design course in cartography, rather than our course on interactive and web-based mapping. It is important to note that our decision to prioritize open libraries was specific to our emphasis on education rather than production, and should not be interpreted as a statement of superiority of open libraries over other forms of web mapping technology.

When interpreted vertically, Table 4 provided us with a snapshot of trends in contemporary web map design. Widely supported representation functionality included custom vector overlays (29/35 supported; 82.9%), loading of map versus imagery basemaps (26/35; 74.3%), and choropleth (19/35; 54.3%) or proportional symbol (16/35; 45.7%) thematic maps. Overall, the competitive analysis suggested a general focus on reference mapping over thematic mapping in existing web map technologies, as most of the reviewed technologies required an advanced, custom solution to implement advanced thematic map types beyond the choropleth and proportional symbol techniques. The lack of support for advanced thematic mapping is a real and significant gap between contemporary web mapping practice and traditional cartographic scholarship that should be addressed as web design and cartographic design continue to collide. Basemap styling and tile rendering exhibited the greatest variation in support across technologies; both were supported by eight (8/35; 22.9%) technologies, but not possible in thirteen (13/35; 37.1%) technologies. This variation was explained by inclusion of tile rendering services in the competitive analysis, rather than restriction to frameworks, libraries, and APIs.

Widely supported interaction functionality included panning (29/35; 82.9%), zooming (29/35; 82.9%), retrieval of details using an information window (25/35; 71.4%), and overlay of context layers (24/35; 68.6%). Arguably, these four interaction operators (overlay, pan, retrieve, zoom) along with a multiscale reference basemap have coalesced to define the prototypical web map, an extension

to the combination of panning and zooming explicit in the colloquial use of ‘slippy map.’ Tracking the evolution of the prototypical web map is useful for cartographers, as it exposes the expectations of non-specialist web map users and reveals potential gaps in contemporary design solutions due to technology constraints. Such gaps included support for reexpress (not supported natively by any technology; 0.0%), filter (2/35; 5.7%), and calculate (8/35; 22.9%). Reexpress and filter are considered important for exploratory visualization, while calculate is essential for advanced WebGIS. Dynamic reprojection exhibited the greatest variation across technologies, which was supported by sixteen (16/35; 45.7%) technologies but not possible in fifteen (15/35; 42.9%). Many of the technologies supporting reprojection were limited to a small set of cylindrical projections, further defining the prototypical web map as a reference map served as raster tiles. Finally, eleven (11/35; 31.4%) of the technologies natively included responsive mobile support, but only six (6/35; 17.1%) were location aware. Such a finding suggested that cartographic design for mobile has garnered some attention in client-side web map design, but the implementation of location-based services using the Open Web Platform has been limited to date.

ONLINE NEEDS ASSESSMENT SURVEY

As described in the third section, we organized the online needs assessment survey around three topics related to web mapping. The first section of questions addressed existing use of the web mapping technologies that we collected through the competitive analysis. Table 5 presents the frequency that survey participants were aware of or had used the collected set of web mapping technologies. We listed three proprietary technologies in this section of the online needs assessment survey—ArcServer, Adobe Flash, and Adobe Flex—as a baseline against which to compare the collected set of open source web mapping technologies, resulting in evaluation of 38 technologies in total.

Survey participants had used just a subset of the collected technologies. Only the Google Maps API was used by a majority of participants in the past year (11/21; 52.4%), with OpenLayers (9/21; 42.9%), ArcGIS Server (8/21; 38.1%), and Adobe Flash (6/21; 28.6%) used in the past year by a large minority. There were several technologies that numerous participants were aware existed, but had never used themselves, most notably the MapQuest (17/21; 81.0%) and Bing Maps (15/21; 71.4%) APIs, the

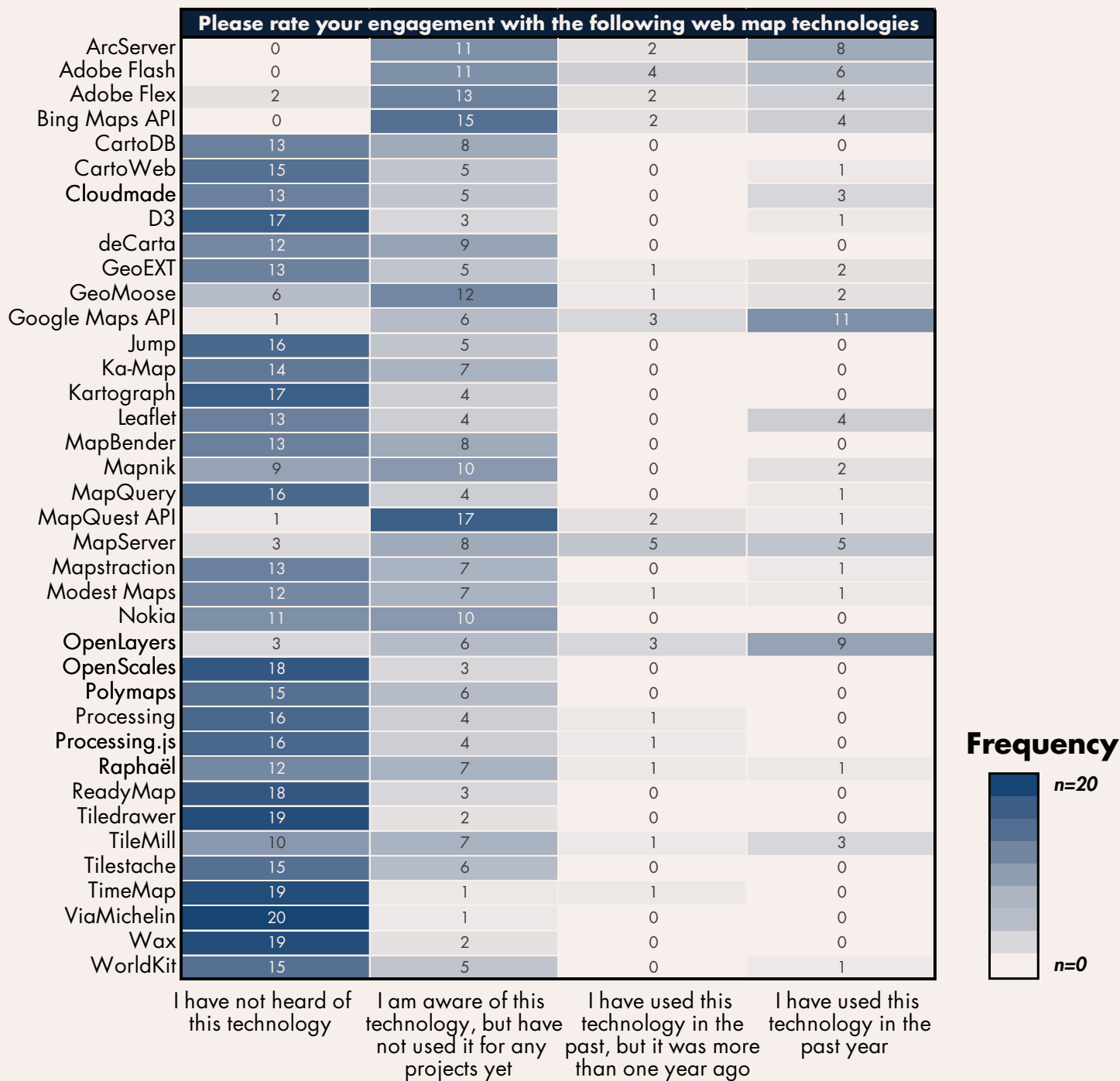


Table 5. The level of engagement with the set of web mapping technologies gathered through the competitive analysis study. The proprietary technologies ArcServer, Adobe Flash, and Adobe Flex are added to the top of the table to provide a comparison against open-source technologies.

GeoMoose framework (12/21; 57.1%), and the ArcServer (11/21; 52.4%), Adobe Flash (11/21; 52.4%), and Adobe Flex (13/21; 62.0%) proprietary technologies. Overall, participants had not heard of the majority of the surveyed technologies, including technologies that have gained in popularity across the cartographic community since administering the survey, such as D3 (17/21; 81.0%),

Processing/Processing.js (16/21; 76.2%), CartoDB (13/21; 62.0%), and Leaflet (13/21; 62.0%). Such a shift in awareness signals the fast pace of technological change in web mapping. This finding also justified our pairing of the competitive analysis study with the online needs assessment study, as reliance on an internal survey alone would have limited discussion to a small subset of available

technologies (e.g., the Google Maps API, Open Layers, ArcServer) not fully representative of the trajectory of web mapping at the time.

Open-ended comments regarding the technologies that participants continued to leverage versus those they completely abandoned revealed broad awareness of the technology transition in web mapping underway at the time. Overall, participants acknowledged the move towards the Open Web Platform and JavaScript, with one participant stating, “In testing technologies for next generation of web apps, we’re quickly moving toward primarily JavaScript-based frameworks” and a second adding, “I am going to transition to JavaScript.” This discussion provided further justification for narrowing our focus to JavaScript-based technologies implemented on the Open Web Platform. Looking towards the future, several participants predicted a move away from closed APIs and towards full-stack frameworks or client-side mapping libraries. Following such sentiment, one participant indicated that his or her institution does not “employ programs like Bing and Google Maps API unless students are working on navigational aids,” and a second stated, “I suspect the Google Maps API is on its way out.” A third participant gave justification for the move away from closed APIs, stating that the “advancement of many of these libraries/frameworks [provides] highly-customizable standard mapping interface components and interaction behaviors.” Thus, responses to the first section of questioning revealed a general preference for openness and extensibility, but an overall poor awareness of the emerging frameworks and libraries that could be used in place of closed APIs and proprietary technologies.

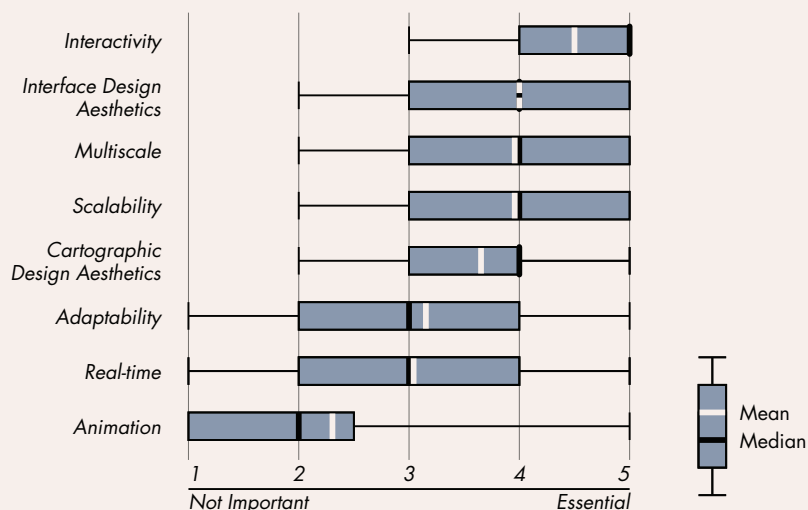
The second section of questions solicited feedback about the qualities of web mapping technologies that should be considered when selecting an appropriate technology or set of technologies. Figure 1 presents a series of box plots depicting participant responses to a series of five-point Likert ratings ranging from ‘not important’ to ‘essential.’ The box plots are organized according to three qualities of web mapping technologies: (1) design characteristics of the resulting web map, (2) technical considerations, emphasizing constraints in applying the technology associated with hardware or software, and (3) practical considerations, including other non-functional constraints when applying the technology.

Participants rated interactivity as the most essential characteristic of web maps that should be supported by a web mapping technology (mean=4.50; median=5), with no participant rating interactivity lower than a ‘3’ (‘important’). Such a finding justified inclusion of both representation and interaction functionality in the competitive analysis coding (Table 4), and reflected the growing importance of UI and UX design to web mapping specifically, and the discipline of cartography broadly. Participants also listed interface design aesthetics (mean=4.00; median=4), multiscale (mean=3.95; median=4), and scalability (mean=3.95; median=4) as important aspects of web map design that must be supported in the underlying technology. Participants rated animation as the least essential property of web maps to consider when selecting a technology (mean=2.30; median=2), a surprising finding given the substantial body of research on animation in the cartographic literature. Overall, Likert scale ratings on web map characteristics suggested an increase in importance on user-driven display changes (i.e., interactivity) and a decrease in importance on system-driven display changes (i.e., animation and real-time updates) in contemporary web map design.

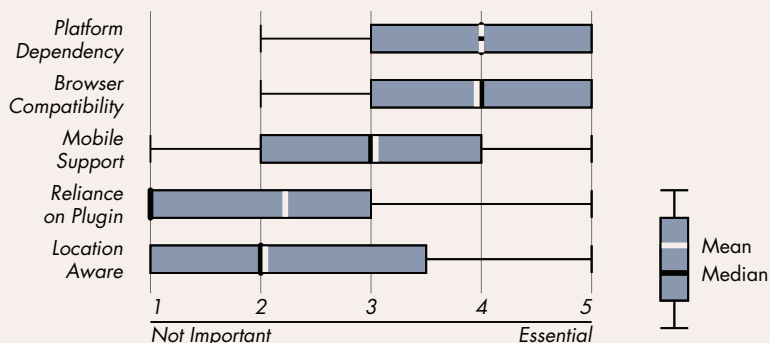
Participants rated platform dependency as the most important technical consideration for web mapping (mean=4.00; median=4), directly followed by browser compatibility (mean=3.95; median=4). As reviewed above, cross-browser and cross-platform compatibility were major advantages to using plugin-based technologies for web mapping through the mid-2000s, and the sharp decline in cross-platform compatibility, specifically mobile support, was an important driver away from plugins like Flash Player in the early 2010s. Participant responses regarding technical considerations indicated that cross-browser and cross-platform compatibility remain a high priority in web mapping, and provides further justification for leveraging frameworks and libraries that can be used in combination with other open libraries that enable cross-browser and cross-platform compatibility. Location awareness was rated as the least important technical consideration (mean=2.05; median=2), providing further evidence that implementation of in-browser, location-based services was not common at the time of conducting the survey.

Finally, participants rated maintenance/stability as the most important practical consideration when selecting a web mapping technology (mean=4.05; median=4). Poor long-term maintenance and source code instability

A. Please rate the importance of the following characteristics of web maps:



B. Please rate the importance of the following technical considerations:



C. Please rate the importance of the following practical considerations:

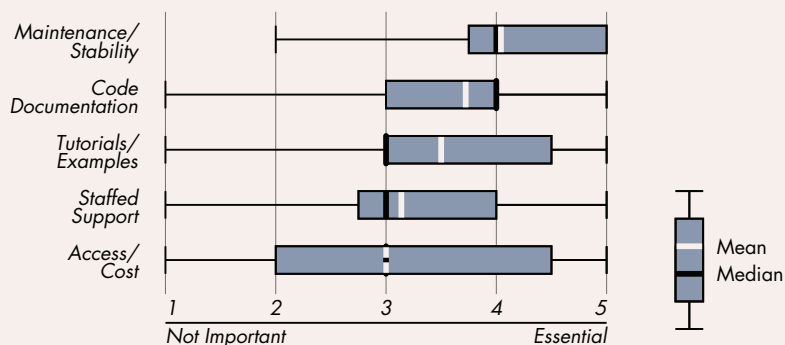


Figure 1. The importance of different qualities of web mapping technologies when choosing an appropriate technology or set of technologies: (A) web map characteristics, (B) technical considerations, and (C) practical considerations. The qualities are listed vertically in the order of descending mean value.

historically have been criticisms of open source technologies, but are improving as the open source web mapping community strengthens and matures, adding clout to the enforcement of open web standards. High quality code documentation (mean=3.70; median=4) and tutorials/

examples (mean=3.50; median=3) also were listed as important practical considerations, both of which aid in learning a new technology as well as keeping one’s skills up-to-date as the technology evolves.

Opinion was split across surveyed participants regarding the value of open source technology. Access/cost was rated as the least important practical consideration (mean=3.00; median=3), a finding that contrasts with the above participant comments about transitioning to open source frameworks and libraries. Responses to the access/cost Likert scale revealed a divergence in opinion regarding open source web mapping technology, with nine (9/21; 42.9%) participants listing access/cost as ‘not important’ or only ‘somewhat important’ and eight (8/21; 38.1%) participants listing access/cost as ‘very important’ or ‘essential.’ One participant shed light on this bimodal distribution in an open-ended response, stating, “I personally think open source is a great ideal... but not as important as people make it sound.” This participant went on to state that “there are many good open source products...there are many good closed products too. I will use whatever software is most user-friendly and easily adaptable. I don’t care if it is open or closed.” A second participant stated, “Increasingly it is a blurry line between commercial, open source, [and] cloud-based options and hybrid applications utilizing all of these are a growing trend.” Therefore, it is important to remember that good

design matters more than novel tools, and that a robust cartography curriculum should introduce students to a representative portfolio of industry-standard technologies, open and proprietary. Because of this feedback, we decided to include one closed-API in the diary study to enable consideration across different degrees of openness.

The third and final set of questions in the online needs assessment survey solicited approaches used by the participants to keep pace with evolving web mapping technologies. The most common strategy listed for experimenting with new web mapping technologies was the completion of a pilot study or proof-of-concept prototype (6 participants), followed by working through posted examples and tutorials (3), reading other developers' experiences on forums and web blogs (2), and directly reviewing the available documentation (2). In particular, completion of a pilot study falls in line with the process we describe in this paper, as the process represents a structured, repeatable approach to prototyping. Participants indicated that before they are willing to experiment with a technology, they need details about its cost (3 participants), documentation (3), examples and tutorials (3), server requirements (3), development environment (3), functional capabilities (2), base programming language (2), security (1), stability (1), and supported data formats (1).

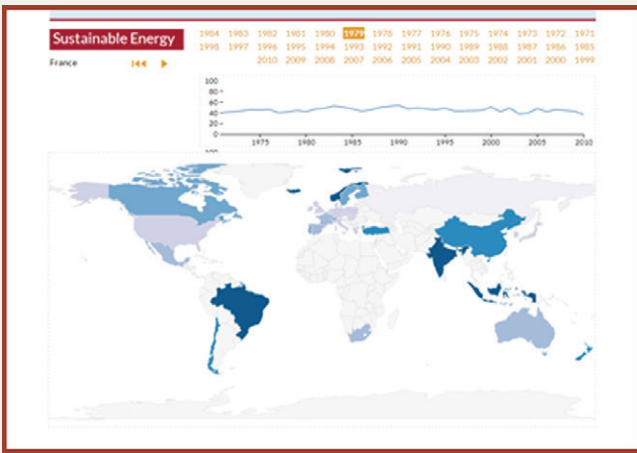
Several participants (3/21; 14.3%) indicated they rarely experiment with new technologies, with one participant stating "experimentation does not occur too much unless someone requests the change" and a second stating "we know what we know and use it and tweak it to the utmost...we only really evolve if we learn of a new software or plugin that fits with our current ecosystem." A third participant indicated that experimentation is limited because "resources [are] committed to existing projects...and [we] don't usually pick technologies on a project-by-project basis," and went on to say that too much experimentation may lead the team to "become novices in many technologies instead of proficient in a few." Therefore, constraints on resources and time may lead to path dependencies, with a program or firm leveraging the same web mapping technology long beyond its functional viability. Again, these comments fall in line with our recommended process for running a pilot study, as the discount, convergent approach enables effective use of resources and time. Additional barriers to learning new web mapping technologies listed by participants included poor or incomplete code documentation (4 participants), poor or incomplete examples

and tutorials (4), difficulty in knowing where or how to get started (2), limited awareness of available technologies (1), difficulty in working across a stack of technologies (1), and the prerequisite of learning a new programming language, such as JavaScript (1).

DIARY STUDY

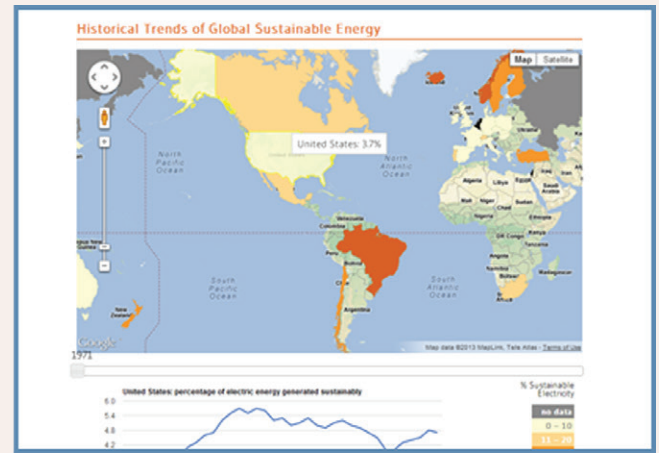
Insights from the competitive analysis and needs assessment were triangulated to identify four candidate technologies for inclusion in the diary study. As described above, we placed an emphasis on open libraries implemented in JavaScript, given the needs of a contemporary curriculum in web cartography, yet maintained one closed API for comparison.

- *The Google Maps API* is a JavaScript API made available by Google for the creation of slippy map mashups. As reviewed above, the AJAX-based Google Maps, and its subsequent API release, was an important innovation in web mapping, giving rise to the multiscale, slippy map mashup. We selected the Google Maps API (Version 3.0) because it was the most robust in terms of supported functionality across the closed APIs reviewed in the competitive analysis study (Table 4) and was the most commonly used technology (11/21; 52.4%) by participants in the online needs assessment study. The source code of the Google Maps API is closed and therefore not available for modification or compiling on non-Google web servers, foreclosing possibilities of customization beyond methods afforded by the API itself. Further, the Google Maps API has several usage restrictions, including a maximum number of website visits before Google charges for use of its service and a requirement that web maps using the API must be freely and publicly accessible. The Google Maps API therefore served as a baseline in the diary study against which to compare the open libraries without usage restrictions.
- *OpenLayers* is an open library based in JavaScript supported by the OSGeo community. We selected OpenLayers (Version 2.12) for the diary study because it was the most robust in terms of supported functionality across the reviewed open libraries (Table 4) and was the most frequently used open library (9/21; 42.9%) by participants in the needs assessment survey, and second most frequently used technology



D3

Leaflet



Google Maps API

OpenLayers

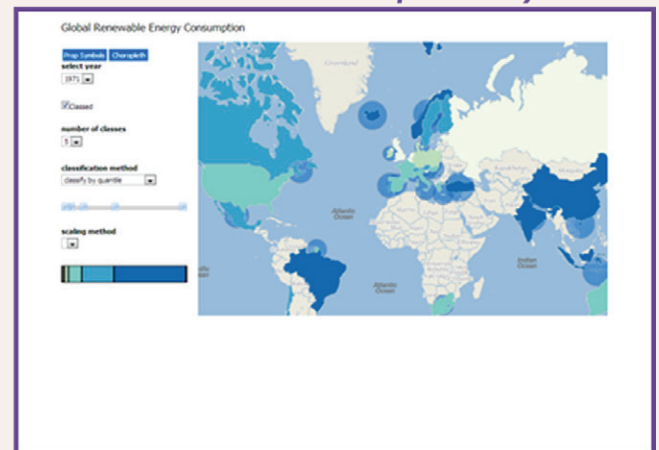
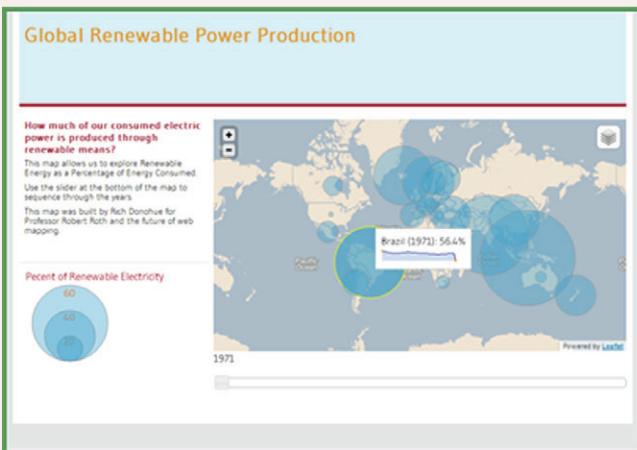


Figure 2. Example solutions for the energy web mapping scenario resulting from the diary study.

overall, behind the Google Maps API. With its initial release in 2006, OpenLayers also had a level of long-term maintenance and stability uncommon to other open web mapping libraries reviewed in the competitive analysis study, an important consideration identified through the needs assessment survey. OpenLayers is released under a 2-clause BSD License, which requires a copyright notice under code redistribution and absolves the creators of any liability; otherwise, the library is open for customization and reuse.

- *Leaflet* is an open JavaScript library pioneered and maintained by Vladimir Agafonkin (agafonkin.com/en). Leaflet supports SVG rendering within Internet Explorer 7 and 8, one advantage over most other open libraries using the SVG specification for client-side rendering. At the time of writing, Leaflet

was considered among the best web mapping libraries when designing for mobile devices because of a small file size (28MB in Version 0.4) and support of touch-based interactions. However, Leaflet was among the newest technologies included in the competitive analysis study, and was not a commonly used technology among the needs assessment participants (Table 5). We included Leaflet in the diary study due to the above advantages, and because it was the second most robust open library in terms of supported functionality, following the OpenLayers/OpenScales combination (Table 4). Leaflet is released under the same 2-clause BSD License as OpenLayers.

- *D3* (Data Driven Documents) is an open JavaScript library pioneered and maintained by Mike Bostock (bost.ocks.org/mike). We selected D3 (Version 2.0) over other open libraries that natively supported a

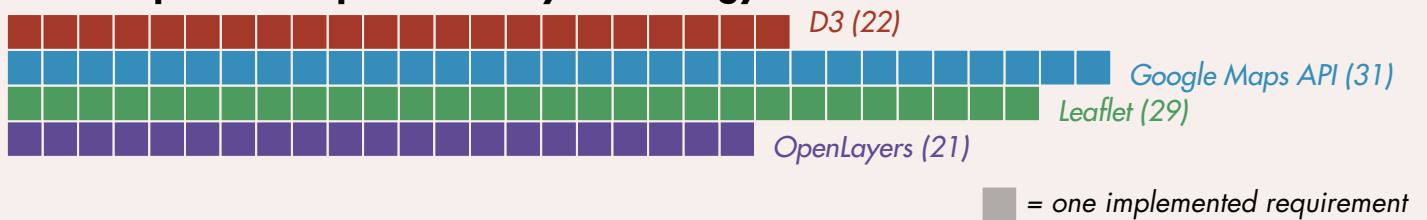
similar amount of functionality because of its unique approach to client-side rendering and interaction. Unlike tile-based technologies, D3 explicitly supports dynamic projection of linework into a wide array of map projections, using SVG to draw the projected vectors in-browser. This SVG then can be exported for manipulation in graphic design software, a unique advantage supporting other cartographic design workflows. Finally, D3 was designed to support rendering of any interactive visualization, not just maps, and therefore offers potential for multiview, coordinated geovisualization unavailable by alternative web mapping technologies. D3 is released under a 3-clause BSD License, which adds that the name of the creator (Mike Bostock) may not be used to promote or endorse any product made with D3 without written consent. D3 has no usage restrictions beyond this, and thus may be customized to the same comprehensive degree as OpenLayers and Leaflet.

Figure 2 presents example solutions to the energy web map scenario completed within the 40-hour time limit of the diary study, illustrating the relative affordances and constraints in web map design of the four candidate technologies.

Figure 3 presents an overview of the diary study results. Figure 3a illustrates the total number of diary study requirements by candidate technology. Again, each candidate technology had a pooled sample size of two, resulting in a maximum of 48 requirements per technology (2x24). On average, participants completed the most scenario requirements using the Google Maps API (31/48; 64.6%), with Leaflet a close second (29/48; 60.4%). Fewer requirements were accomplished with D3 (22/48; 45.8%) and Open Layers (21/48; 43.8%).

Figure 3b reorganizes the diary study results by individual scenario requirements. There was substantial variation in the final maps by individual requirement, with

A. Accomplished Requirements by Technology



B. Frequency by Individual Requirement

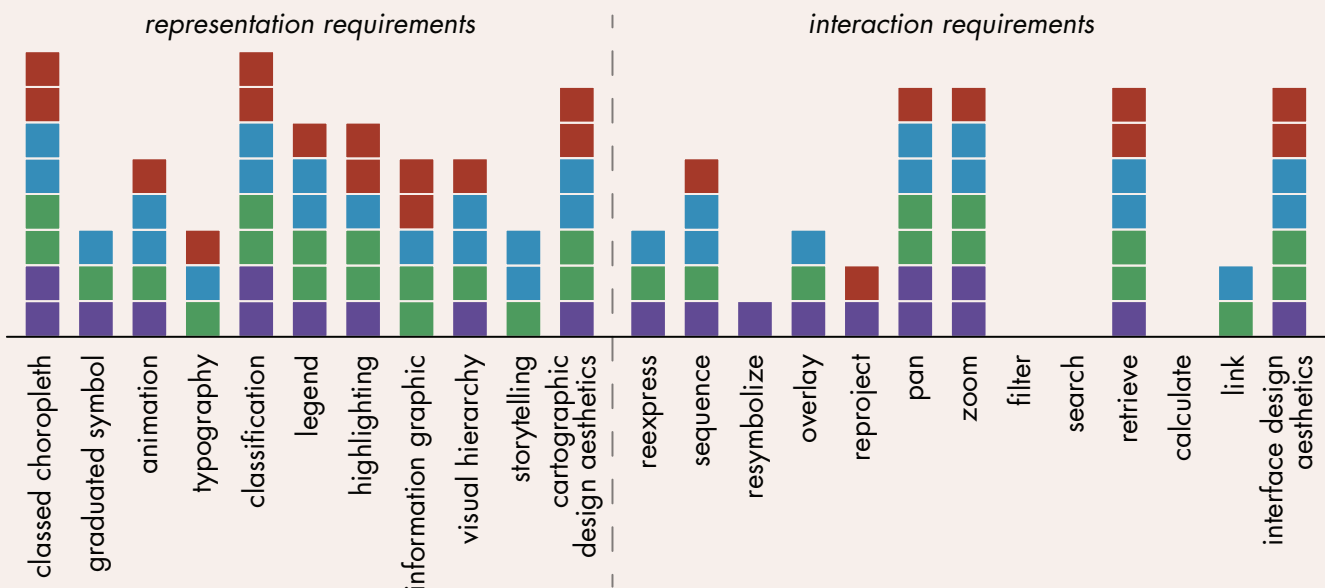


Figure 3. Overview of the diary study results: (a) total frequency of accomplished requirements by technology; (b) frequency of individual accomplished requirements from Table 3.

the choropleth map and dynamic classification the only features implemented in all eight (n=8) diary sessions. Overall, many more representation requirements (59 total, or 7.4 per diary session) were implemented compared to interaction requirements (44 total, or 5.5 per diary session), despite the energy scenario including 11 representation requirements and 13 interaction requirements. Such a finding reflects the primacy of representation over interaction in the web development workflow, and potentially decreased native support for interaction versus representation across the candidate technologies. The operators pan (7/8; 87.5%), zoom (7/8; 87.5%), and retrieve (7/8; 87.5%) were implemented in the large majority of diary sessions, but the fourth common operator, overlay (3/8; 37.5%), was implemented less frequently, likely in part due to its decreased relevance to the thematic mapping energy scenario. Looking at the absences, calculate, filter, and search were not implemented in any web map (0/8; 0.0%), suggesting increased difficulty in implementing these operators across the candidate technologies (and perhaps in all web mapping technologies broadly).

There were several differences across candidate technologies that suggest their relative affordances and limitations. Visual storytelling and live linkage between graphics were

implemented using the Google Maps API and Leaflet, but not D3 or OpenLayers. The reproject operator was implemented in D3 and OpenLayers, but not the Google Maps API or Leaflet. The resymbolize operator was implemented using D3 only. There also were several gaps in which a requirement was implemented in three of the four technologies, suggesting a limitation of the absent technology. Such gap requirements included the graduated symbol map and the reexpress operator for D3 and typography, a linked information graphic, and the overlay operator for OpenLayers.

Table 6 provides an overview of the participants' emotional experience while working with their candidate technologies. Overall, participants used 65 of the 125 (52.0%) unique terms to describe their emotional status across the eight diaries, entering their moods a total of 320 times across the diary study (8 diaries, each with 40 entries). The most commonly supplied mood was the neutral 'Okay' (31/320; 9.7% of all entries), followed closely by the negative 'Frustrated' (30/320; 9.4%). Other frequently supplied moods across the eight diaries included 'Blank' (17/320; 5.3%), 'Confused' (15/320; 4.7%), 'Content' (14/320; 4.4%), 'Excited' (14/320; 4.4%), 'Anxious' (13/320;



Table 6. The participants' overall emotional experiences during the diary study. Participants used 65 of the provided 125 moods across the eight diaries. A single mood was supplied for each diary entry, totaling 320 moods across the diary study (8 diaries by 40 work hours).

4.1%), 'Good' (11/320; 3.4%), 'Blah' (10/320; 3.1%), and 'Aggravated' (10/320; 3.1%).

Figure 4 breaks down the participants' emotional experiences according to the four candidate technologies. Figure 4a compares the overall valence of supplied moods across technologies. Across all eight diaries, participants were balanced nearly perfectly in their valence, supplying 125 negative moods (39.1%), 74 neutral moods (23.1%), and 121 positive moods (38.8%). In comparison to the overall average, the valence was more positive with both the Google Maps API and Leaflet. The pair of participants working with the Google Maps API supplied 26 negative moods (32.5%), 23 neutral moods (28.8%), and 31 positive moods (38.8%), while the pair of participants working with Leaflet supplied only 23 negative moods (28.8%), 19 neutral moods (23.8%), and 38 positive moods (47.5%). This means that, when working with Leaflet, participants were in a positive emotional state nearly half of the 40-hour work sessions, while in a negative emotional state just over one-quarter of the session. Therefore, participant experiences with Leaflet were slightly more positive (+8.7%) compared to participant experiences with the Google Maps API, despite the Google Maps API sessions resulting in two more implemented requirements than the Leaflet sessions.

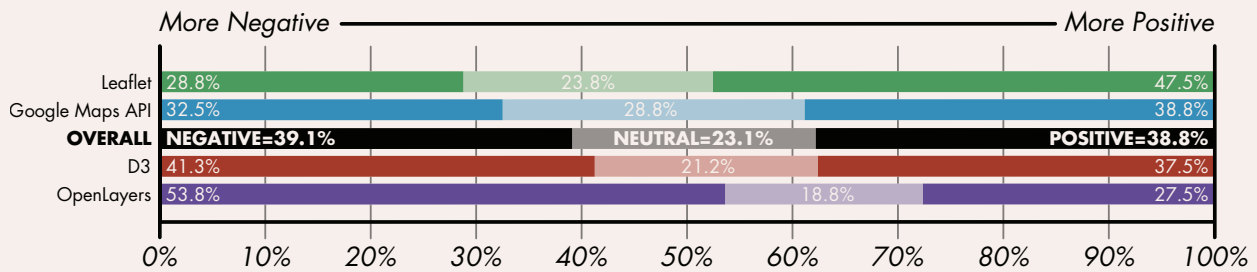
In contrast, the valence of supplied moods was more negative with D3 and OpenLayers compared to the overall average. The emotional experience with D3 was only slightly more negative than average, with the pair of participants supplying 33 negative moods (41.3%), 17 neutral moods (21.2%), and 30 positive moods (37.5%). However, the emotional experience with OpenLayers was considerably more negative than the overall average, as well as any of the other three evaluated web mapping technologies. The pair of participants working with OpenLayers supplied 43 negative emotions (53.8%), 15 neutral emotions (18.8%), and only 22 positive emotions (27.5%). Thus, the experience with OpenLayers was the opposite of Leaflet, with participants working in a negative emotional state over half of the 40-hour work session and working in a positive state just over one-quarter of the time. Inspection of the most commonly supplied moods by technology provides further evidence of this emotional disconnect between OpenLayers and the other technologies (Figure 4b), as no positive mood was supplied more than three times by participants using OpenLayers, whereas participants using

the other technologies supplied an even mixture of negative, neutral, and positive emotions.

The above summaries of implemented functionality and emotional experience are specific to the four candidate technologies included in the diary study. By analyzing the individual diary entries themselves, we were able to expose broader characteristics of web mapping technologies—and the overall web mapping process—that helped to explain the variation in implemented functionality and emotional experience. We first coded the diary entries according to the technical (Figure 1b) and practical (Figure 1c) considerations surveyed in the needs assessment. Across the 320 diary entries, 79 discussed available tutorials or examples (24.7%), 40 discussed code documentation (12.5%), 1 discussed browser compatibility issues (0.3%), and 1 discussed staffed support (0.3%); there was no discussion in the diary entries of the other technical or practical considerations listed in Figure 1.

The discussion on tutorials/examples versus code documentation revealed confusion among the participants over the best approach for getting started with their assigned technology. One participant working with Leaflet noted, "It's difficult right away to figure out what I need to read first, what is most important, and where to begin" while a second participant working with OpenLayers was "a little overwhelmed by the number of examples and possible directions." The balance in discussion between tutorials/examples and code documentation indicated opposing strategies for getting started, with six diaries starting with code examples and two starting with a multi-hour review of the code documentation. Interestingly, the participants starting with code examples ultimately second-guessed this approach. A participant working with D3 stated that "I took one of the examples and decided to manipulate it to meet my needs...This seemed like a good idea until I realized I have no idea what the code does, which led to me spending inordinate amounts of time trying to understand my own code," and went on to say "I can't decide if starting from scratch would have been more efficient or not." Similarly, a participant working with the Google Maps API stated that "the development practice of pulling from various examples, specific examples that may not work well together, [requires] thorough knowledge of the code to modify accordingly." Finally, a participant working with OpenLayers stated "one problem [is] the lack of ownership/authorship of the code I've been horsing around with the past 40-hours...[it is] perhaps better as a learner

A. Valence of Moods by Technology



B. Most Common Moods by Technology

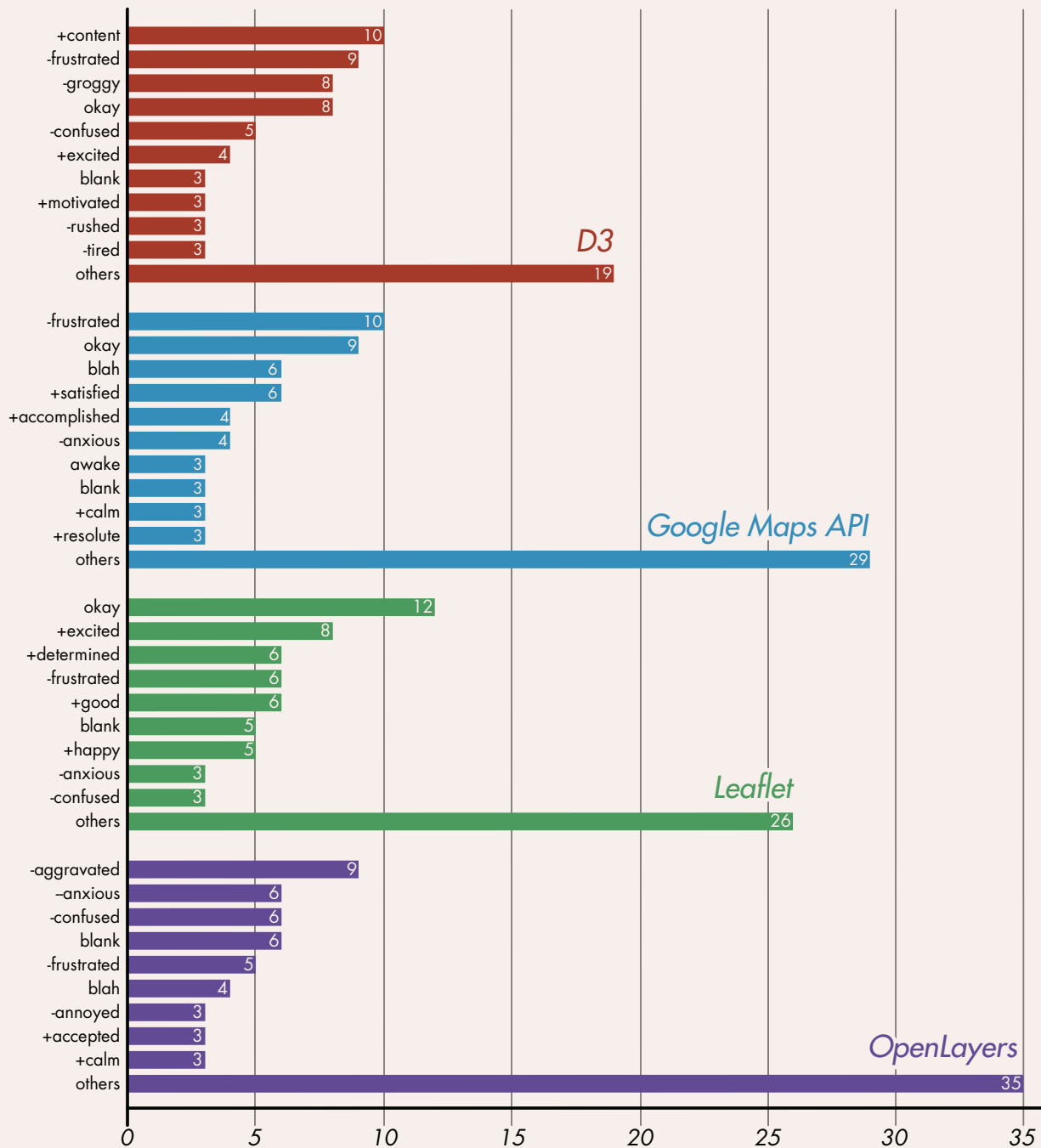


Figure 4. The participants' emotional experience with each of the four candidate technologies: (a) valence of emotional descriptions by technology, organized by negative, neutral, and positive moods (percentages out of 80 for individual technologies and 320 for the overall summary); (b) all moods provided at least three separate times for each technology (maximum frequency of 80).

and early developer to struggle through simple, less-than-ideal solutions of my own making, rather than [to be] lost debugging the more ideal examples.” Thus, while all four candidate technologies had a plethora of code examples, most of these examples were targeted toward seasoned developers and thus may not be appropriate for classroom education. Comments in the diary study instead suggested that beginning students would benefit from an initial, condensed overview of code documentation combined with simplified code examples to improve their emotional experience and encourage active learning.

Notably, there was one example of ‘staffed’ support regarding D3, with the participant writing “After my frustration earlier in the day, venting on Twitter got the attention of Mike Bostock...I spent the hour uploading data for him to look at and troubleshoot,” with the conversation resulting in the participant having a much deeper understanding of how to implement D3. While anecdotal, this interaction between a student and the creator of D3 was indicative of the positive atmosphere of the open web mapping community. It also provided an example of how online collaboration—through social media such as Twitter and forums such as Google Groups and Stack Overflow—has become part of the support process for open source web mapping technologies. As such, the developers of D3, Leaflet, and OpenLayers explicitly state that users are free to contact them with questions through these collaborative outlets.

Discussion around the best way to get started with a technology ultimately led to comments about the optimal web mapping workflow, with consensus being to first format and load the dataset, then implement the representation requirements (e.g., symbolize the dataset), and finally implement the interaction requirements (i.e., build the user interface). While the scenario requirements focused on representation and interaction design, participants spent the largest portion of their time formatting and loading the energy dataset. Across the 320 diary entries, 125 (39.1%) primarily referenced the data, 122 (38.1%) the representation requirements, and 73 (22.8%) the interaction requirements. Such a work distribution in the diary sessions signaled an importance of teaching to the *data* → *representation* → *interaction* workflow, and also revealed a blind spot in many of the existing code examples that limited their utility. A participant working with OpenLayers stated, “All examples use online data sources for the base-map, making it very difficult to figure out how to use my own data...documentation and examples for importing

data is very weak,” while one working with Leaflet observed, “There just doesn’t seem to be much information telling me how to get to the point of taking data out of [the dataset].” Therefore, we need to teach data formats and loading first—even if they are not the primary goals of the course—before teaching representation and interaction techniques.

Interestingly, one of the key advantages of the Google Maps API, leading to the high level of implemented functionality, was the documentation for loading data through Google Fusion Tables, with one participant “able to get started much more quickly on the representation, given how the [Google Maps] API makes loading and styling tiles straightforward” and the second stating that he or she “plugged the data into Fusion Tables, from which point it was pretty easy to merge with the KML and get it to render as a layer.” However, the initial decision to use Fusion Tables for the dataset led to constraints in both representation and interaction design later in both diary sessions using the Google Maps API. A first participant noted a problem with representation, stating, “Each map is limited to five layers, and each layer is limited to five styles...this means I can only have five classes (including a null value class) and won’t be able to allow users to reclassify the map,” while a second noted a problem with interaction, stating “tooltips fusion library has its own constraints... unsure if Fusion Tables are cool or not.” Ultimately, the initial decision to use Fusion Tables led to a large amount of code refactoring midway through the diary sessions to better support the representation and interaction requirements, and ultimately to some of the dissatisfaction with the proprietary Google Maps API in comparison with the fully open and more flexible Leaflet (Figure 4a).

The importance of initial data formatting and loading for subsequent representation and interaction development was not specific to the Google Maps API, however. One participant working with Leaflet reformatted the dataset numerous times throughout the diary session, stating, “working on building stats and all of a sudden I realized my data is actually completely incorrect...time to rebuild AGAIN!” This participant was unable to start on the representation and interaction requirements until the second half of the diary study due to issues with data formatting, but was able to implement the requirements quickly once the data were formatted and loaded correctly. In one extreme case, a participant working with OpenLayers struggled to implement any of the requirements due to issues

with loading the dataset until finding a set of symbolization examples that included code for data loading, which in turn led to a period of rapid development of the representation requirements. However, this participant then was unable to extend these examples to implement the interaction requirements, leading to a plateau in development over the final third of the work period. Thus, proper formatting of geospatial data remains paramount in web mapping, and should be processed not just to optimize the initial loading, but to enable the representation and interaction design as well.

Participant issues with data formatting and loading reflected broader issues with transitioning to the Open Web Platform. While the process focused on JavaScript web mapping libraries, the diaries revealed a multiplicity of competencies required to develop on the Open Web Platform. Related to the above discussion on data processing, participants struggled to manipulate data objects through the DOM. In total, 61 (19.1%) entries noted problems with manipulating GeoJSON or TopoJSON, the geospatial variants of JSON. One participant working with OpenLayers stated, “Accessing feature properties of a JSON has proven to be difficult,” while a second, working with Leaflet, was in the second half of the 40-hour period before “really understanding how to dig into the GeoJSON now, which I think is one of the most important parts of this entire exercise.” In addition to issues related to JSON and the DOM, 19 (5.9%) of the entries noted problems with SVG, 15 (4.7%) noted problems with HTML, 7 (2.1%) noted problems with CSS, and 7 (2.1%) noted problems with XML. Thus, participants spent approximately one third of their time (109 of 320 entries; 34.1%) working on development tasks unrelated to the writing of JavaScript code, an indication that students require competency in both basic website design and data formats before implementing web map behavior.

Interestingly, new versions were released during the diary study for two of the four candidate technologies: D3 and Leaflet. As discussed above, maintenance/stability was identified as the most important practical consideration from the needs assessment survey (Figure 1c). In both cases, the update was positively received by participants and aided development, rather than hindering it. One participant working with D3 stated, “A new version of D3 was released this morning which allows a thresholded

color ramp...it means I can use ColorBrewer to pick out colors, and then feed exact hex codes into D3 for my classification!” Similarly, a participant working with Leaflet stated, “With the new version of Leaflet coming out, there’s some new additions that make some of the work [simpler] so I decided to recode the map in the updated version...the language took me 3 lines to get my basemap and GeoJSON in and styled...super concise!” While only two examples, the ease participants had with integrating new releases of the D3 and Leaflet core libraries pointed to the broader trend of improved stability in open web mapping technology.

Finally, the diary entries suggested two limitations of the diary method design that could be improved in subsequent applications of the process. The most common complaint was about the rigid, hour-long structure imposed for each diary entry. Articulating this issue well, one participant working with D3 stated, “[I] had a hard time with the format of this project, mostly because I’m not very good at staying focused but also because I like to work in small chunks of time,” and went on to say “If I have only half an hour to do some work, I feel like it’s not worth it because, on average, I need about an hour and 15 minutes for each hour of this project.” While the 40-hour structure promoted consistency across the diary sessions—allowing for a more reliable comparison across technologies—it would be more practical in a professional setting to instruct participants to log a diary only after making a significant breakthrough or running up against a difficult challenge. Several participants also felt the constraint of using only a single web mapping technology was counterproductive. One participant working with Leaflet stated, “I feel like if I want to bring in something like a graph or chart to complement this I would use D3...Leaflet doesn’t support that and isn’t intended to.” A separate participant working with OpenLayers noted both of the aforementioned limitations of the diary study, stating, “Two of the constraints of the experiment that must be considered in terms of how they impact the practice of development: the [interrupted] 40-hours and mutual exclusivity of technologies.” Because most firms are likely to combine web mapping technologies based on their relative affordances and limitations—rather than relying on only one ‘winner’ technology—allowing the mixing of technologies in the diary study would have better mimicked real-world development.

CONCLUSION AND OUTLOOK

THE RESEARCH PRESENTED HERE describes a case study process for keeping pace with emerging web mapping technologies. The process supports selection of an appropriate technological solution—or combinations of solutions—for a specific web mapping context. The purpose of the process is not to identify an overall winner for all web mapping contexts, but rather to shed light on the dynamic landscape of web mapping technologies as it shifts and to select viable options from this solution space for a specific project. Following a discount, convergent approach, the process is designed to efficiently make use of project resources by iteratively narrowing available technologies across three stages: (1) a competitive analysis of available technologies, (2) a needs assessment survey of past experiences with and current opinions about these technologies, and (3) a diary study following the application of a small subset of candidate technologies.

The process successfully achieved the practical goal of identifying a candidate set of web mapping technologies for teaching web mapping, and also revealed broader insights into web map design and education generally as well as ways to cope with evolving web mapping technologies. In the following, we summarize our findings about each of these four research questions introduced earlier:

1. *What technologies currently are available for web mapping and how do they vary?* The technologies surveyed in the competitive analysis took one of four forms: frameworks, open libraries, closed APIs, and tile rendering services. The large majority leveraged JavaScript as the base programming language, and thus integrated with the Open Web Platform broadly. Multiple participants in the needs assessment survey noted the growing importance of learning and applying JavaScript-based technologies. Survey participants had used a small subset of the technologies identified through the competitive analysis study, and were unaware of a large majority of these technologies. We ultimately identified open libraries as most appropriate for higher education, as frameworks required too many additional competencies, closed APIs were limited in their openness and extensibility, and tile rendering services provided limited opportunity to teach interaction design. Four candidate technologies were selected for the diary study: three

open libraries (D3, Leaflet, and OpenLayers) and one closed API (Google Maps). While participants accomplished slightly more scenario requirements with the closed Google Maps API, they had a slightly more positive emotional experience using the open Leaflet library, in part due to the larger amount of code refactoring necessary when working around a closed API. Overall, the insight generated through the process reminded us that good web map design is more important than using novel tools—open or proprietary—and that university programs, government agencies, and cartography firms actively should combat path dependencies on one technology that lead to its use beyond its functional utility.

2. *What are the important characteristics of web maps that should inform the selection of web mapping technologies?* The competitive analysis revealed notable patterns in supported representation and interaction functionality across open web mapping technologies. The majority of technologies natively supported reference maps served as a set of raster tiles in a cylindrical projection, as well as panning, zooming, retrieval of details, and overlay of context information. Altogether, this representation and interaction functionality defines the prototypical web map. The competitive analysis also revealed gaps between contemporary web mapping practice and traditional cartographic scholarship, including thematic mapping beyond choropleth and proportional symbol representation techniques and the calculate, filter, reexpress, and reproject interaction operators. Participants in the needs assessment survey placed an emphasis on support for (user-driven) interactivity when choosing a technology, and placed less importance on (system-driven) animation and real-time updates. Despite this emphasis on interactivity, participants in the diary study accomplished nearly two more representation requirements than interaction requirements per diary session, suggesting the primacy of representation over interaction in the web mapping workflow. Only the choropleth map and dynamic classification were implemented in all eight diary sessions, with the common interaction operators pan, zoom, and retrieve implemented in

all but one diary session. The interaction operators calculate, filter, and search were not implementing in any diary session, further identifying gaps between practice and theory in web cartography. Finally, the diary study identified nuanced differences in supported functionality across the four candidate technologies, suggesting their relative affordances and limitations. Such insight can be used to derive preliminary recommendations for pairing web map requirements with potentially viable technology solutions, allowing for design to precede development (rather allowing technology to constrain design).

3. *How should web mapping be taught in higher education?* The diary study yielded multiple insights that inform the way web mapping should be taught in a university setting. First, the collection of participant moods across the diary sessions highlighted the role of emotional experience when learning a new technology. The valence of moods overall was balanced nearly perfectly across all 320 diary entries, but varied considerably by technology. When choosing a web mapping technology, therefore, it is equally important to understand both what the student can do with it and how the student feels while doing it. Second, discussion in the diary entries suggested confusion about how best to get started, with six diary sessions beginning with manipulation of code examples and two with a multi-hour review of documentation. Participants in the needs assessment identified good tutorials/examples and code documentation as practical considerations of near equal importance. However, participants in the diary study who started with code examples ultimately came to question this decision due to their complexity, with comments suggesting that an initial, condensed overview of code documentation combined with simplified code examples would be a better approach to reducing the initial learning curve. Having simple ‘beginner’ exercises early in the learning process also would provide students with early ‘victories,’ improving their emotional experience and promoting active learning. Finally, the diary studies revealed the complete set of competencies required for web mapping. This included the importance of teaching across the *data* → *representation* → *interaction* workflow, with an emphasis on data formats and loading that enable future

representation and interaction development. They also highlighted the need to teach across the Open Web Platform, with a sequence of modules on manipulating JSON in the DOM and the HTML, CSS, SVG, and XML specifications.

4. *How can we better cope with continued evolution in web mapping technologies?* The proposed three-stage process was successful in identifying viable client-side web mapping technologies for a contemporary curriculum in web cartography. Importantly, the process aligned with the pilot study approach to exploring emerging technologies already completed by several of the participants in the needs assessment survey. The process proceeded in a discount, convergent manner, which should allay concern over the resource investment of technological experimentation, and ultimately act to combat path dependencies in one technology. The case study revealed two ways to improve the diary stage of the process: requiring entries only following critical incidents (rather than hourly for 40 hours), and allowing the flexible combination of technologies using one as a base (rather than artificially restricting development to a single technology). We also put several structures in place to improve the scientific reliability of the generated insights, such as employing a pair of coders in the competitive analysis, having a fifth participant complete a diary session with all candidate technologies, and restricting group work; such structures may be removed when applying the process in a non-research context. Finally, the process suggested additional mechanisms for coping with the continued evolution in web mapping technology centered upon the active and growing open source web mapping community. From the academic world, this includes translating the development features of technologies into the *lingua franca* of cartographic design as well as the sharing of both conceptual and technical learning materials as open educational resources. From the development world, this includes crowdsourcing the organization and synthesis of web mapping technologies across the community to support young developers as they forge careers in web cartography.

As a result of the case study process, we began using Leaflet in the fall of 2012 as the base JavaScript library

for the advanced course, “Interactive Cartography and Geovisualization” at the University of Wisconsin–Madison, but included one advanced lab introducing D3 after JavaScript and Leaflet are learned, given its broad potential for thematic mapping and coordinated visualization

(see Donohue et al. 2013; Sack et al. 2014). We anticipate administering the process at approximately three-year intervals through the UW Cartography Lab—with the laboratory curriculum revised accordingly—to enable us to evolve along with emergent web mapping technologies.

ACKNOWLEDGEMENTS

WE WISH TO THANK John Czaplewski, Isaac Dorsch, and Sam Matthews for their contribution to this project.

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Cartographic Collaborations at the David M. Rubenstein Rare Book & Manuscript Library, Duke University

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THE CARTOGRAPHIC COLLECTIONS at Duke University's David M. Rubenstein Rare Book & Manuscript Library stretch from atlases of the Age of Exploration to twentieth-century fire insurance maps. Historically, they have been built in conjunction with, and to support, holdings of rare books and manuscript collections in particular subject areas and geographic regions. These have included the American Southeast, the American Civil War, the British Empire, and Africa and African exploration. However, Library collecting staff has remained open to faculty input on desirable collections and individual maps outside of these areas. That has led to a collection with broad geographic range, containing true highlights and unique holdings, primarily used in teaching and instruction. The Library holds around 2000 flat maps, over 100 atlases, and thousands of maps and city views in books related to travel and exploration.

The Library's cartographic collections have seen increased use and visibility in the last three years. This is thanks in large part to collaborations with the faculty and students of the BorderWork(s) Lab, one of the Humanities Labs hosted by Duke University's Franklin Humanities Institute. The Lab, which was active from 2012 until May 2014, explored (per its website) "acts of division and demarcation" from a variety of disciplinary perspectives, but with a focus on "the human consequences of cartographic divisions." The cartographic collections were the basis of two large exhibitions curated by BorderWork(s) undergraduate students, which have led to a number of additional uses of the collections.

Philip Stern, co-director of the BorderWork(s) Lab and Associate Professor of History, has been a strong supporter of undergraduate students gaining hands-on experience with using primary sources, frequently bringing classes on the history of exploration and the British Empire to study



Figure 1. Exhibition space for "Mapping the City: A Stranger's Guide."

original maps, rare books, and archival resources. Building on this existing relationship, Dr. Stern approached Libraries staff, including myself and Meg Brown—E. Rhodes and Leona B. Carpenter Foundation Exhibits Coordinator at Duke University Libraries—about facilitating an exhibition in the Library, as well as another at Duke's Nasher Museum of Art. A team of undergraduates worked with Dr. Stern and other faculty advisors, as well as Libraries staff, to identify potential topics and pertinent materials for the exhibits. The first exhibition, "Mapping the City: A Stranger's Guide," was on display from December 2012–March 2013.

"Mapping the City" included a range of maps and guide books for New York, London, Durham, NC, and other cities. It also featured a volume from the Library's complete, six-volume set of Willem Janszoon Blau's *Toonneel des Aerdriicx, ofte Nieuwe Atlas* (1648–55) and German festival books with city views of the seventeenth and eighteenth centuries.



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Figure 2. Rocque, John. 1746 [1749?]. A plan of the cities of London and Westminster, and borough of Southwark, with the contiguous buildings. Section Seven. London: John Pine & John Tinney



Figure 3. Miller, Frank T. 1929. Index sheet-map of Hope Valley Country Club & University Community. Durham, NC?: Hope Valley, Inc.



Figure 4. Blaeu, Willem Janszoon. 1648. Europa. In Tooneel des Aerdrickx, ofte Niewwe Atlas, vol. 1. Amsterdam: Joan and Willem Blaeu.

The second exhibit, “Defining Lines: Cartography in the Age of Empire,” was on display at the Nasher Museum of Art from September to December 2013. This exhibit included maps of Latin America, Africa, and India, focusing on the roles of cartography in European colonial enterprises. It was a companion exhibition to a large, traveling art exhibition entitled “Lines of Control: Partition as Productive Space.” According to its website, this exhibition featured contemporary art about “the creation and maintenance of borders, both physical as well as psychological.”

Based on available maps as well as the exhibition space, “Defining Lines” had a greater emphasis on large sheet maps, though some atlases and bound volumes were also included. Highlights included two eighteenth- or early-nineteenth-century manuscript maps of areas of modern-day Bolivia by Spanish official Manuel Pantosa y Moreno, and *Neueste Karte von Hindostan...* by Franz Anton Schrämbl, a rare 1788 Austrian map based on James Rennell’s famous 1782 *Map of Hindoostan*.

The Library also digitized its copy of Abraham Ortelius’s *Theatrum Orbis Terrarum* (1574) for the exhibition. The digital images of the atlas were able for browsing via an iPad display in the physical exhibition space.

Students also collaborated on digital versions of both exhibitions, creating a website for each with interpretive text and images of items. This allowed students to expand on their research findings beyond the limitations of explanatory labels in the physical exhibitions. For “Mapping the City,” the students included essays on “Types of Maps,” “How to Read a Map,” and “Maps and Art.” For “Defining Lines,” students wrote research essays on each item in the exhibition, and the site also provided background information on the process by which the exhibition was created. An essay on the website entitled “The Maps of Defining Lines” also reflects on the conjunction of cartography and colonialism, and includes a reference map that positions each map in the exhibition on a present-day world map, with a color-coded timeline for the dates of the maps.

The investment of time to assist students with finding, selecting, and exhibiting these maps has proven worthwhile for the Library. The students certainly received valuable experience in the history of geography and cartography, but also in curation, writing for a large and diverse public audience, and library and museum studies. The Library, in turn, has received increased exposure for its cartographic



Figure 5. Student curators (left to right) Rachel Fleder, Lauren Jackson, Elizabeth Blackwood, and Jordan Noyes discuss Hermann Habenicht’s *Spezial-Karte von Afrika* (1887) in the exhibition space for “Defining Lines: Cartography in the Age of Empire.”



Figure 6. Pantosa y Moreno, Manuel. ca. 1797–1817. Untitled manuscript map. From folio entitled *Alto Perù Cartas Topograficas*, In *Manuel Pantosa y Moreno Manuscript Maps*.



Figure 7. Schrämbl, Franz Anton. 1788. *Neueste Karte von Hindostan....* Wien.

collections, leading to further integration of the collections into the Duke curriculum in coming semesters, as well as other pedagogical opportunities. Visiting scholars hosted by BorderWork(s) have also been frequent users of the collections, thanks in no small part to their increased awareness of materials in the collections thanks to these exhibitions.

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Figure 8. Ortelius, Abraham. 1574. *Americae sive Novi Orbis Nova Descriptio*. In *Theatrum Orbis Terrarum*. Antwerp: Ant. Coppenius Diesth.

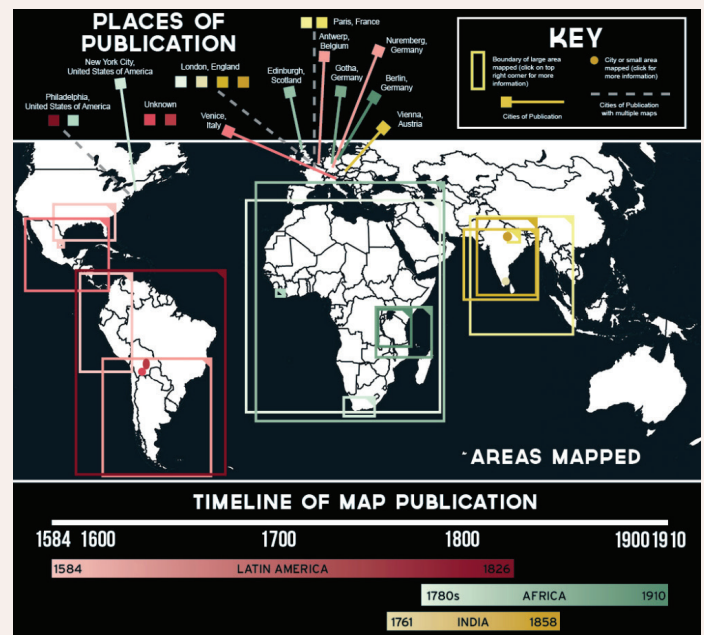


Figure 9. The Maps of Defining Lines. Reference map and timeline for "Defining Lines: Cartography in the Age of Empire." Accessed May 1, 2014. <http://sites.fhi.duke.edu/defininglines/about-2/untitled/>.

Interactive and Multivariate Choropleth Maps with D3

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ASSUMED SKILLS AND LEARNING OUTCOMES

THE FOLLOWING TUTORIAL describes how to make an interactive choropleth map using the D3 (Data-Driven Documents) web mapping library (d3js.org). This tutorial is based on a laboratory assignment created in the fall of 2014 for an advanced class titled Interactive Cartography and Geovisualization at the University of Wisconsin–Madison. This is the second of two *On the Horizon* tutorials on web mapping and extends a previous tutorial that used the Leaflet JavaScript library (see Donohue et al. 2013; dx.doi.org/10.14714/CP76.1248). Fully commented source code for both tutorials is available on GitHub (github.com/uwcart/cartographic-perspectives). All code is distributed under a Creative Commons 3.0 license and available for unconditional use, with the exception of the files in the `lib` directory, for which certain license conditions are required as described in the file *LICENSE.txt*.

This tutorial assumes literacy in JavaScript, HTML, and CSS programming for the web. In particular, you should be comfortable with the manipulation of JavaScript arrays and objects. Free tutorials and reference documentation for these languages are available at www.w3schools.com.

GETTING STARTED WITH D3

D3, OR *Data-Driven Documents*, presents a different philosophy of web mapping than the majority of technologies that currently produce web maps. Leaflet and most other web mapping libraries produce *slippy maps* based on sets of tiled raster images loaded dynamically into the browser when needed. A common complaint from cartographers about slippy maps is their virtually universal reliance on cylindrical projections, most commonly Web Mercator, which is highly distorted at higher latitudes and inappropriate for many forms of data visualization at small map scales. The D3 alternative utilizes vector graphics rendered

Additionally, D3 makes heavy use of jQuery-style DOM element selection and dot syntax (jquery.com). It is further assumed that you are familiar with in-browser development tools such as those provided by Google Chrome (developers.google.com/chrome-developer-tools), Mozilla Firefox (developer.mozilla.org/en-US/docs/Tools), and Firebug (getfirebug.com). An important limitation of D3 is its incompatibility with Microsoft's Internet Explorer browser prior to version 9; use of Internet Explorer below version 10 is not recommended. Finally, the tutorial assumes you have set up a development server running either remotely or as a localhost. MAMP for Mac (www.mamp.info/en) and WAMP for Windows (www.wampserver.com/en) are useful for this.

After completing the tutorial, you should be able to:

- work with the TopoJSON data format;
- use the D3 library to publish a multivariate choropleth map to the web; and
- implement interactivity, including attribute selection, mouseover highlighting, and dynamic labels.

in the browser for the basemap, allowing for dynamic map projection and direct feature interaction.

D3 is an open source JavaScript library pioneered and maintained by Mike Bostock of the *New York Times* (bost.ocks.org/mike). Increasingly recognized as a leading data visualization library, D3 simplifies loading and interacting with information. It draws all graphics as client-side (in the browser) vectors using the SVG (Scalable Vector Graphics) standard. Maps created using D3 can be transformed into a multitude of projections thanks to the work



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of freelance developer Jason Davies and the *proj4.js* library of map projections (trac.osgeo.org/proj4js).

The goal of this tutorial is to provide you with a broad introduction to using D3 for web cartography. The following tutorial extends two excellent online learning resources: (1) Mike Bostock’s “Let’s Make a Map” tutorial (bost.ocks.org/mike/map), and (2) developer Scott Murray’s e-book *Interactive Data Visualization for the Web* (chime-ra.labs.oreilly.com/books/1230000000345); the web version is free as of this writing). Refer to these materials for additional background and guidance as you complete the tutorial.

1. FINDING AND FORMATTING MULTIVARIATE INFORMATION

THE FIRST STEP is assembly of appropriate *multivariate* (i.e., multiple attributes enumerated over the same set of spaces) information to portray in a choropleth map. Your data should be numerical, with attributes (or fields) organized as separate table columns and each enumeration unit (region) represented by a single table row. Because enumeration units typically vary in size and shape, it is important to normalize the attribute information according to a relevant variable (i.e., divide by area, population, etc.).

Although they could be combined into one file, this tutorial maintains the attribute data and geographic data (i.e., the linework) as separate files in order to demonstrate how to join data from disparate sources together using JavaScript. This is useful when drawing on data from dynamic web services. Prepare your attribute information as a *.csv* file using spreadsheet software (e.g., Microsoft Excel, Google Sheets, OpenOffice Calc). In addition to attribute columns, the file should include columns for a unique ID, the name of each enumeration unit, and a code that can be linked to the geographic dataset.

Figure 1 provides an example multivariate attribute dataset for the regions of France. The attribute “admin1_code”

	A	B	C	D	E	F	G	H
1	id	name	adm1_code	varA	varB	varC	varD	varE
2	1	Alsace	FRA-2686	85	38	75	30	9
3	2	Aquitaine	FRA-2665	28	29	38	26	15
4	3	Auvergne	FRA-2670	18	59	22	60	82
5	4	Basse-Normandie	FRA-2661	35	45	31	26	14
6	5	Bourgogne	FRA-2671	12	31	15	22	28
7	6	Bretagne	FRA-2662	25	50	25	25	25
8	7	Centre	FRA-2672	88	46	56	15	12
9	8	Champagne-Ardenne	FRA-2682	52	51	46	68	75
10	9	Corse	FRA-2666	7	12	18	11	9
11	10	Franche-Comte	FRA-2685	23	18	16	24	26
12	11	Haute-Normandie	FRA-2673	32	28	29	25	22
13	12	Ile de France	FRA-2680	8	15	22	25	29
14	13	Languedoc-Roussillon	FRA-2668	82	74	72	10	85
15	14	Limousin	FRA-2681	9	16	14	23	45
16	15	Lorraine	FRA-2687	33	45	68	96	102
17	16	Midi-Pyrenees	FRA-2669	15	38	85	96	82
18	17	Nord Pas de Calais	FRA-2683	12	10	9	4	74
19	18	Pays de la Loire	FRA-2664	42	18	28	30	22
20	19	Picardie	FRA-2684	9	15	15	8	29
21	20	Poitou-Charentes	FRA-2663	38	31	28	32	85
22	21	Provence-Alpes Cote D'Azur	FRA-2667	25	100	88	74	45
23	22	Rhone-Alpes	FRA-1265	25	46	66	85	45
24								

Figure 1. An example multivariate attribute dataset.

will be used to link the attribute dataset to the geographic dataset in the code. This is a dummy dataset with no meaning in the real world; you should replace it with data from a phenomenon that is of interest to you. To avoid problems in your code later on, be sure the column names are logical and do not contain spaces or start with a number or special character. These headers will be used as keys to reference the data values in your code.

Next, prepare the geographic dataset in GIS software. For this tutorial, you will convert your geography to *TopoJSON* format (github.com/mbostock/topojson/wiki). TopoJSON is similar to GeoJSON, introduced in the Leaflet tutorial, but it can have significantly reduced file sizes and also stores *topology*: the spatial relationships of features. Both are variants on *JSON*, which stands for JavaScript Object Notation. TopoJSON structures each map feature as a series of *arcs*, or lines connecting sets of nodes, with the node sets stored in a separate object that indexes the arcs, and a transform equation that situates the nodes in the coordinate reference system. This format greatly reduces the data volume and improves rendering efficiency by storing each arc only once, rather than duplicating arcs along shared edges. The lightweight TopoJSON library, available from github.com/mbostock/topojson, is required to translate the TopoJSON format for use by D3 or any other web mapping library that can utilize GeoJSON files.

The sample geography datasets used in this tutorial (*EuropeCountries.topojson* and *FranceRegions.topojson*, included in the tutorial source code) were prepared using two shapefiles downloaded from the Natural Earth website (www.naturalearthdata.com): one with the nations of Europe as a whole, and one with the regions of France. A number of technologies may be used to convert data to TopoJSON format, including the TopoJSON command line tool (available from the wiki cited above),


```

1    <!DOCTYPE HTML>
2    <html>
3        <head>
4            <meta charset="utf-8">
5            <title>My Coordinated Visualization</title>
6
7            <!--main stylesheet-->
8            <link rel="stylesheet" href="css/style.css" />
9        </head>
10       <body>
11           <!--libraries-->
12           <script src="lib/d3.v3.js"></script>
13           <script src="lib/topojson.v1.min.js"></script>
14           <script src="lib/queue.js"></script>
15
16           <!--link to main JavaScript file-->
17           <script src="js/main.js"></script>
18       </body>
19 </html>

```

Example 1. Basic HTML5 boiler plate (in: index.html).

3. LOADING YOUR .TOPOJSON FILES INTO THE BROWSER

THE NEXT STEP is loading the geographic information assembled in your .topojson files. One of the excellent code classes provided by D3 includes several methods for loading various data formats using *AJAX* (Asynchronous JavaScript and XML) and parsing the contained information into JavaScript arrays. The loaders used here are *d3.csv* and *d3.json*. These methods work even better when used in conjunction with the *queue.js* plug-in, as explained below.

Because the data are loaded *asynchronously*—separately from the rest of the script, so the browser does not have to wait for the data to load before displaying the web page—all code that manipulates the asynchronous data must be contained within a *callback* function that is triggered only after the data are loaded. A callback function can be

specified for each D3 data loader. The downside of this is that each loader requires a separate callback, requiring you to nest loaders and callbacks in order to manipulate data from multiple files.

Example 2 provides the logic needed to initialize the webpage and print the two .topojson files used in this example to the console. The `queue()` method (**EX3: 12–16**), which accesses the *queue.js* plug-in, allows data from multiple files to be loaded in parallel rather than in series, thus speeding up the process, and allows you to specify a single callback function for all data sources. Load the *index.html* page in your browser; you now will see the TopoJSON loaded to the DOM (**Figure 3**).

4. DRAWING YOUR BASEMAP

NOW THAT YOUR INFORMATION is loading properly, it is time to draw your basemap. The first step in creating a map or any other visualization using the D3 library is creation of an HTML element in which to draw the map. You need not create any elements in *index.html*; instead you will use D3 to create a blank `svg` element for the map and populate its content. It will be easier to interpret the

following instructions in this subsection if you first review the SVG specification at www.w3.org/TR/SVG.

Start creation of the choropleth map by drawing its basemap, or geographic context. The basemap makes use of the geometry included in *EuropeCountries.shp* and converted to the `EuropeCountries` object in your first TopoJSON. All

```

1 //begin script when window loads
2 window.onload = initialize();
3
4 //the first function called once the html is loaded
5 function initialize(){
6     setMap();
7 };
8
9 //set choropleth map parameters
10 function setMap(){
11     //use queue.js to parallelize asynchronous data loading
12     queue()
13         .defer(d3.csv, "data/unitsData.csv") //load attributes from csv
14         .defer(d3.json, "data/EuropeCountries.topojson") //load
15         .defer(d3.json, "data/FranceRegions.topojson") //load geometry
16         .await(callback); //trigger callback function once data is loaded
17
18     function callback(error, csvData, europeData, franceData){
19         console.log();
20     };
21 }

```

Example 2. Loading data files and printing *FranceRegions.topojson* data to the console (in: *main.js*).

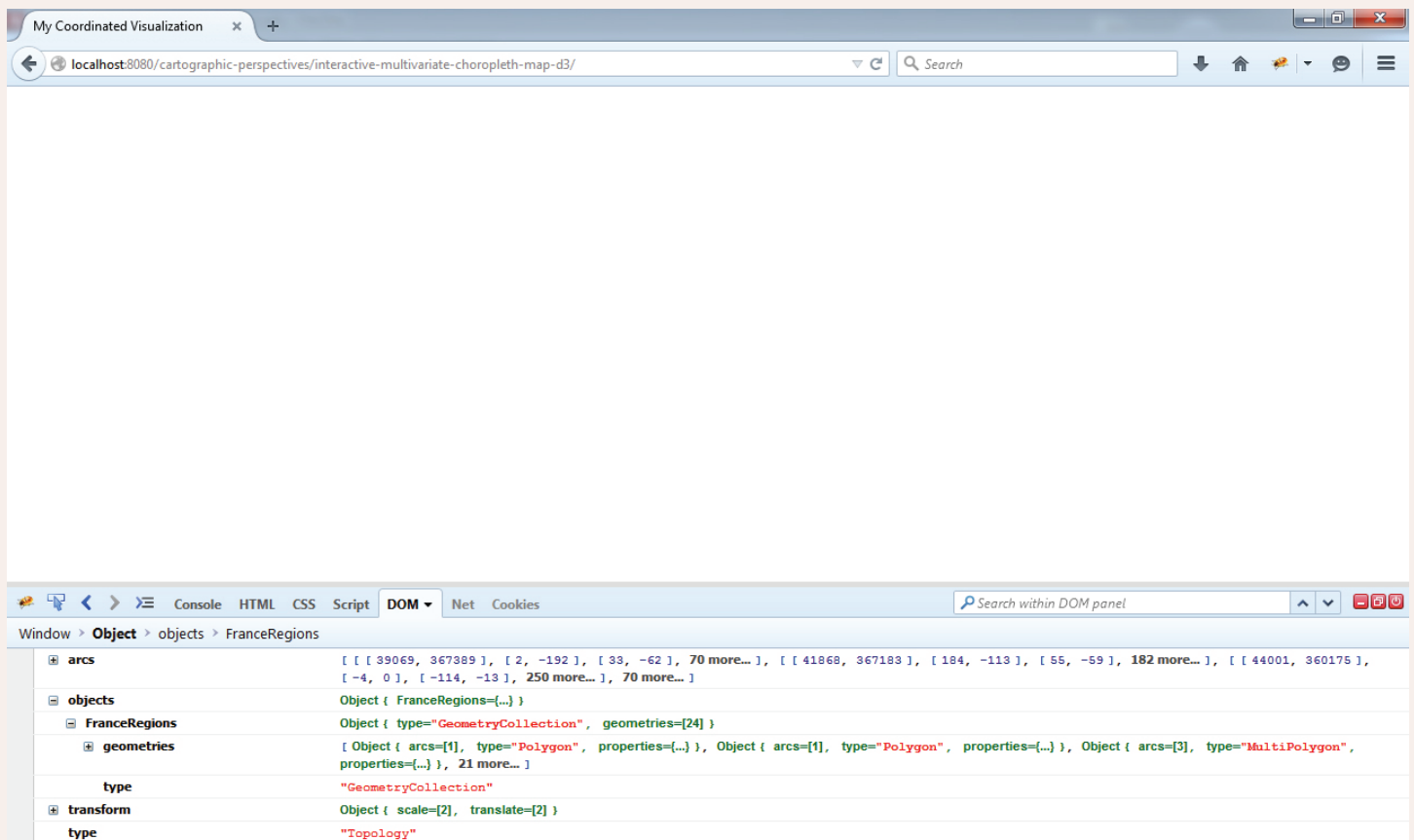


Figure 3. Printing a TopoJSON to the DOM. The object name should match the name given in Figure 2, which in turn should match the original shapefile.

graphics associated with the choropleth view are drawn within the `setMap()` function, created in **Example 2** and extended in **Example 3**. First, set the size of the map view in pixels (**EX3: 3–5**). Note the absence of `px` after each number, as used in stylesheets; dimensions given without units to SVG elements will automatically be translated to pixels.

Next, create an `<svg>` element to contain the choropleth map using the `d3.select()` function (**EX3: 7–11**). A D3 *selection* creates an array with one or more DOM elements to be operated on by subsequent methods. The string parameter passed to `.select()` references the DOM element to be selected and is therefore called the *selector*. The statement `d3.select("body")` is essentially the same as

```
1  function setMap(){
2
3      //map frame dimensions
4      var width = 960;
5      var height = 460;
6
7      //create a new svg element with the above dimensions
8      var map = d3.select("body")
9          .append("svg")
10         .attr("width", width)
11         .attr("height", height);
12
13     //create Europe Albers equal area conic projection, centered on France
14     var projection = d3.geo.albers()
15         .center([-8, 46.2])
16         .rotate([-10, 0])
17         .parallels([43, 62])
18         .scale(2500)
19         .translate([width / 2, height / 2]);
20
21     //create svg path generator using the projection
22     var path = d3.geo.path()
23         .projection(projection);
24
25     //use queue.js to parallelize asynchronous data loading
26     queue()
27         .defer(d3.csv, "data/unitsData.csv") //load attributes from csv
28         .defer(d3.json, "data/EuropeCountries.topojson") //load geometry
29         .defer(d3.json, "data/FranceRegions.topojson") //load geometry
30         .await(callback); //trigger callback function once data is loaded
31
32     function callback(error, csvData, europeData, franceData){
33         //add Europe countries geometry to map
34         var countries = map.append("path") //create SVG path element
35             .datum(topojson.feature(
36                 europeData, europeData.objects.EuropeCountries))
37             .attr("class", "countries") //class name for styling
38             .attr("d", path); //project data as geometry in svg
39     }
```

Example 3. Extending `setMap()` to draw the basemap.

`$(“body”)` in jQuery; it passes the selector “body” and returns the first matching element in the DOM. Like jQuery, D3 uses dot syntax to string together function calls, an approach known as *method chaining*. This code selects the `<body>` element of the DOM and adds an `<svg>` element, then sets the size to the values already stored in the `width` and `height` variables. This new `<svg>` element essentially is a container that holds the map geometry. Another method, `selectAll()`, can be used to select *every* matching element in the DOM as well as create new elements from data. It will be evoked later in the tutorial.

After creating the `<svg>` container, you then need to indicate how the geographic coordinates should be projected onto the two-dimensional plane (the computer screen). As stated in the introduction, one of the exciting things about D3 for cartographers is its support for an extensive and growing library of map projections. The list of projections currently supported by D3, either natively or through the extended projections plug-in, is available at: github.com/mbostock/d3/wiki/Geo-Projections. Choose an equal-area projection, given the choropleth mapping context.

The following example applies the Albers Equal-Area Conic projection using `d3.geo.albers()`, centered on France (EX3: 13–19); this projection is native to `d3.v3.js`. The projection parameters following the function call apply mathematical transformations to the default Albers projection:

- `.center` recenters the map at a given `[lon, lat]` coordinate;
- `.rotate` rotates the globe counter-clockwise (from the North Pole) given angles of `[lon, lat, roll]` away from the geographic center;
- `.parallels` sets the standard parallels of the projection, given as `[lat1, lat2]`;
- `.scale` is the scale of the map, set using an arbitrary scale factor; and
- `.translate` adjusts the pixel coordinates of the map’s center, and always should be set as half the width and height to keep the map’s center in the center of the SVG area.

Next, you need to project your geometry according to these projection parameters. D3 uses a “geo path” SVG element to render the geometry included in a GeoJSON object as SVG. The `d3.geo.path()` function creates a new

`path` generator with a default projection of Albers, centered on the USA. This logic may run counter to previous experience with JavaScript; if D3 worked like Leaflet, you might expect that calling `d3.geo.path()` will return an object or an array. Instead, `d3.geo.path()` is a D3 *generator function* that creates a new function (the *generator*) based on the parameters you send it. You then can store this generator as a variable, and access the variable like you would call a function, passing it parameters to manipulate. Note that the `d3.geo.path()` function requires that you specify the previously created projection. Each time the `path` generator is used to create a new SVG element (i.e., a new graphical layer in the map), the SVG graphics will be drawn using the projection indicated in the `d3.geo.path()` generator function. Hopefully, the idea and usage of generator functions will become clearer as you proceed through the tutorial.

First, make use of the `d3.geo.path()` generator function to define a `path` generator that creates projected SVG paths from the geometry based on your map projection (EX3: 21–23). Then, make use of this `path` generator through the `append()` function to add an SVG `<path>` element containing the geometry derived from your TopoJSON, projected according to the generator definition (EX3: 33–37); note that this code should be part of the callback function, replacing the `console.log` statement. The first line adds the `<path>` element to the DOM and to the `map` selection and assigns the new selection to a variable `countries` (EX3: 34). The second line specifies the `datum()` that will be attached to the `countries` selection (EX3: 35). In D3 terms, a *datum* is a unified chunk of information that can be expressed in SVG form (as in the singular form of *data*, **not** a geometric model of Earth’s surface). D3’s `.append()` method returns the new element, so the `countries` selection will reference the appended `<path>` element and its associated datum.

At this point, it is acceptable to treat the polygons in the `EuropeCountries` JavaScript object altogether, as this is the background context for the choropleth map and will not be interactive. This is why the `append()` function is used, rather than first calling the `selectAll()`, `data()`, and `enter()` functions (described below). The `datum()` function expects a JSON or GeoJSON; to use the newer TopoJSON format, access the `topojson.feature()` method from `topojson.js`, indicating the object (`EuropeCountries`) in the TopoJSON you want translated. The third line assigns the `countries <path>` element

the class name `countries` so that it can be styled in `styles.css` (EX3: 36). In the fourth line, the `d` attribute contains a string of information that describes the `<path>` (see: developer.mozilla.org/en-US/docs/SVG/Attribute/d) (EX3: 37). It is for this purpose that the `path` generator is so useful: it projects the `EuropeCountries` geometry and translates it into an SVG `<path>` description string.

Altogether, the revisions in **Example 3** result in four D3 *blocks* of chained methods connected by dot syntax to minimize the file size (8–11; 14–19; 22–23; 33–37). It is important that you do **not** place a semicolon between lines of a block, as this interrupts the block and results in a syntax error. To maximize clarity, the following instructions designate a variable for each block that creates at least one new element, with the same variable name as the class

5. STYLING YOUR BASEMAP

WITH THE BASEMAP GEOMETRY drawing in the browser, it is now time to style the basemap. Style rules can be applied to the SVG element containing the projected map using the `countries` class reference (EX3: 36). Return to `style.css` and add the basic style rules provided in **Example 4**. These styles add default gray outlines to the `countries` as a starting point; continue to improve the applied basemap styles as you progress through the tutorial.

A nice cartographic function supported by D3 is the ability to add graticule lines to any map (**Example 5**). Graticule methods are included in the D3 Geo Paths documentation (github.com/mbostock/d3/wiki/Geo-Paths), and an example is available at: bl.ocks.org/mbostock/3734308.

To add the graticule to your basemap, begin by creating a generator called `graticule` (EX5: 1–3). Where you place this code matters, as you are conceptually building your visual hierarchy from the bottom up in the map as you add new code from the top down in the `setMap()` function.

```

1  .countries {
2      fill: #fff;
3      stroke: #ccc;
4      stroke-width: 2px;
5  }
```

Example 4. Basic styles for the `countries` class (in `style.css`).

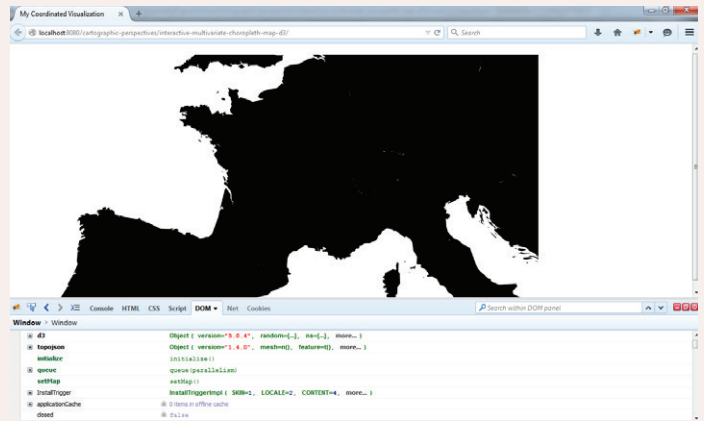


Figure 4. Drawing the basemap.

attribute designated for that element, even if that variable is not accessed again. Now refresh your browser and you should see a map (**Figure 4**).

The `graticule` generator should be placed **after** creating the `path` generator, but **before** loading and processing the TopoJSON files with `queue()`; this order will place the countries above the graticule.

Next, use the `path` generator to add two SVG elements named `gratBackground` (i.e., the water) and `gratLines` to the map. First, add `gratBackground` using the `append()` function and configure its attributes (EX5: 5–9). Then, add `gratLines` to the `map` using `selectAll()`, `data()`, and `enter()` and configure its attributes (EX5: 11–17). The sequence of these three methods is used to create multiple new `<path>` elements at once, and thus to draw each desired graticule line individually. This is required by D3 for graticule lines, but also is useful when individual features are styled differently or are interactive.

Consider carefully the code provided in **Example 5**, particularly the final block. It might appear as though D3 warped the space-time continuum to select DOM elements before they were created. Really, D3 just “sets the stage” for them. The `selectAll()` function creates an *empty selection*, or a blank array into which will be placed one element for each graticule line (EX5: 12). The `data()` method operates like `datum()`, but creates *undefined* placeholders in the selection array for future elements associated with each datum (each value or object within the overall data array) (EX5: 13). The `enter()` function adds

```

1 //create graticule generator
2 var graticule = d3.geo.graticule()
3   .step([10, 10]); //place graticule lines every 10 degrees
4
5 //create graticule background
6 var gratBackground = map.append("path")
7   .datum(graticule.outline) //bind graticule background
8   .attr("class", "gratBackground") //assign class for styling
9   .attr("d", path) //project graticule
10
11 //create graticule lines
12 var gratLines = map.selectAll(".gratLines") //select graticule elements
13   .data(graticule.lines) //bind graticule lines to each element
14   .enter() //create an element for each datum
15   .append("path") //append each element to the svg as a path element
16   .attr("class", "gratLines") //assign class for styling
17   .attr("d", path); //project graticule lines

```

Example 5. Adding a graticule to `setMap()` (in: `main.js`).

each datum to its placeholder in the selection array, changing the placeholders from `undefined` to objects, each of which has a `__data__` property that holds the associated datum (EX5: 14). Every method placed below `enter()` will be executed once for each item in the array; you can think of this as a kind of “for” loop. The `append()` function adds a new `<path>` element for each object in the selection, binding the datum to that element (EX5: 15). The first `attr()` call assigns each `<path>` element a class for styling purposes (EX5: 16); note that you must assign this class, as the only function of `selectAll(".gratLines")` is to select elements that do not exist yet in the DOM. The second `attr()` call projects each datum through the path generator into the `d` attribute, just as `gratBackground` and `countries` are projected.

Finally, style the `gratBackground` and `gratLines` in `style.css` using the class names “`gratBackground`” and “`gratLines`” (Example 6); you are encouraged to tweak these styles as your design evolves. Refresh your `index.html` page in your browser to view your basemap (Figure 5).

6. DRAWING YOUR CHOROPLETH MAP

WITH THE BASEMAP CONTEXT in place, you are ready to draw your choropleth map. Again, the choropleth map uses the geometry included in `FranceRegions`.

```

1 .gratBackground {
2     fill: #D5E3FF;
3 }
4
5 .gratLines {
6     fill: none;
7     stroke: #999;
8     stroke-width: 1px;
9 }

```

Example 6. Styling the graticule (in `style.css`).

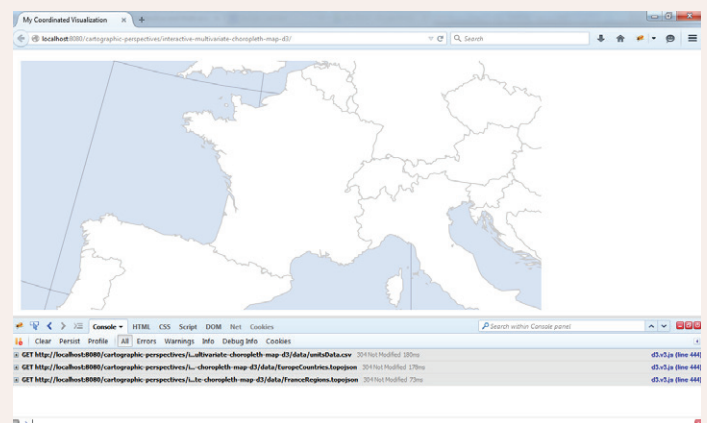


Figure 5. Styling the basemap.

```

1 //retrieve and process data
2 function callback(error, csvData, europeData, franceData){
3
4     //add Europe countries geometry to map
5     var countries = map.append("path") //create SVG path element
6         .datum(topojson.feature(europeData,
7             europeData.objects.EuropeCountries))
8         .attr("class", "countries") //class name for styling
9         .attr("d", path); //project data as geometry in svg
10
11     //add regions to map as enumeration units colored by data
12     var regions = map.selectAll(".regions")
13         .data(topojson.feature(franceData,
14             franceData.objects.FranceRegions).features)
15     .enter() //create elements
16     .append("path") //append elements to svg
17     .attr("class", "regions") //assign class for additional styling
18     .attr("id", function(d) { return d.properties.adm1_code })
19     .attr("d", path) //project data as geometry in svg
20 }

```

Example 7. Drawing the choropleth map in `setMap()` (in: `main.js`).

`shp` and converted to the `FranceRegions` object in your second TopoJSON. The `FranceRegions` object could be added through the `path` generator using `datum()`, as with `EuropeCountries` above. Unlike the basemap, however, each region is unique in both representation and interaction. You need to add each region separately in order to set different properties and attach different event listeners to each individual region. Therefore, you need to use the `selectAll()`, `data()`, and `enter()` methods—much like you did to draw each graticule line—rather than the simpler `append()` and `datum()` methods—like you did for drawing the basemap countries and graticule background (Example 7). A new selection named `regions` is created using the `selectAll()` method and each region is added to the map by the `path` generator (EX7: 10–17). It is important to note that Example 7 must be added within the `callback` function, as the TopoJSON must first be processed before adding the `regions` element.

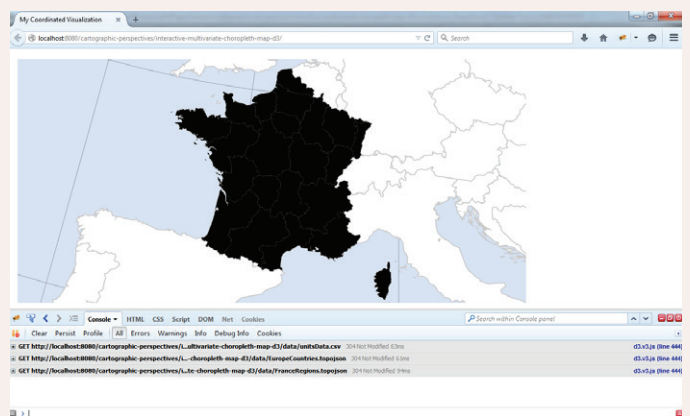


Figure 6. Drawing the enumeration units.

Reload your `index.html` file in your browser; you now should see your enumeration units plotted atop the basemap and graticule with a default black fill (Figure 6).

7. RELATING YOUR .CSV AND .TOPOJSON INFORMATION

YOU NOW ARE READY to load the `.csv` file containing your multivariate information so that you can color the enumeration units according to their unique attribute values.

Example 8 makes use of a file named `unitsData.csv`. Again note that this file includes a column with the `adm1_code` header for each region (Figure 1), which can be used to

```

1  queue()
2      .defer(d3.csv, "data/unitsData.csv") //load attributes data from csv
3      .defer(d3.json, "data/EuropeCountries.topojson") //load geometry
4      .defer(d3.json, "data/FranceRegions.topojson") //load geometry
5      .await(callback);
6
7  function callback(error, csvData, europeData, franceData){
8      //variables for csv to json data transfer
9      var keyArray = ["varA","varB","varC","varD","varE"];
10     var jsonRegions = franceData.objects.FranceRegions.geometries;
11
12     //loop through csv to assign each csv values to json region
13     for (var i=0; i<csvData.length; i++) {
14         var csvRegion = csvData[i]; //the current region
15         var csvAdm1 = csvRegion.adm1_code; //adm1 code
16
17         //loop through json regions to find right region
18         for (var a=0; a<jsonRegions.length; a++){
19
20             //where adm1 codes match, attach csv to json object
21             if (jsonRegions[a].properties.adm1_code== csvAdm1){
22
23                 // assign all five key/value pairs
24                 for (var key in keyArray){
25                     var attr = keyArray[key];
26                     var val = parseFloat(csvRegion[attr]);
27                     jsonRegions[a].properties[attr] = val;
28                 };
29
30                 jsonRegions[a].properties.name = csvRegion.name; //set prop
31                 break; //stop looking through the json regions
32             };
33         };
34     };
35
36     //add Europe countries geometry to map
37     var countries = map.append("path") //create SVG path element
38         .datum(topojson.feature(europeData, europeData.objects.EuropeCountries))
39         .attr("class", "countries") //assign class for styling countries
40         .attr("d", path); //project data as geometry in svg
41
42     //add regions to map as enumeration units colored by data
43     var regions = map.selectAll(".regions")
44         .data(topojson.feature(franceData,
45             franceData.objects.FranceRegions).features)
46         .enter() //create elements
47         .append("path") //append elements to svg
48         .attr("class", "regions") //assign class for additional styling
49         .attr("id", function(d) { return d.properties.adm1_code })
50         .attr("d", path) //project data as geometry in svg

```

Example 8. Relating your `.csv` and `.topojson` information within `setMap()` (in: `main.js`).

join each region's multivariate information in the `.csv` file to its geographic information in the `.topojson`.

Example 8 includes part of **Example 2**, which shows the use of the `d3.csv` function with `queue()` to load and parse `unitsData.csv`. The `d3.csv` function parses each row into an object using the column headings as *keys*, while `queue().await(callback)` passes the object to the callback function (**EX8: 4**). In order to attach the multivariate information from the `unitsData.csv` to the geographic information in `FranceRegions.topojson`, both sets of data must be accessed from inside the callback function, which must in turn be fully contained in `setMap()` to make use of the generator functions previously created.

In **Example 8**, a set of nested loops is used to attach the multivariate information contained in `csvData` to the `FranceRegions` topojson object as properties of each topojson `geometry` (feature). First, an array is created containing the attribute names for the attributes to be transferred, and the desired topojson geometries array is

assigned to a variable for neatness (**EX8: 9–10**). An outer loop then loops through each of the region objects in the `csvData` array, assigning each object to the variable `csvRegion` and assigning the region's `adm1_code` to the variable `csvAdm1` (**EX8: 12–15**). An inner loop then cycles through each topojson `geometry` object, testing whether that object's `adm1_code` matches the `adm1_code` from the `csvData` region (**EX8: 17–21**). If the region codes match, a final loop runs through each `key` in the `keyArray` and assigns the corresponding key/value pair from the `csvData` region object to the `properties` object of the topojson `geometry` (**EX8: 23–28**). Also within the `if` statement, the topojson region is assigned the name of the `csvRegion` (**EX8: 30**). Once the right match has been found and attribute values transferred, the `jsonRegions` loop can be broken to save on processing time (**EX8: 31**). If this loop structure remains unclear, it is recommended that you add `console.log` statements line-by-line to inspect how the `.csv` and `.topojson` contents are being manipulated and combined through the nested `for` loops.

8. STYLING YOUR CHOROPLETH MAP

NOW THAT THE MULTIVARIATE information in the `unitsData.csv` file is attached to the `FranceRegions` topojson object, you can color each region according to its unique attribute value. The example `csvData.csv` file contains five variables using the column headers “varA” through “varE” (**Figure 1**). Before implementing the choropleth styling solution, you first need to implement a method for determining which of the five variables should be represented in the choropleth map.

First, move the `keyArray` created within the callback in **Example 8** to the top of `main.js` to make it a global variable (**EX9: 2**). Since the keys contained by `keyArray` are hard-coded strings, they do not actually need to be inside of the callback. **Be sure to move this variable from within the `setMap()` function to the top of the `main.js` document, rather than duplicating it in both places in your code.** Declare a second global variable, `expressed`, which

indicates which of the keys in the `keyArray` is currently in use for coloring the choropleth map. Set the default index to `0`, or the first attribute in the `.csv` file. This index value can be changed later on to sequence through the different attributes.

Next, you need to add two new functions providing the logic for styling the choropleth map (**Example 10**): `colorScale()` and `choropleth()`. These functions are **external** to the `setMap()` function. The `colorScale()` function (**EX10: 1–23**) provides the logic for setting the class breaks using a *quantile* classification, which divides a variable into a discrete number of classes with each class containing approximately the same number of items. Quantile classification is supported natively by D3 through the `d3.scale.quantile()` generator function. Importantly, the `colorScale()` function takes the `csvData` object from the callback function as a parameter (**EX10: 1**),

```
1 //global variables
2 var keyArray = ["varA","varB","varC","varD","varE"]; //array of property keys
3 var expressed = keyArray[0]; //initial attribute
```

Example 9. Global variables for setting the choropleth variable (in: `main.js`).

```

1  function colorScale(csvData){
2
3      //create quantile classes with color scale
4      var color = d3.scale.quantile() //designate quantile scale generator
5          .range([
6              "#D4B9DA",
7              "#C994C7",
8              "#DF65B0",
9              "#DD1C77",
10             "#980043"
11         ]);
12
13     //build array of all currently expressed values for input domain
14     var domainArray = [];
15     for (var i in csvData){
16         domainArray.push(Number(csvData[i][expressed]));
17     };
18
19     //pass array of expressed values as domain
20     color.domain(domainArray);
21
22     return color; //return the color scale generator
23 };
24
25 function choropleth(d, recolorMap){
26
27     //get data value
28     var value = d.properties[expressed];
29     //if value exists, assign it a color; otherwise assign gray
30     if (value) {
31         return recolorMap(value);
32     } else {
33         return "#ccc";
34     };
35 };

```

Example 10. Functions for styling the choropleth map (in: main.js).

demonstrating the value of the AJAX solution. Because of this, the call to `colorScale()` must be added within the callback function, but before the `regions` block where the resulting scale will be used (EX11: 2). The `colorScale()` function first creates a `d3.scale.quantile()` generator named `color` and indicates the color scheme for the choropleth using the `range()` method, which specifies the scale's output (EX10: 3–11); a five-class, purple color scheme from ColorBrewer (colorbrewer.org) is used here. The `d3.scale.quantile()` method also requires an array of input values, specified using the `domain()` method. To

determine the quantile class breaks properly, the domain array must include all of the attribute values for the currently expressed attribute (note: an equal-interval classification can be created by instead passing a two-value array to `domain()` with just the minimum and maximum values of the expressed attribute). A loop through the `csvData` is used to push the expressed attribute value for each enumeration unit into a single array, which is then passed to the `domain()` method (EX10: 13–20). The `color` generator is returned to `setMap()` and stored locally in `recolorMap` (EX10: 19–EX11: 2).

```

1  function callback(error, csvData, europeData, franceData){
2      var recolorMap = colorScale(csvData);
3
4      //EXAMPLE 8 SUPPRESSED FOR SPACE
5
6      var regions = map.selectAll(".regions")
7          .data(topojson.feature(franceData,
8              franceData.objects.FranceRegions).features)
9          .enter() //create elements
10         .append("path") //append elements to svg
11         .attr("class", "regions") //assign class for styling
12         .attr("id", function(d) { return d.properties.adm1_code })
13         .attr("d", path) //project data as geometry in svg
14         .style("fill", function(d) { //color enumeration units
15             return choropleth(d, recolorMap);
16         });

```

Example 11. Styling the choropleth map in `setMap()` (*in: main.js*).

The `choropleth()` function then colors the enumeration units according to this quantile classification. The `choropleth()` function is called on the `style()` method in the `regions` block, within the callback function in `setMap()` (EX11: 13–15). The `choropleth` function takes two parameters: (1) a datum from the `FranceRegions` object associated with a given region (passed through the selection) and (2) the color generator, stored locally in the `recolorMap` variable. (EX11: 14). The `choropleth` function identifies the attribute value of the region under investigation (EX10: 25) and then checks if a value is valid (EX10: 27). If the value exists, the class color associated with that value's quantile is returned (EX10: 28); if it does not, a default grey is returned (EX10: 30).

Refresh `index.html` in your browser. Bingo! You now have a choropleth map (Figure 7).

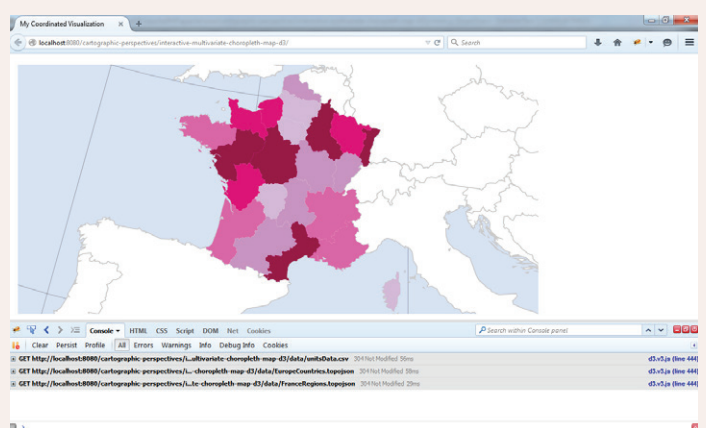


Figure 7. Styling the choropleth map.

9. IMPLEMENTING DYNAMIC ATTRIBUTE SELECTION

WITH THE MAP DRAWING PROPERLY, you are now ready to make it interactive. Interactivity changes a computer-generated map from static to dynamic, increasing both its utility and its aesthetic attraction for the user. D3 allows for an indefinite variety of map interactions, although implementing interaction behavior is not automatic and requires some creativity on the part of the developer. This tutorial will cover two dynamic interactions: user selection

of the represented attribute in this section, and highlighting of individual enumeration units with retrieval of details about the enumeration unit using a dynamic label.

Dynamic attribute selection requires an input control allowing users to choose the attribute they would like to see represented in the choropleth map. A simple and appropriate HTML input tool is the `<select>` element, which

```

1  function createDropdown(csvData){
2      //add a select element for the dropdown menu
3      var dropdown = d3.select("body")
4          .append("div")
5          .attr("class","dropdown") //for positioning menu with css
6          .html("<h3>Select Variable:</h3>")
7          .append("select");
8
9      //create each option element within the dropdown
10     dropdown.selectAll("options")
11         .data(keyArray)
12         .enter()
13         .append("option")
14         .attr("value", function(d){ return d })
15         .text(function(d) {
16             d = d[0].toUpperCase() +
17                 d.substring(1,3) + " " +
18                 d.substring(3);
19             return d
20         });
21     };

```

Example 12. Adding a dropdown menu in `setMap()` (in: `main.js`).

provides a dropdown menu with a list of options. As described above, creating new HTML elements using D3 involves the `.append()` method. At the end of the callback, add a call to a new function called `createDropdown()` and pass it the `csvData` object as a parameter; define this function below the `setMap()` function.

The first block (EX12: 2–7) selects the HTML `<body>` element and appends a new `<div>` element, giving it the class `dropdown` so that its position can be adjusted in `style.css`. The `.html()` method is used to simplify the creation of an `<h3>` element and its content (the title of the menu) within the dropdown `<div>`. The final line of the block appends a new `<select>` element (the menu itself). The second block (EX12: 9–20) then uses `.selectAll()` to recursively create each menu item, feeding in the `keyArray` so that each string in the array (e.g., “varA”) is used as a datum for a selection. For each selection, an `<option>` element is appended to the parent `<select>` element, and the selection’s datum is assigned as the value of the `<option>` element’s `value` attribute. The text content of the `<option>` element is assigned using the `.text()` method, which contains a function that uses JavaScript string methods to manipulate the datum for plain English display to

the user (EX12: 15–20). In `style.css`, a `.dropdown` selector should be added with a `margin-left` property to adjust the position of the dropdown menu div on the page.

In order to enable the attribute selection dropdown, an event listener must be added that will update the choropleth map when the user changes the selected attribute. D3 uses `.on()` as the primary method for adding event listeners. This method specifies the type of event and a function that will execute when the event is fired. HTML `<select>` elements use the “change” event to determine when a user has selected a new menu item. Use the `.on()` function to add a “change” event listener and trigger the `changeAttribute()` function when this event is fired (EX13: 8–10). The `changeAttribute()` function contains the code that restyles the map according to the selected attribute (EX13: 14–23). First, the `expressed` variable is reassigned with the attribute option selected by the user (EX13: 16). Then, the `path` elements of all of the existing regions on the map are selected and restyled by the `choropleth()` function using a new `color` generator. Recall that the `colorScale()` function sets the scale range using the `.csv` data values of the expressed attribute, as shown in Example 10.


```

1  function createDropdown(csvData){
2      //add a select element for the dropdown menu
3      var dropdown = d3.select("body")
4          .append("div")
5          .attr("class","dropdown") //for positioning menu with css
6          .html("<h3>Select Variable:</h3>")
7          .append("select")
8          .on("change", function(){
9              changeAttribute(this.value, csvData);
10         });
11
12     //REMAINDER OF EXAMPLE 12 AND EXAMPLE 10 SUPPRESSED FOR SPACE
13
14     function changeAttribute(attribute, csvData){
15         //change the expressed attribute
16         expressed = attribute;
17
18         //recolor the map
19         d3.selectAll(".regions") //select every region
20             .style("fill", function(d) { //color enumeration units
21                 return choropleth(d, colorScale(csvData)); //->
22             });
23     };

```

Example 13. Adding an event listener and callback function (in: main.js).

10. IMPLEMENTING HIGHLIGHTING AND DYNAMIC LABELS

THERE ARE TWO STEPS left for completing the interactive choropleth map: (1) providing visual feedback when probing an enumeration unit (i.e., *highlighting*) and (2) activating a tooltip (i.e., a *dynamic label*) supporting the retrieval of details about the probed enumeration unit. You will create three functions to make these work: (1) `highlight()`, which restyles the probed enumeration unit and populates the content for the dynamic label on `mouseover` (EX14: 11), (2) `dehighlight()`, which reverts the enumeration unit back to its original color and deactivates the dynamic label on `mouseout` (EX14: 12), and (3) `moveLabel()`, which updates the position of the dynamic label according to changes in the x/y coordinates of the mouse on `mousemove` (EX14: 13). The event listeners should be added at the end of the `regions` block in `setMap()` (EX11: 6–15) to make each enumeration unit in the choropleth interactive, making sure you update the position of the semicolon that ends the block.

When implementing highlighting across features that are styled differently (as with the varying color scheme in a

choropleth map), it is necessary to store the original color of the highlighted feature for when the feature is subsequently “dehighlighted”. This approach is faster than re-processing the JSON object. The solution in **Example 14** appends the original color as a text string in a `<desc>` SVG element (EX14: 14–17). The contents of the `<desc>` element then can be referenced to extract this color when reverting the enumeration unit to its original choropleth styling upon `dehighlight()`. Note that for highlighting to work properly for all attributes, the `<desc>` element should be selected and reset at the end of the block in the `changeAttribute()` function, as shown in **Example 15**.

Once adding the event listeners to the `regions` block of `setMap()`, you then must define the event handler functions. First, add a new function named `highlight()`, which should be defined outside of `setMap()` (EX16: 1–19). The `highlight()` function receives the `data` object associated with highlighted enumeration unit as the parameter. The `data` object’s properties are stored in a local variable named `props` (EX16: 3). The `highlight()`

```

1    var regions = map.selectAll(".regions")
2        .data(topojson.feature(franceData,
3            franceData.objects.FranceRegions).features)
4        .enter() //create elements
5        .append("path") //append elements to svg
6        .attr("class", "regions") //assign class for styling
7        .attr("id", function(d) { return d.properties.adm1_code })
8        .attr("d", path) //project data as geometry in svg
9        .style("fill", function(d) { //color enumeration units
10           return choropleth(d, recolorMap);
11       })
12       .on("mouseover", highlight)
13       .on("mouseout", dehighlight)
14       .on("mousemove", moveLabel)
15       .append("desc") //append the current color
16           .text(function(d) {
17               return choropleth(d, recolorMap);
18           });

```

Example 14: Adding event listeners to regions in setMap() (in: main.js).

```

1    function changeAttribute(attribute, csvData){
2        //change the expressed attribute
3        expressed = attribute;
4
5        //recolor the map
6        d3.selectAll(".regions") //select every region
7            .style("fill", function(d) { //color enumeration units
8                return choropleth(d, colorScale(csvData)); //->
9            })
10           .select("desc") //replace the color text in each desc element
11               .text(function(d) {
12                   return choropleth(d, colorScale(csvData)); //->
13               });
14    };

```

Example 15. Resetting the <desc> element in changeAttribute() (in: main.js).

function then calls `d3.select()` to find the SVG path for the region, using the `adm1_code`, and changes its `fill` style to black (EX16: 5–6). There are many other possible highlighting solutions; this one was chosen for simplicity.

The `highlight()` function then designates two HTML strings used in the dynamic label, one with the attribute data (`labelAttribute`) and one with the region name (`labelName`) (EX16: 8–9). Note how the `labelAttribute`

variable makes use of the global `expressed` variable to determine the attribute to include in the label. As above, you are encouraged to adjust the content of the dynamic label based on the purpose of your map. Finally, the `highlight()` function creates a new `<div>` element named `infolabel` to hold the dynamic label (EX16: 11–19). A child `<div>` named `labelname` is added to `infolabel` to position the region name within the label.

```

1  function highlight(data){
2
3      var props = data.properties; //json properties
4
5      d3.select("#"+props.adm1_code) //select the current region in the DOM
6          .style("fill", "#000"); //set the enumeration unit fill to black
7
8      var labelAttribute = "<h1>"+props[expressed]+
9          "</h1><br><b>"+expressed+"</b>"; //label content
10
11     var labelName = props.name; //html string for name to go in child div
12
13     //create info label div
14     var infolabel = d3.select("body").append("div")
15         .attr("class", "infolabel") //for styling label
16         .attr("id", props.adm1_code+"label") //for label div
17         .html(labelAttribute) //add text
18         .append("div") //add child div for feature name
19         .attr("class", "labelname") //for styling name
20         .html(labelName); //add feature name to label
21 };
22
23 function dehighlight(data){
24
25     //json or csv properties
26     var props = data.properties; //json properties
27     var region = d3.select("#"+props.adm1_code); //select the current region
28     var fillcolor = region.select("desc").text(); //access original color from desc
29     region.style("fill", fillcolor); //reset enumeration unit to original color
30
31     d3.select("#"+props.adm1_code+"label").remove(); //remove info label
32 };

```

Example 16. Highlighting and de-highlighting the choropleth map (in: main.js).

Add style rules to the dynamic label in *style.css*, using the `infolabel` and `labelname` class identifiers. **Example 17** provides basic style rules to create a 200×50px dynamic label with white text and a black background. Note that the `<h1>` and `` tags are styled for the `infolabel` text (**EX17: 17–26**), as these are used in the `labelAttribute` HTML string (**EX16: 8**); you are not limited to these tags in the design of your dynamic label.

Reload your *index.html* page in your browser and inspect your work. At this point, mousing over an individual enumeration unit should result in highlighting the unit and retrieving the associated attribute value in a label (**Figure 8a**). The `dehighlight()` function must be implemented to revert the enumeration unit to its original color and deactivate the dynamic label (**EX16: 21–30**). First, the

properties of the `data` object for the selected enumeration unit are stored in the `props` variable (**EX16: 24**). Then the enumeration unit itself is selected and the text within its `<desc>` element is retrieved and assigned to the variable `fillcolor` (**EX16: 21–30**). The selected region is assigned this color as its fill (**EX16: 27**). Finally, the dynamic label is selected using its id and removed (**EX16: 29**).

Although the enumeration units should now correctly highlight and dehighlight, the dynamic label is positioned away from the map itself rather than near the highlighted region. To make the dynamic label follow the user’s mouse cursor, first change the positioning of the `svg` map container to `absolute` in *style.css* (**EX17: 1–3**); this should be defined early in the stylesheet so it may be overridden

```

1  svg {
2      position: absolute;
3  }
4
5  //EXAMPLES 4 & 6 SUPPRESSED FOR SPACE
6
7  .infolabel {
8      position: absolute;
9      width: 200px;
10     height: 50px;
11     color: #fff;
12     background-color: #000;
13     border: solid thin #fff;
14     padding: 5px;
15 }
16
17 .infolabel h1 {
18     margin: 0;
19     padding: 0;
20     display: inline-block;
21     line-height: 1em;
22 }
23
24 .infolabel b {
25     float: left;
26 }
27
28 .labelname {
29     display: inline-block;
30     float: right;
31     margin: -25px 0px 0px 40px;
32     font-size: 1em;
33     font-weight: bold;
34     position: absolute;
35 }

```

Example 17. Styling the dynamic label (in: *style.css*).

by individual class rules. Then, define the `moveLabel()` function in *main.js* that is called on `mousemove` atop an enumeration unit (**Example 18**). The `moveLabel()` function uses the `d3.event()` method to access the current mouse event (`mousemove`), which includes mouse coordinate properties (`clientX` and `clientY`). The function simply accesses the mouse coordinates of the event and uses them to offset the label in relation to the `body` element,

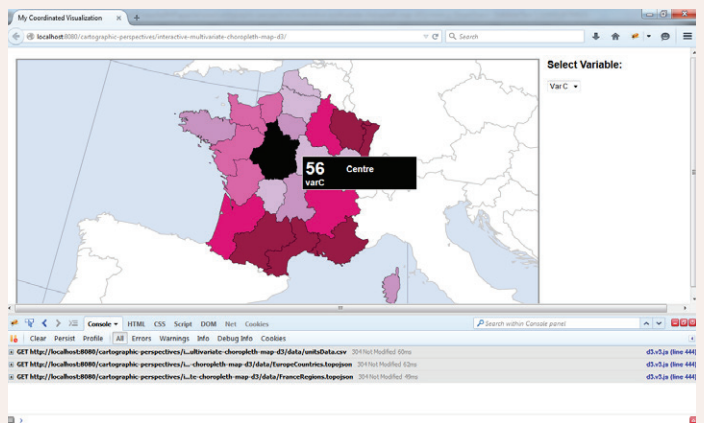
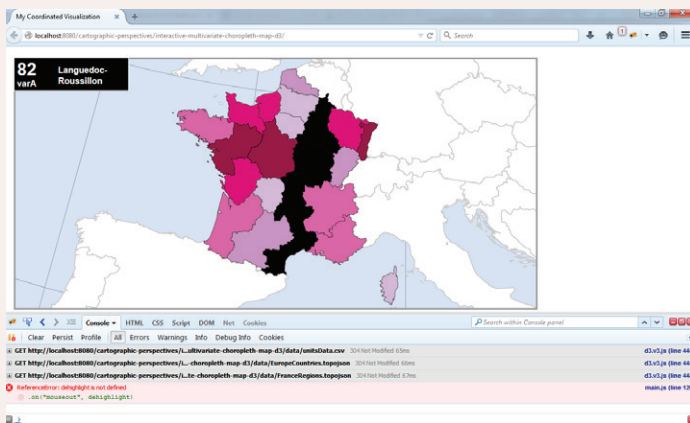
the lowest DOM element that is relatively positioned. If you changed the size of the dynamic label in *style.css*, you need to adjust the horizontal and vertical label coordinates according to the revised width and height (**EX18: 3–4**). Reload the *index.html* page; you now should be able to mouse over each enumeration unit, resulting in highlighting of the enumeration unit and activation of a dynamic label that follows the mouse (**Figure 8b**).

```

1  function moveLabel() {
2
3      var x = d3.event.clientX+10; //horizontal label coordinate
4      var y = d3.event.clientY-75; //vertical label coordinate
5
6      d3.select(".infolabel") //select the label div for moving
7          .style("margin-left", x+"px") //reposition label horizontal
8          .style("margin-top", y+"px"); //reposition label vertical
9  };

```

Example 18. Styling the dynamic label (in: main.js).



Figures 8a (left) and 8b (below). Implementing highlighting and tooltips in the choropleth map.

DOING MORE WITH D3

AT THIS POINT, you should be comfortable with the essential workings of D3’s mapping functionality. This tutorial has covered finding and formatting data, converting geographic data into GeoJSON and TopoJSON formats, asynchronously loading data into the browser, using D3 Projections and a D3 Geo Path generator to draw a graticule and basemap, styling the basemap based on one of multiple attributes, creating a dropdown menu to allow the user to select between attributes, and implementing some interactions for retrieving information from the choropleth map.

Much more can be done with the example data provided than has been covered here. D3 provides many different types of visualizations that allow for dynamic data journalism (for examples: github.com/mbostock/d3/wiki/Gallery). These may be used independently or have their interactions linked through the magic of JavaScript. The authors hope that this toehold into the world of D3 lowers the bar for readers seeking to experiment with new web-mapping technologies, and that you will contribute to the growing canon of interactive multivariate web maps that follow sound cartographic principles.

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Introducing the Patterson Cylindrical Projection

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The Patterson cylindrical, a new projection designed for general-purpose mapmaking, is an alternative to other cylindrical projections. It is positioned between the Plate Carrée projection, which has a 1:2 aspect ratio, and the Miller 1 projection, which excessively exaggerates the size of polar areas. The Patterson cylindrical balances polar exaggeration against maintaining the familiar shape of continents and has a compact height-to-width aspect ratio. Creating the projection started with a graphical template made in Flex Projector that served as a guide for developing the polynomial equations, which are introduced in this article. The reference source code is available in the Java Map Projection Library.

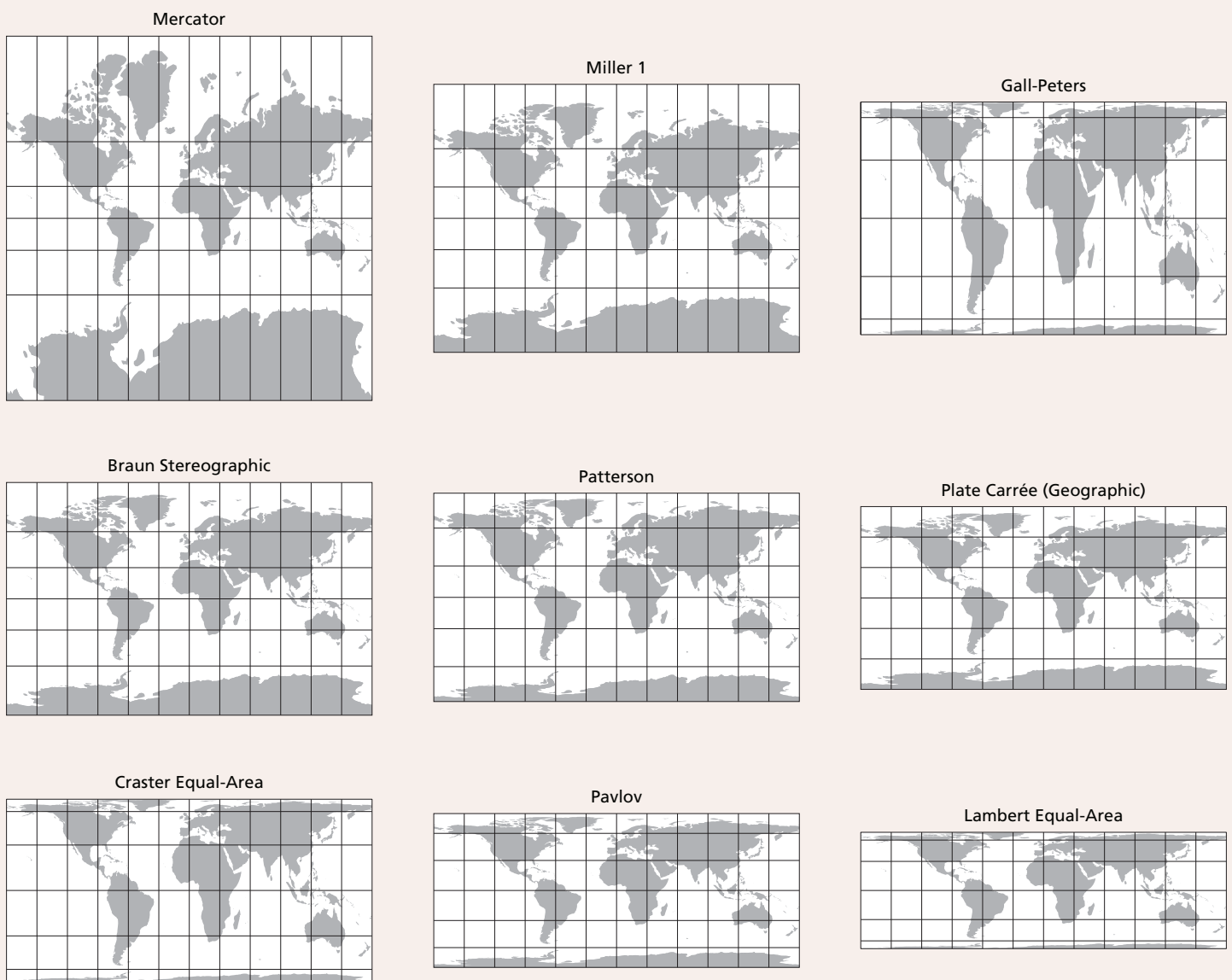


Figure 1. The Patterson (middle) compared to other commonly used cylindrical projections.

DESIGN OF THE PATTERSON CYLINDRICAL PROJECTION

CYLINDRICAL MAP PROJECTIONS depict the nearly spherical Earth as a rectangle, showing meridians and parallels as straight lines. The North and South Poles, actually points on the Earth, appear as lines across the top and bottom of the map. Designing a cylindrical projection therefore requires finding, for higher latitude areas, a compromise between two extremes: maintaining the general shape of map features and exaggerating their relative area, or vertically compressing map features and maintaining their area. One extreme is the conformal Mercator projection, developed for navigation during the age of sail, which grossly exaggerates high-latitude areas; the other extreme is the family of equal area cylindrical projections, such as the Gall-Peters, Craster, or Lambert cylindrical, which come at the expense of vertically compressed and deformed shapes (Figure 1). The Patterson projection is an addition to a variety of existing compromise cylindrical projections (Jenny et al. 2015), but has its own unique traits. The Patterson packages the world in a relatively compact rectangle with a height-to-width aspect ratio of about 0.57. The exaggeration of high-latitude areas is considerably lessened compared to the Miller 1 and other similar projections.

The Patterson projection derives from the Miller 1 projection, modified graphically using Flex Projector software (Jenny et al. 2008; 2010). The Miller 1 projection, introduced by Osborn Maitland Miller (Miller 1942; Monmonier 2002), was a good starting point because it depicts features in tropical and mid-latitude regions with relatively balanced proportions. For example, the tapered

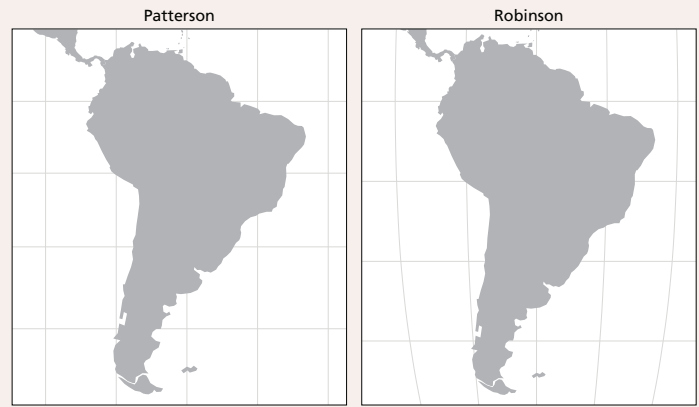


Figure 2. Excerpts of world maps with the same width centered on 0 north, 60 west. The proportions of South America on the Patterson projection are similar to that of the Robinson, a pseudocylindrical projection.

shape of South America does not look too stretched or stubby and compares favorably to the popular Robinson projection (Figure 2). The Miller 1 and Patterson projections are nearly identical between 55 degrees north and south latitude, where most of the people on Earth live.

Developing the Patterson cylindrical projection involved three steps. In the first step, we modified the Miller 1 projection, which resulted in the Compact Miller projection. In the second step, we compressed higher latitudes, which resulted in a graphical template for the Patterson projection. In the third step, we developed the projection equations.

STEP 1: DESIGNING THE COMPACT MILLER PROJECTION

UNLIKE THE MILLER 1, which has increasing spacing between lines of latitude moving from the equator toward the poles, we first applied constant spacing to high-latitude regions. Beyond 55 degrees, the spacing between lines of latitude remains constant, as on an equirectangular projection. This adjustment yielded the intermediate Compact Miller projection, which compresses polar areas in comparison to the Miller 1 projection (Figure 3). The design considerations for the development of the Compact Miller projection and its equations are described by Jenny et al. (2015).

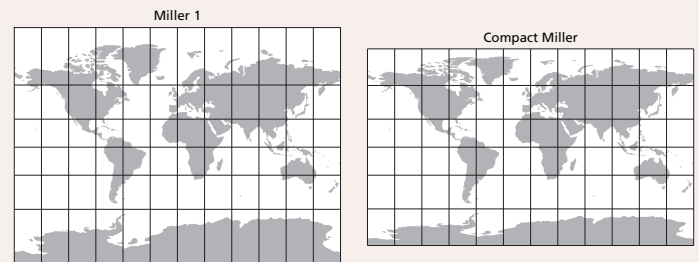


Figure 3. The Miller 1 and Compact Miller, an intermediate production step, are identical from latitude 55 north to 55 south.

STEP 2: DESIGNING THE PATTERSON PROJECTION

ALTHOUGH THE COMPACT MILLER greatly reduces the area of polar regions compared to the original Miller 1, Antarctica and the high arctic still appear disproportionately large. For example, Greenland, actually roughly equal in area to the Indian subcontinent, appears excessively large in the Compact Miller projection. A partial solution to this problem was to reduce the distance between lines of latitude poleward of 65 degrees. In Flex Projector, we applied the most compression to areas immediately adjacent to the poles. The compression gradually diminishes, and ends at about 65 degrees latitude. This adjustment created a graphical template of the Patterson cylindrical projection for which the final equations were developed (Figure 4).

One concern when applying polar compression was to maintain the distinctive shape of Alaska and other landmasses at high latitudes. Figure 5 shows the relative distance between lines of latitude for the Patterson projection, which steadily increase in length moving from the equator to 55 degrees, level off around 60 degrees, and then decrease toward the poles. This pattern is a distinguishing trait of the Patterson projection, as all other commonly used cylindrical projections do not vary latitudinal distances in this manner. On the Patterson projection, the polar compression is only obvious when a graticule with latitude increments of 15 degrees or less is used.

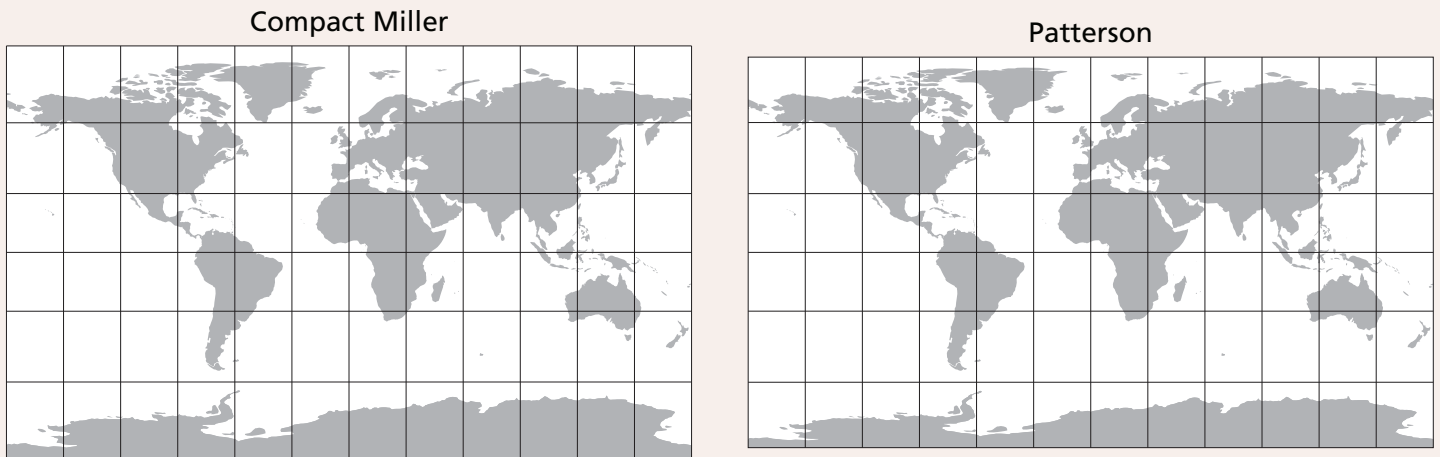


Figure 4. Compared to the Compact Miller, the Patterson has compressed polar regions.

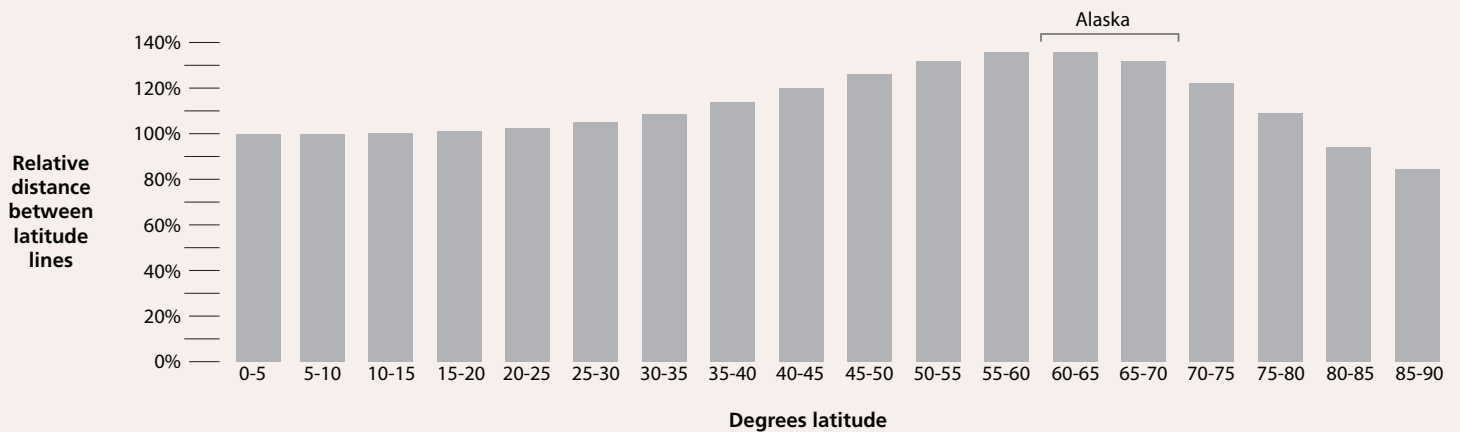


Figure 5. Relative distance between latitude lines on the Patterson projection.

STEP 3: FINDING EQUATIONS FOR THE PATTERSON PROJECTION

THE LAST STEP involved developing polynomial equations approximating the Flex Projector template for the Patterson projection. The process was similar to that used for the Natural Earth projection (Šavrič et al. 2011). Between 55 degrees north and south latitude, the polynomial equation does not exactly match the Miller 1, but the differences are only noticeable at high magnification near 15 degrees latitude. Equation 1 transforms spherical longitude and latitude coordinates to projected coordinates.

$$\begin{aligned}x &= \lambda && \text{(Equation 1)} \\y &= c_1 \cdot \varphi + c_2 \cdot \varphi^5 + c_3 \cdot \varphi^7 + c_4 \cdot \varphi^9\end{aligned}$$

In Equation 1, x and y are the projected coordinates, φ and λ are the latitude and longitude, and the polynomial coefficients are $c_1 = 1.0148$, $c_2 = 0.23185$, $c_3 = -0.14499$, and $c_4 = 0.02406$. The computational cost per point consists of six multiplications and three additions when the polynomial in Equation 1 is factorized as in Equation 2:

$$y = \varphi \cdot (c_1 + \varphi^2 \cdot \varphi^2 \cdot (c_2 + \varphi^2 \cdot (c_3 + \varphi^2 \cdot c_4))) \quad \text{(Equation 2)}$$

To convert projected coordinates to spherical coordinates, the Newton-Raphson method is used to find the latitude φ from the y equation; longitude λ is computed by inverting the x equation.

AVAILABILITY

THE PATTERSON CYLINDRICAL projection is currently available in the latest version of Flex Projector (available for free at flexprojector.com). With Flex Projector, you can make maps from vector and raster geospatial data (Figure 6). If the Patterson projection is not yet offered in

your favorite cartographic or GIS software, please direct the developer to the Java Map Projection Library (github.com/OSUCartography/JMapProjLib) to obtain the reference source code.

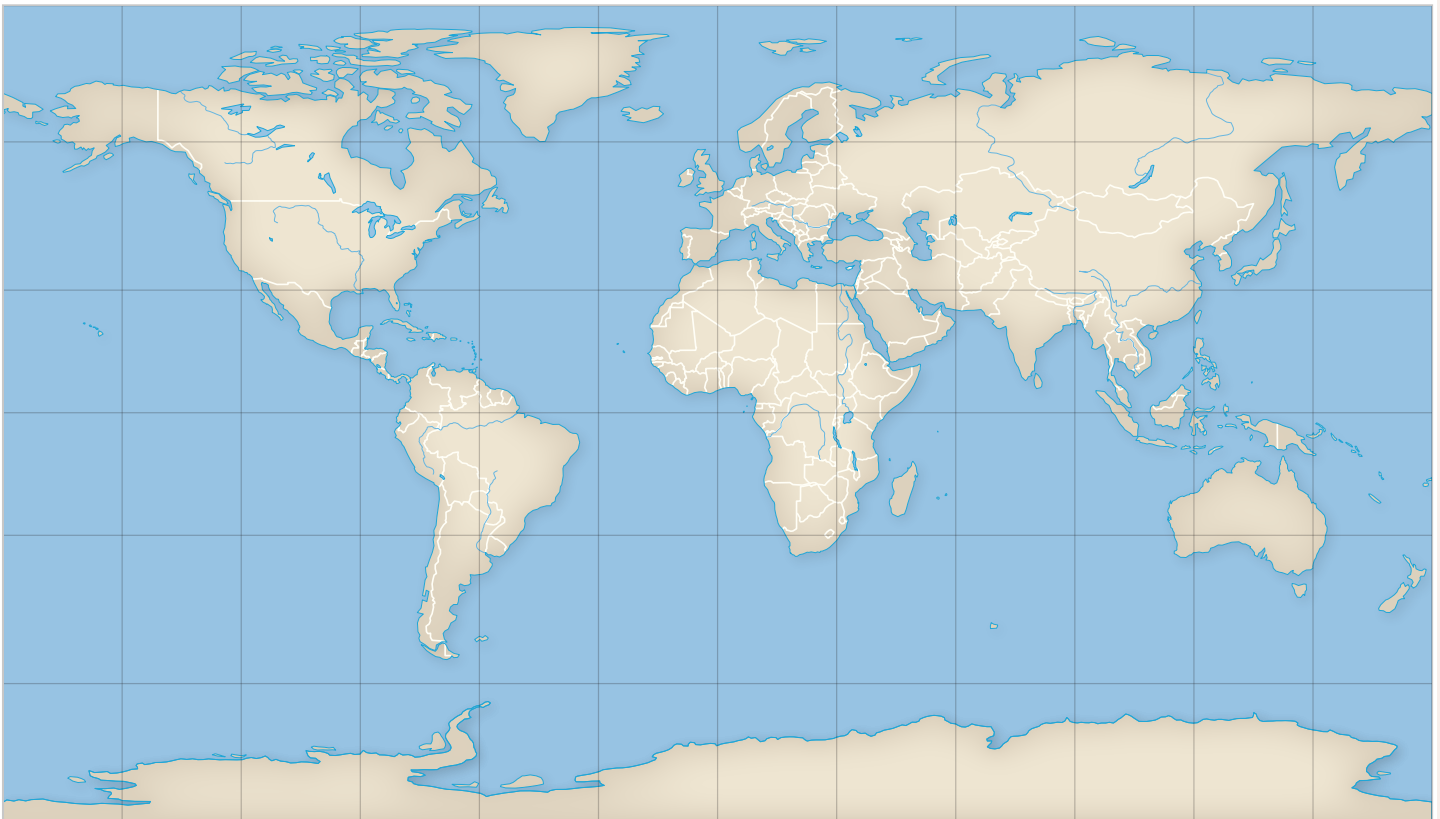


Figure 6. Map with the Patterson projection created with Flex Projector using Natural Earth 110m vector data.

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"Course of Empire"

MY PROCESS INVOLVES the excavation, intervention, and reconstruction of remnants from the past. I employ printed matter as a surrogate for paint, using maps in particular to facilitate a deliberate symbolic palette and to simulate the gesture of a brushstroke. Their palette is deliberate and symbolic, helping to internalize the external. I sort and catalog my collection of maps according to their formal and contextual properties, creating an archive from which I draw upon to compose my work. Then I precisely cut and inlay fragments of maps and other ephemera into the picture plane, creating a unified surface.

I began collecting and working with maps as a new medium in 2002. I use maps as raw material to depict the

tenuous relationship we have with our environment. As visual aids to our cognitive understanding of spatial complexity, maps also embody a textual, representational, and abstract depiction of our milieu. The pictorial façade of my work is assembled upon this linguistic and conceptual infrastructure, challenging the polarizing notions of representational and abstract art. Rather than seeing cartography as the cognitive representation of our environment, I have repurposed cartography as a substance with which to depict the pictorial illusion of our reality.

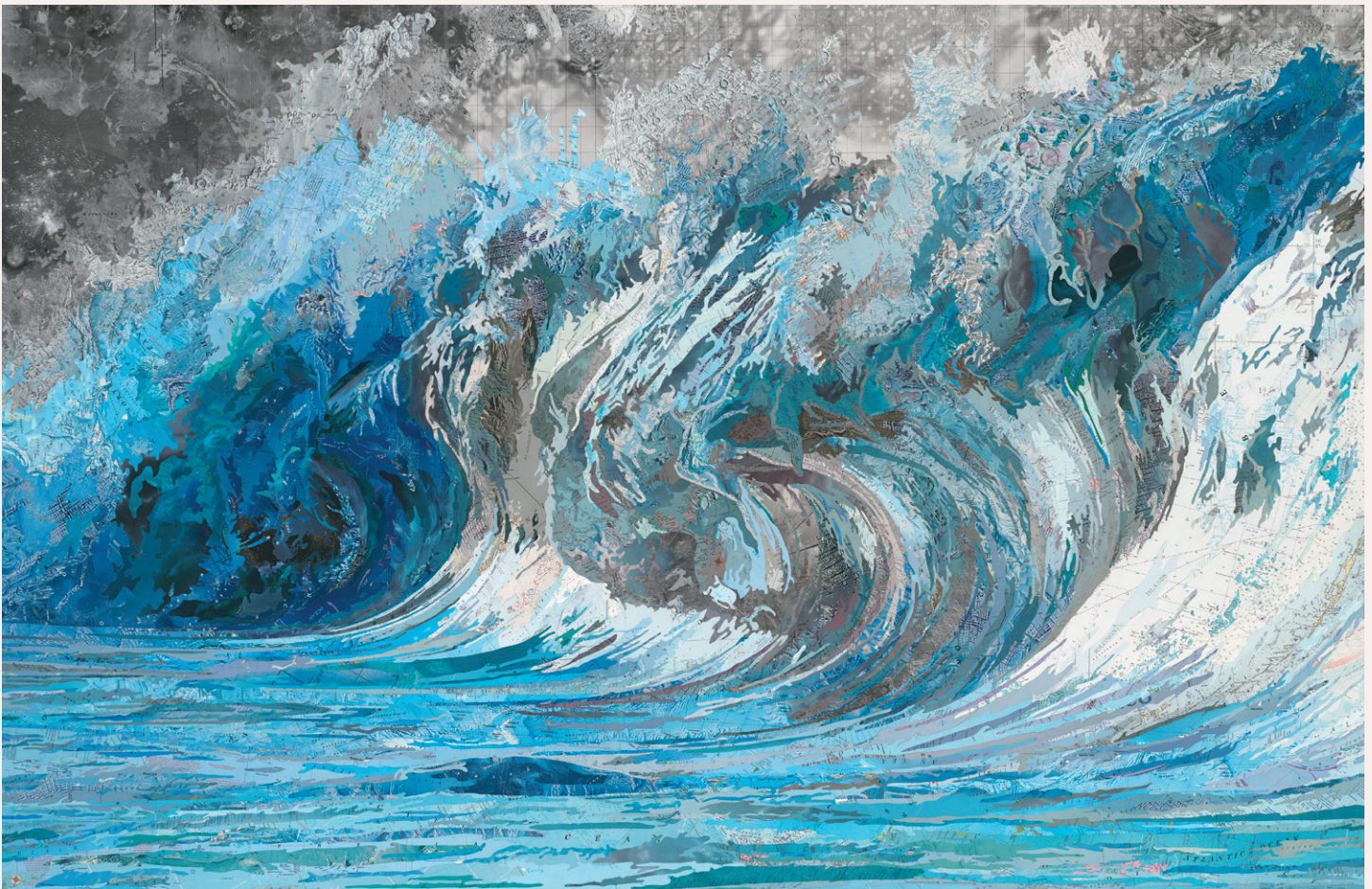
Maps are a perfect union of science and art, and their inherent beauty and visual complexity continue to inform my aesthetic choices. The Map Work collages integrate

mythology with territory by rendering my subject matter with the authentic relics of its own timeline and history. Each map fragment is a representation of an existence and an index of a specific time and place. The merging of dissimilar map fragments into the matrix of an illusory image allows for the rendering of hybrid geographical timelines

and topographies while also generating contemporary meaning from obsolete narratives. The Map Works are essentially conceptual mosaics: pictures composed of dislocated, yet related fragments of maps that have a story waiting to be revealed beneath their precisely crafted surface.

Matthew Cusick's work has been shown in galleries and institutions across the United States and Europe including solo exhibitions at the Columbus Museum of Art, Pavel Zoubok Gallery, Kent Fine Art, and Andrew Kreps Gallery. Matthew has been a visiting artist and lecturer at The Cooper Union, The University of Nevada, Las Vegas, and The Dallas Museum of Art and his work is held in numerous public and private collections around the world, including the Museum of Contemporary Art San Diego, the Nasher Sculpture Center, and the Progressive Corporation Art Collection. Since 2007 he has lived in Dallas.

All images courtesy of the artist and Pavel Zoubok Gallery.



"Genevieve's Wave"



"Empire Revisited"



"Many Rivers"



"Chasing the Dragon"

Visual Fields focuses on the appreciation of cartographic aesthetics and design, featuring examples of inspirational, beautiful, and intriguing work. Suggestions of works that will help enhance the appreciation and understanding of the cartographic arts are welcomed, and should be directed to the section editor, Laura McCormick: laura@xnrproductions.com.

NACIS 2015: Call for Participation



Minneapolis

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Abstracts due May 31st

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Love maps, data, visual storytelling, and cartographic design? Make your plans now to participate in the Annual Meeting of the North American Cartographic Information Society in Minneapolis, Minnesota: October 14th–17th, 2015. Join with other professionals and enthusiasts from government, commercial, and not-for-profit groups along with academics, scholars, map/GIS librarians, artists, technologists, and students. Visit nacis.org/2015 for more details, including hotel reservations.

We'd love for you to be a part of our program in Minneapolis! You are invited to submit proposals for traditional presentations or you can organize custom sessions, panels, discussions, and workshops. We encourage presentations related to our theme of *Mapping Interactions*, but all cartographic topics are welcome! Visit us at nacis.org/abstracts to tell us how you'd like to participate. **Online submissions are due by May 31st** at nacis.org/abstracts. Please send questions to program chair Amy Griffin: veep@nacis.org.

In addition to participating in the main program, you can also get involved in one of our two all-day preconference events:

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Rosemary Wardley and Carolyn Fish
pcd@nacis.org

GEOGRAPHIC DATA COLLECTIONS DAY

This all-day session will focus on cartographic and geographic data collections management. New ideas welcome!

Abraham Kaleo Parrish and Tsering Wangyal Shawa
gdcd@nacis.org

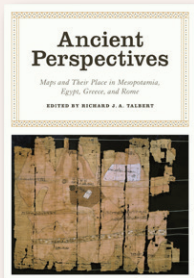
MORE WAYS TO PARTICIPATE

Map Gallery: Display your latest creation for all to ponder throughout the meeting.

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ANCIENT PERSPECTIVES: MAPS AND THEIR PLACE IN MESOPOTAMIA, EGYPT, GREECE, AND ROME



Edited by Richard J. A. Talbert.

The University of Chicago Press, 2012.

280 pages, 9 color plates, 82 halftones, 34 line drawings. \$65.00, cloth.

ISBN: 978-0-226-78937-8

Review by: Robert Cioffi, Bard University

Cartography has a long and diverse history, at once scientific, artistic, political, and social. It is precisely this history that forms the subject of the seven essays in *Ancient Perspectives*, the most recent volume from the Kenneth Nebenzahl, Jr., Lectures in the History of Cartography series. First delivered in November 2007 at the Newberry Library in Chicago, these lectures marked the twentieth anniversary of the first volume of the monumental *History of Cartography*, edited by J. B. Harley and David Woodward. Now published together in 2012, they seek to build upon the groundbreaking work of Harley and Woodward by reevaluating our understanding of ancient cartography in light of the scholarly developments of the past quarter century.

Ancient Perspectives spans some two and half millennia and four cultural contexts: Mesopotamia, Egypt, Greece, and Rome. The Classical world, which is the focus of five of the seven contributions, remains front and center, but, by combining the study of the Greco-Roman context with other related ancient cultures, Talbert's volume stands out from other recent contributions to the history of cartography. While it is not light reading, *Ancient Perspectives* has embraced its mission to make each contribution accessible to non-specialists in other fields. Almost all ancient terms have been translated, and readers will be pleased by the generous supply of maps, diagrams, photographs, and color plates. Contributors tend to stick to well-established consensus on most points of interpretation. As a result, the volume rarely engages with the nexus of theoretical approaches from disciplines such as urban studies,

anthropology, and cultural geography that have come to characterize the “spatial turn” in the study of the ancient world. Contributors have preferred instead to collect, organize, and present ancient evidence.

What, then, counted as a map in antiquity? In Classical Latin *mappa* was the word for a napkin. Quite apart from the challenge of distinguishing dirty linen from cartography, the difficulty of defining a map is compounded by the absence of unambiguous ancient terminology for one. Contributors to *Ancient Perspectives* have operated with broad definitions to include building plans, charts of the heavens, instructions for constructing a map, and even textual representations of the world. While strict cartographic constructionists might balk, the advantage of casting such a wide net is that it shows the pervasive influence of what might be termed “cartographic thinking”: maps are shown to be deeply intertwined with all aspects of ancient society.

Mesopotamia offers both the earliest examples of historical maps and some of the most plentiful and diverse cartographic traditions. In her chapter, “The Expression of Terrestrial and Celestial Order in Ancient Mesopotamia,” Francesca Rochberg skillfully navigates this rich material, tracing the representation of space from the home to the cosmos. The majority of her chapter organizes cuneiform maps by topic (house plans, temple plans, field plans and cadastral surveys, city maps, regional maps, world maps, and the divine celestial landscape); this organization reflects her observation that there is “no coherent tradition” of cuneiform cartography (13). Throughout, Rochberg highlights the broader significances of spatial representation, concluding: “Various orders of power are implicit in the expression of these aspects of order in the environment. Administrative and economic powers support, or even require, the making of maps, as well as determining overtly the topographies that maps depict” (43). Her dense chapter, laden with examples, allows little room for detailed analysis of these various orders of power, but it provides the reader judicious guidance for further exploration

and it presents a sophisticated, thoughtful, and reliable introduction to a fascinating body of ancient material.¹

If Mesopotamia offers an overabundance of maps, there are far fewer examples from Egypt. David O'Connor's chapter, "From Topography to Cosmos: Ancient Egypt's Multiple Maps," suggests that the paucity of our evidence can be best explained by archaeologists' focus on excavating temples rather than administrative centers. Through an analysis of "maplike" artifacts, he emphasizes the pervasiveness of cartographic thinking in Egyptian art and text, ranging from the "world map" of Seti I (ca. 1290–1279) from the Karnak temple at Thebes, which depicts the Pharaoh smiting foreign foes, to the vignettes of the "Book of the Fayum," which encode the region's geography, cosmography, and sacred landscape. The connections between cartography and art can also be seen in the only extant map from Pharaonic Egypt. Probably drawn by the scribe Amenakhte in the 12th century BCE, the so-called Turin Papyrus Map depicts the Wadi Hammamat, a riverbed route that connected the Nile Valley to the Red Sea. With remarkable precision, the map blends schematic and pictorial representations of the landscape, illustrated mountains, quarried bekhen-stone blocks, and the pebbled surface of the wadi bed. Despite the scarcity of extant maps, this chapter elucidates rich connections between cartography, texts, and religious art in ancient Egypt and it shows how deeply mapping was integrated with the rest of Egyptian culture.

Two closely linked chapters examine the traditions of Greek world mapping. Georgia L. Irby's "Mapping the World: Greek Initiatives from Homer to Eratosthenes," does not, despite its title, feature any ancient maps. She cautions: "We cannot know how many Greek maps were produced, or what exactly their content and purpose may have been. The different materials on which they were presented have rarely survived" (84). Instead, she traces the development of Greek cartographic thinking from Homer to the Hellenistic period, emphasizing the ideological implications of the study of geography in ancient Greece and the tension between empirical and philosophical bases for cartography. Her account points to two major catalysts for Greek cartographic revolutions: first, scientific thinkers from Miletus, whose influence reverberates especially in

fifth-century Athens, and, second, Alexander the Great, whose campaigns fundamentally altered Greek views of the known world. The chapter culminates in Eratosthenes' measurement and mapping of the earth—the "acme" of Greek theoretical cartography (100)—and Hipparchus' criticisms of his methodologies and data. Irby's contribution traces the development of Greek cartography through an impressive range of sources and serves as a useful reference. Its heavy focus on summarizing sources and reconstructing their maps, however, leaves less time for exploring some of the most interesting questions it poses, such as the way in which "maps are an important expression of Greek culture" (105).

The second chapter on Greek cartography, Alexander Jones's "Ptolemy's *Geography*: Mapmaking and the Scientific Enterprise," is much more narrowly focused. A second-century CE text written in Greek, Ptolemy's *Geography* may not have included a map, but it certainly provided its readers with detailed instructions on how to make one. Jones examines and explains with remarkable clarity the "theoretical presuppositions" that lie behind this highly technical work, as he situates it in its intellectual context. Reading the *Geography* in dialogue with Ptolemy's other works, he focuses particularly on Ptolemy's epistemology and relationship to his predecessors. According to Jones, although Ptolemy vociferously criticized the data collection of his forerunner Marinus, his coordinate system for plotting the world was fundamentally agnostic about what it represented and the resulting map was "unpolitical" (125). He writes: "Strikingly, Ptolemy does not give the slightest indication that there exists such an entity as the Roman empire. . . . The center of the map is not Rome or Alexandria, but the Persian Gulf" (125). While Jones is certainly right to point to Ptolemy's independence from the Roman *Weltanschauung*, even a decision not to acquiesce to Rome's world view could be interpreted as an act of resistance (think of Galileo). In fact, Ptolemy's decentering of the eternal city might be understood as running parallel to Rome's absence in other Greek authors of the second century CE. This thought-provoking chapter is highly recommended for anyone studying Ptolemy's *Geography*.

Michael Lewis's chapter, "Greek and Roman Surveying and Surveying Instruments," builds upon his 2001 book *Surveying Instruments of Greece and Rome* (Cambridge). Combining experimental archaeology with close reading of ancient sources, Lewis reconstructs the instruments and

1. Readers should be aware, as Leif Isaken has pointed out in a review published online in the *American Journal of Archaeology* 117.4 (2013), that an important recent article by Stephanie Meece in *Anatolian Studies* 56 (2006), 1–16 has reinterpreted the wall painting from Çatal Hüyük, which Rochberg identifies as a map (10–11), as an image of leopard.

methodologies of ancient surveying and engineering, by means of which the Romans were able to record and transform their landscape. He demonstrates that Greek surveying was primarily accomplished by the *dioptra*, a circular instrument that could be used both vertically and horizontally. Roman surveyors had a more sophisticated toolkit, including the *libra*, which Lewis argues was a highly precise balance equal in precision to a modern level. His chapter concludes with a series of case studies, which suggest how Greeks and Romans might have employed such tools to construct roads, aqueducts, and tunnels. This chapter crosses into a world of engineering where few Classicists have dared to tread and it provides us with a much clearer picture of the complexities and challenges of Greek and Roman construction projects. Lewis is to be commended on making such a technical subject so accessible.

Richard J. A. Talbert's chapter on Roman cartography, "*Urbs Roma to Orbis Romanus: Roman Mapping on the Grand Scale*," focuses on monumental cartographic projects and their relationship to Roman power. Talbert collects an impressive range of examples which demonstrate the intimate connections between representing the world and owning it: monumental cadastral plans recording Roman centuriation (division) of newly acquired territory, a "shape" or "outline" (*forma* in Latin) of Sardinia dedicated in commemoration of the island's subjugation, the enormous marble plan of Rome known as the *Forma Urbis Romae*, and even a "picture of the world" (*orbis depictus*) placed in a rhetorical school in Augustodunum (modern Autun, France). To these monumental and ideologically-charged maps, Talbert seeks to add two examples about whose context we know considerably less, the map of Agrippa and the Peutinger Map. Although no trace of Agrippa's map survives, it is described by Pliny the Elder as containing "the lands of the globe for the city to look at" (*orbis terrarum urbi spectandus*). Such language, which suggests a connection between empire and cartography, is consistent with a map, but it does not entirely rule out an equally monumental textual inscription along the lines of Augustus' own *Res Gestae*. In the case of the Peutinger, a medieval copy of what is likely a fourth-century CE original, Talbert presents an abbreviated version of the argument advanced in his 2010 volume, *Rome's World: The Peutinger Map Reconsidered* (Cambridge). His close analysis of the artifact allows him to show that Roman ideology is reflected in the map's most basic features, such as its choice of center (Rome), its extent (from Britain to India), and its variable scale (Italy is depicted larger and in greater

detail than anywhere else). More controversial, however, is his suggestion that the map was originally a monumental display piece, which may have hung as part of a globe image in an apse behind the emperor's throne. Talbert is the world's leading expert on the Peutinger Map and he is right to demand a sophisticated analysis that does justice both to the artifact and to its intellectual context, but his account would have also benefited from some consideration of the possibility that it was originally drawn on papyrus. This possibility, already suggested by its long, thin shape and the way its artist distorted the map to fit such a constricted medium, receives further support from the recently discovered Artemidorus Papyrus, which appears to use a similar iconography for depicting settlements, topographical features, roads, and waterways. Taken together, the artifacts' shared visual language for cartographic description may, in fact, reflect another genre of maps not for public display.

The final chapter turns from Roman artifacts to Roman texts. In "Putting the World in Order: Mapping in Roman Texts," Benet Salway considers the textual cartography of documentary, epigraphic, and literary sources. This chapter begins from the observation that texts impose a specific order on the way that geography is to be read. Salway's contribution, which is divided topically rather than generically, reacts against the scholarly trend to "downplay the role of graphic illustration in the description of geographic information by the Romans" (193). By examining the organization of itineraries, the mapping of continents, and the ordering of tribes, legions, and Roman provinces, Salway argues that "there is some circumstantial evidence for familiarity with cartographic images, either in informing the organization of the material or for facilitating its comprehension" (230). His argument is a persuasive one, based on close reading of documentary and inscriptional evidence, which could be further extended to even more literary texts, such as Roman poets (many of whom show a great deal of interest in geography), orators, and authors of prose fiction.

In light of this volume's admirably broad coverage in limited space, it is perhaps unfair to lament what it is missing. Nonetheless, I think that many readers would appreciate more explicit connections between mapping traditions across cultures, especially given the emphasis placed in the Introduction on the interrelatedness of Greco-Roman, Mesopotamian, and Egyptian mapping. Cross-references between entries tend to be superficial, with each chapter

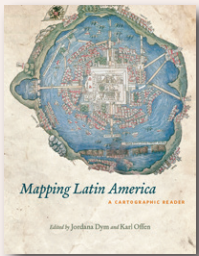
appearing to have been developed independently. Some atomization is to be expected given the diversity of fields represented in this volume, but there seem to have been several missed opportunities for fruitful connections (e.g., between the Book of the Fayum and Salway's contribution or between the Turin Papyrus and the Peutinger Map).

The most regrettable absence, in terms of coverage, is the Artemidorus Papyrus. Although it is mentioned twice (7; 106n.4), it never receives any serious consideration. In addition to its importance as an example of Greco-Roman cartography, it might also have helped to connect several authors' contributions. The papyrus was first widely publicized in 2006 and was subsequently published in full in 2008. Its front contains an unfinished map of an unidentified territory, excerpts from geographical texts including the work of the Greek geographer Artemidorus, and remarkably realistic sketches of human faces, hands, and feet. The back features a menagerie of some forty sketches of exotic animals, many of which are accompanied by

Greek labels. Although a vocal minority of scholars initially claimed the papyrus to be a fake, a series of articles in 2009 have led most scholars to accept it as a genuine artifact. As such, it provides important evidence for Greco-Roman cartographic practices, and I have no doubt that the combined expertise of the contributors to this volume could have made significant and timely interventions in the scholarly discussion about it.

Ancient Perspectives is a very welcome addition to an exciting and rapidly growing field in the study of the ancient Mediterranean. Talbert and his fellow contributors have brought together into a single volume a sweeping analysis of the mapping traditions of the ancient Mediterranean and Near East, which as a whole makes a powerful argument for the pervasiveness of ancient cartographic practice and the importance of studying the ancient Mediterranean and the Near East together. For specialists and non-specialists alike, this book will be an important reference and a catalyst for further research on this important topic.

MAPPING LATIN AMERICA: A CARTOGRAPHIC READER



Edited by Jordana Dym and Karl Offen.

University of Chicago Press, 2011.

360 pages, 118 color plates, 12 halftones, 1 line drawing. \$40.00, paperback.

ISBN: 978-0-226-61822-7

Review by: Judith Tyner, Professor Emerita, California State University Long Beach

Although *Mapping Latin America* would appear, from the title, to be a history of Latin American cartography, it is much more. As the subtitle indicates, the book is a reading of various maps throughout the history of Latin America. They are used not to simply illustrate a place or time period, but are “read” for their meaning and significance to the time.

The book is organized chronologically with three major sections: Colonial, Nineteenth Century, and Twentieth Century. Each of those sections is divided into thematic subsections that deal with particular map types. The editors, Karl Offen and Jordana Dym, a geographer and a historian respectively, have put together a first-rate multidisciplinary team of fifty-four contributors. Some

contributors come from geography, history, and Latin American Studies, as would be expected, but others are from archaeology, anthropology, city planning, economics, and environmental science. There are fifty-seven well-written articles, each of which is illustrated by at least one color map, for a total of ninety-eight maps. It is a real plus to have all of the maps in color and within the essays rather than grouped in a color signature.

In a brief but cogent foreword, Matthew Edney speaks of new views of maps and cartography, and notes that the essays in the book embody those new (since 1980) approaches to the history of cartography. He observes that the maps discussed are examined “in terms of the societies and culture in which they were made and consumed.” In many older histories of cartography, the context of a map’s making was generally ignored.

Regardless of whether one reads the book cover to cover or dips into subjects of particular interest, the Introduction by the editors is a must-read. It is an excellent discussion of current thinking on the study of maps. The authors note that they were frustrated with the limited use of maps in the study of Latin America, as maps were usually used

only for location or to show distribution of products. In this chapter, which draws on the work of Woodward and Harley, the editors provide the now requisite discussion of “what is a map?” and a section titled “How to read maps”. Defining “map” is important here because most of the maps illustrated are not the conventional maps of traditional histories of cartography, but include such non-traditional types as transit maps, chamber of commerce maps, propaganda maps, and *arpilleras*—fabric maps of political resistance stitched by women. Many of these map types have been ignored by cartographic historians in the past as not being “real” maps.

How to read maps might seem at first to be an elementary subject for a book of this type, but it is crucial to understanding these discussions. Here the editors are not referring to how to use a road map to find the way from Point A to Point B, but to reading the meaning of maps, to analyzing and interpreting them. They provide a reading of a map of the Bolivar Railway as an opening to the Introduction and go on to discuss how title, legends, scale, projection, and symbols impact the interpretation of maps. Importantly, they discuss putting a map into the context of its time and technology. These last two contexts are often

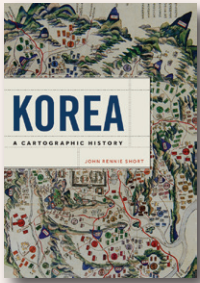
ignored in studies of maps as material culture and can lead to serious misinterpretations.

The editors also provide introductory essays for each of the chronological sections that discuss the period and mapping during that time. These nicely set the scene for the chapters that follow and are helpful for those readers who might be interested in the maps, but are not familiar with Latin American history.

Each essay has notes at the end and a list of resources/bibliography, but at the end of the book is a section titled “Additional Resources.” This is not simply a list of references, but is an essay in itself discussing the literature of the various topics that form the basis of the book, such as “Maps, Lies, and Silences,” “Critical Cultural Cartography,” and “Maps as Art” as well as “National Cartographies” and “Scientific Missions.” It is a succinct review of the literature on the subject of mapping Latin America.

Mapping Latin America could be used as a model of how to create a multi-disciplinary work and I highly recommend it.

KOREA: A CARTOGRAPHIC HISTORY



By John Rennie Short.

University of Chicago Press, 2012.

160 pages, 71 color plates. \$50.00, cloth.

ISBN: 978-0-226-75364-5

Review by: Jonathan F. Lewis, Benedictine University

Having produced more than forty books about geography, urban development, and the history of cartography, John Rennie Short knows how to construct a focused and readable manuscript. *Korea: A Cartographic History* displays to good effect his writing and research skills in this short history of Korean cartography copiously illustrated with color plates.

Inspired by his late father, a veteran of the Korean War, Short directs his book toward a general audience rather than experts in historical cartography. He begins his

task with a brief description of global space and how Korea’s cartographic legacy fits into the narrative of that concept’s development and diffusion. He quickly documents the existence of this process by showing how two different regions generated similarly self-centered world maps at almost exactly the same time, using as examples one of Korea’s oldest maps (centered on East Asia) and a European world map made using Ptolemy’s *Geographia*. Each leaves unknown areas blank, which is to say everything that appears on the other region’s map (plus the Americas, an area unknown in both regions). A third map, produced in Korea a few centuries later, demonstrates the changes that cultural contact with the Jesuits and Chinese had by that time wrought on Korean mapmaking. By the book’s end, Korean cartography reflects mapping practices common throughout the world, with results comparable to maps made in other parts of the globe.

Short divides his book into three chronologically successive sections to explain how this convergence came about:

the early Joseon period in Korea (covering the 15th through the 16th centuries), the late Joseon period (covering the 17th through the 19th centuries), and the modern period of the 20th and 21st centuries. His first section (“Separate Worlds”) consists of two chapters. Given the enormous span of time involved in reaching the 17th century, the first chapter’s coverage is necessarily brief, identifying the major dynasties and monarchs shaping Korea’s political development and cultural practices. Short makes clear that key to both of those was the centrality of China, an influence that the country retains to this day. For example, until the 15th century, Korea’s written language utilized Chinese characters and literacy was restricted to a very small segment of the population. Even after a more popular version of the language appeared, Chinese script remained in use for official documents (including maps) for several hundred years. Though dominated by their much larger neighbor, Korean monarchs in the Joseon period saw an opportunity to legitimate their own authority over a distinct area by identifying themselves with the land they ruled, a process that relied on maps to help visualize both the country itself and the society inhabiting it. This visualization included landscape painting, another area greatly influenced by Chinese practices, and resulted in representations of land appearing throughout Korean political culture. Not surprisingly, professional landscape painters often became professional producers of pictorial maps. Short describes several of the more prominent mapmakers whose styles had an enormous impact on those who followed. Chong Ch’ok, for example, created national and provincial maps for two successive kings that had the effect of uniting in one detailed visual image what had previously been a disparate area. Demonstrating both the country’s diverse approaches to mapping and to the author’s commitment to acknowledge that variety, Short concludes this chapter with a description of a very different mapping tradition, one having more spiritual than administrative purposes. Connected with the Zen monk Doseon, this approach saw “the landscape as alive with energy or life force... A correct reading of the landscape to maximize positive energy was essential for the proper siting of graves, shrines, houses, temples, palaces, and other buildings” (26).

Short then devotes a chapter to Europe’s depictions of the Korean peninsula, beginning with reference to the Silk Road, whose easternmost terminus was in Korea. Traveler Marco Polo’s stories of his time in China included references to Korea, but it was not until descriptions from other travelers supplemented this information that European

maps began to include Korea. Foremost among these was Fra Mauro’s famous global map, “one of the first European maps to show the islands of Japan and to suggest the peninsula of Korea” (33). Europe’s persistent unfamiliarity with the area led it to produce a variety of different representations as more knowledge of Asia was acquired from merchants connected with the burgeoning spice trade, and augmented by observations from Christian missionaries. Entirely comfortable with their comparative obscurity, Korea’s leaders had no interest in encouraging greater contact with the outside world. This lack of knowledge led Korea to appear in European maps in one of three ways: “Korea unknown, Korea as an island, and Korea as a peninsula” (40), complicating European mapmakers’ attempts to complete their objective of creating a global gridded space.

In his book’s second part (“Cartographic Encounters”), Short examines influences on Korea’s mapmakers coming from East Asia, understandably beginning with China. Chinese cartographers, who by the 18th century had adopted longitude and latitude from European mapmakers, had access to Korea that Westerners did not. They produced hybrid maps of that region which combined Western practices with existing indigenous procedures. Given its later importance, Japan surprisingly had little impact on Korean cartography, possibly because Korea did not generate much interest among Japan’s mapmakers.

Due to Europe’s increasing contact with East Asia, it is also included in the chapter on Korea’s neighbors. Given their cold and sometimes hostile reception, Europeans generated representations consisting almost exclusively of outlines having no information about the country’s interior, which remained *terra incognita* for a very long time. Though a Jesuit priest became the first European to visit Korea in the late 16th century, for example, it would be another hundred years before Europeans generated first-hand written accounts of the country. The ability of Korea’s leaders to remain outside this expanding system was limited, however, as “Korea, despite its insularity, was gridded and plotted as part of a universal mapping endeavor, being incorporated into the production of global space and becoming part of the modern world” (73). The country’s resistance to becoming known did not prevent it from appearing on maps.

The third chapter in this section distinguishes between the early and late Joseon dynasty and explains how maps from

those periods reflected political struggles of their time. The neo-Confucian social order, for example, emphasized a respect for tradition, and a world atlas produced in the early 18th century contained only maps of China, Manchuria, and Korea, following the style of an atlas produced two centuries earlier. Some of the most interesting and beautiful maps in Short's book appear here, including a particularly striking type, *Cheonhado*, which "depict a circular world centered on East Asia, with the rest of the world on the margins" (86). Bearing a great resemblance to circular European world maps from two centuries earlier, these center on Tibet's Mount Kunlun and include a tree on both the east and west sides to indicate the direction of the rising and setting sun. Although the geography of the outside world was much better understood by Korean cartographers at this point, atlases continued to present Korea in a comfortably familiar Sinocentric world.

But this upholding of tradition could not withstand pressures for producing more scientifically informed maps containing updated information on the peninsula's interior. Short identifies several key figures crucial to this development. Their significant accomplishments included "maps made to a common scale, explicit use of the grid to organize and present geospatial data, and greater use of geodetic data ... Korea's first globe ... [and the] *Korean Geography Book* which described the geography of the country and defined the latitude and longitude of every Korean city" (94–96). One cartographer from this period, Kim Jeong-ho, became something of a national folk hero, as his humble background and devotion to hard work resulted in a map Short particularly admires as something of a hybrid between old and new mapping practices.

Tragically, this epoch closed with violent encounters between Korea and Western powers as Europeans, Americans, and Japanese exerted pressure to open the country to trade. Short documents this key period with maps of treaty ports where foreigners were awarded sweeping rights and permitted access to trade, the results of military defeat. They also were headquarters for Christian missionaries who began to build schools, hospitals, and churches. Though reluctant to employ the term "imperialism" to describe these developments, Short includes enough information to allow readers to reach their own conclusions about how a reclusive people came to relinquish their economic and religious practices in exchange for those from a region possessing superior firepower and

assisted by maps detailing the region they were determined to control.

Part Three ("Representing Korea In The Modern Era") continues the story of Korea's domination by other countries, beginning with Japan, whose comparatively stable and peaceful relationship with Korea ended as the Joseon regime lost power and Japan became more militaristic. Korea sought an isolationist approach that reinforced its close relationship with China, but the Sino-Japanese War of 1894–5 gave Japan considerable control over Korea, which it annexed in 1910. Japanese cartographers subsequently mapped their new territory in a manner reflecting colonial interests and objectives. This most prominently included identification of resources that could benefit the imperial homeland, such as food used to offset shortages in Japan and title to land—with large foreign landowners better able to register and protect their holdings than Koreans having smaller parcels. It also included suppression of the Korean language, reflected in maps by the replacement of Korean names with Japanese ones, revision of some names to more Japanese-sounding equivalents, and sometimes simply to the elimination of Korean names with no Japanese substitutions.

Short's book does not cover the Second World War, and instead moves directly to its aftermath, in which the Korean peninsula was promptly swept up in Cold War politics. In a history strikingly similar to that of China, the country was claimed by two politically opposed leaders, with the one backed by Western leaders having formed a government-in-exile during occupation and the opposing communist leader having participated directly in guerilla action against the Japanese. Outside political leaders arbitrarily imposed a line dividing the country in half along the 38th parallel, ignoring provincial boundaries altogether. Short concisely and effectively summarizes the subsequent military conflicts that led to the 1953 Armistice, a document that included a map depicting the current boundary. Yet because the Armistice was not signed by South Korea, considerable tension remained over how the peninsula would ultimately be mapped.

Short's subsequent chapter briefly examines maps produced of and by the two Koreas. The peninsula's division in a sense expresses its earlier history, with the North retreating into the kind of isolation often found in the early Joseon period while the South's incorporation into the global capitalist economy has led it to expand mapping

initiatives. While the North seeks to withdraw from the view of outsiders (unsuccessfully, given the power of the Internet and such services as Google Maps), the South sets the peninsula's past history aside as it encourages tourism, producing maps that enable outsiders easily to make their way around—for example—the Southern capital of Seoul. Short's example of a 2002 map of Seoul offers a combination of contemporary mapping practices and traditional landscape rendering that can be seen as either an attempt to balance historic, indigenous Korean mapping practices with contemporary scientific approaches or as an effective exercise in postmodern composition. Short's writing makes it clear that he sees it in terms of the former, but readers having different training are likely to see the latter as additional evidence of Korea's convergence with developments in the larger global culture.

Short concludes his book with a chapter describing three cartographic controversies that appear in contemporary Korean mapping. The first involves efforts by both North and South to depict the peninsula as far more unified than it actually is. Both sides cast the area as one nation and identify their own capital as the real (indeed, the only) national capital city. While the demilitarized zone is not entirely ignored, it usually appears as an obscure, thin line, not an internationally acknowledged boundary.

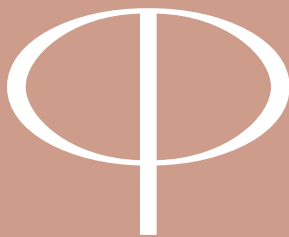
The second controversy involves the proper name of the body of water lying between Korea and Japan. Short provides an excellent summary of both the importance of place names and the difficulty of obtaining consensus on features shared by two countries, and then follows with a historical account of the reasons for Korea to identify as the East Sea what appears on Japanese maps as the Sea of Japan. But just as Korea's history was directly affected by China and Europe, so too is this debate over proper nomenclature. In the last portion of this section, Short encourages a compromise name that South Korea has suggested which accepts both names in a new one: East Sea / Sea of Japan (in contrast with North Korea's preferred East Sea of Korea). He encourages Japan to "embrace a more effective global citizenship. Japan needs to accept its colonial legacy in order to transcend it" (147).

The third mapping controversy centers on the island of Dokdo and the rocks surrounding it, roughly 135 miles east of the Korean Peninsula. An area also claimed by Japan, Short points out that Dokdo has for centuries appeared on Korean maps as part of its territory. In fact, Japanese rulers in the late 17th century acknowledged as

much, but two centuries later a more expansionist and militaristic Japan claimed control over the area, a claim solidified after Korea was subsequently ceded to Japan. After Japan's defeat in 1945, its claims to Korea were made void and Dokdo once again became contested space. Currently, Korea's claim seems the more solid one, as it has constructed a lighthouse there and declared the island a National Monument. Its only occupants are two Koreans. Short concludes this section, and his book, by pointing out the way in which earlier maps have been used to argue for historic claims to territory, despite their admitted shortcomings.

Overall, Short accomplishes exactly what he proposed: a brief but compelling introduction to the role of cartography in Korea's history, designed for the general reader. Although it includes some clear judgments about current cartographic controversies, the book avoids entanglement in the politics of North and South, seeing both as extensions or expressions of earlier cartographic struggles during Korea's long Joseon period. Such contextualization will benefit contemporary readers baffled by what may appear to them as North Korea's odd and unprecedented quest for removal from the global community or its receptivity to advice from China. Moreover, the book's historical sections provide informative insights into the mapping traditions of other areas. His summation of Japanese cartographic history, for example, as well as French efforts to map Korea's interior are particularly well done, making it easy to splice Korea's history and cartographic story with other, larger narratives. Another of the book's strengths is the number of color illustrations and their placement. Nearly all images are in vibrant color and located on the same page they are described. General audiences will find this arrangement (which is not as common as most readers would expect) allows them to engage more readily with the book's arguments, and the pages have ample margins where readers can jot notes. If there is one clear shortcoming in the book's design, it is the lack of an index.

Taken as a whole, *Korea: A Cartographic History* is a successful overview of Korea's history and introduction to the many beautiful maps produced by its cartographers and by mapmakers from other areas. Those interested in learning more about the subject matter can find a list of suggested readings located immediately at the narrative's end. It is well designed, attractive, clearly written, and represents a solid addition to the collection of anyone interested in its topic.



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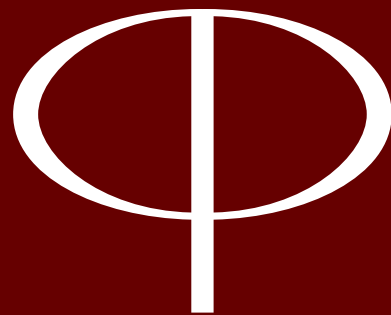
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Cartographic Perspectives

The Journal of **naics**



Number 78, 2014

