Geography Compass 8/5 (2014): 325–335, 10.1111/gec3.12129

Placing the River in Context: James C. Knox, Fluvial Geomorphology, and Physical Geography†

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Abstract

We characterize the fluvial geomorphology research of James C. Knox by considering five of his scholarly papers, selected to illustrate not only some of Knox's methods and results but also his conviction that stream-sediment interactions are intricately connected to a range of environmental variables reflecting the scope of physical geography. Those variables, as we discuss, included hydrology, climate, vegetation, position in the drainage network, and human land use. We conclude with the suggestion that Knox's breadth of geomorphic vision was echoed in his approach to his own academic career, and his belief that academic institutions are best served by broad and integrative perspectives.

Introduction

One could argue that over the past half-century, no fluvial geomorphologist in the world generated more research (~90 publications), enlightened and influenced more scientists, advised and encouraged more graduate students (55 MS advisees; 30 PhD advisees), or taught more undergraduates (typically >400/semester) than James Clarence Knox.

Born, raised, and schooled (in part) in southwestern Wisconsin's unglaciated "Driftless Area," Knox dedicated himself to detailing the Pleistocene, Holocene, and Anthropocene history of his home region while teaching and mentoring hundreds of students in Geography and allied disciplines at the University of Wisconsin. His research approach was perhaps most notable for his insistence on careful analysis of the details of alluvial deposits ("you gotta do the stratigraphy!"), combined with a sophisticated understanding of environmental processes that allowed for extrapolation from those stratigraphic details to an understanding of how river behavior responds to (and provides a record of) a variety of environmental changes at different temporal and spatial scales ("think about the big picture!").

His techniques of analyzing and interpreting alluvial deposits were carried by his students to locales across the continent, establishing what has been informally termed the "Knox School" of geomorphology. For Knox, while the actual physics of river behavior (flood energy, water-sediment interactions) was important, the emphasis was on river responses to even subtle changes in the surrounding environment. He demonstrated that painstaking analysis of the sediments deposited by the river could elucidate not just the physical processes of the river at the time the sediments were being deposited but also the local and regional environmental conditions at that time. Thus, Knox championed the study of rivers not just in the narrow sense of running water, sediment, and the landforms produced by their interaction but also in the broader context of rivers interacting with the full scope of the surrounding environment (including the humans affecting that environment). That is, with all of physical geography.

In some regard, Knox's work was not unique. The research methods that underlay his research situated him squarely in the midst of the "revolution" then occurring in fluvial geomorphology that sets measurement, statistical analyses, and theoretical emphases on process-response systems at the center of the subdiscipline (Chorley 2008). At the same time, use of sedimentary records to quantify past fluvial events was also coming into its own (Baker 2008), and Knox was not alone in relating paleohydrologic change to environmental (especially climatic) change, as he himself noted in a detailed review (Knox 2000). Nor were Knox's conclusions universally accepted (Trimble 1989, see Knox 1989 for a response). But he was particularly influential because of the rigor and breadth of vision with which he combined those elements and the thoughtfulness with which he interpreted them. Indeed, the Association of American Geographers stated, while honoring him just months before his death, "It is difficult to imagine what the subdiscipline of physical geography would look like today without [his] extraordinary contributions." (AAG Newsletter 2012, p. 5). And although Knox's audience and scholarly renown were cross-disciplinary, his work was particularly resonant amongst geographers because he chose to submit major papers to the *Annals of the Association of American Geographers*, rather than more clearly "scientific" earth science journals (Graf 2013).

Our purpose in this essay is to illustrate the breadth of view with which Knox linked fluvial geomorphology to the rest of physical geography and indeed the breadth of his commitment to the discipline. The intent is not to survey all of his research nor to analyze its quality and impact (but see Graf 2013 for an example of the latter approach). Instead, we seek to highlight examples that show the type of connections that made Knox influential, not just among his fellow fluvial geomorphologists but also to scholars across the broader terrain of physical geography.

Toward this end, we have selected particular papers that exemplify his interpretive linkages between stream behaviors and various other elements of physical geography. Although each of these articles deals with complex questions and multiple interactive causes, each does emphasize a particular aspect of the environment, allowing us to highlight Knox's thinking about the role of specific factors in affecting fluvial processes. We begin with water, the most fundamental aspect of the river.

Hydrology… in Which Sediments Reveal Flood Histories

The key to much of Knox's fluvial research was the calculation of flood histories for periods of the Holocene through interpretation of alluvial deposits. Point-bar stratigraphies, the depth of sediment accretions on flood plains, the size of sediment particles entrained by floodwaters, the dimensions of relict stream channels, and the degree of soil development reflecting periods of stability in the sedimentary record—all were combined with hydrologic equations and dating techniques (radiocarbon determinations, ages of human artifacts, including trace minerals from mining, and carefully calibrated estimates based on the depth of overlying sediments) to generate histories of floods. Temporal changes in the magnitudes of floods were then related causally to changing environmental factors.

Knox provided a detailed description of some of his techniques for linking flood histories to alluvial characteristics in a (1985) paper on the Holocene history of streams in southwestern Wisconsin. For this analysis, he took cores across multiple floodplain sites to identify buried relict channels, which were recognizable because the sediment filling them was texturally distinct from the lateral accretion deposits that made up the channel banks. He then used the dimensions of the buried channels to estimate the discharge of the channels' bankfull floods. The magnitude of the flood that just fills the channel to capacity without overflowing the banks is significant because typically it is the modal discharge in a long-term record of annual flood peaks, with a recurrence interval of about 1.58 years. Thus, changes in the bankfull flood represent changes in the magnitude of the oft-occurring floods that shaped the channel, a good marker of overall changes in a river's flood regime.

Knox found that the magnitude of the bankfull floods has varied episodically over the past 10,000 years (Figure 1). In the early Holocene, such floods were smaller than comparable floods today, reaching a nadir between 8000 and 7000 years BP when they were 20% to 30% smaller than their modem counterparts. A sequence of notable periods then appears in the record: first, large floods (10% to15% greater than today's) after about 6000 BP; second, small floods (10% to 20% smaller) between about 4500 and 3000 years BP; and third, larger floods of contemporary magnitudes after about 3000 BP (albeit with a brief period of smaller floods between 2000 and 1200 BP). Knox saw in this carefully constructed flood record a strong link to Holocene climatic fluctuations, a topic next to be discussed.

Climate… in Which Flood Histories Reflect Climate Variability

For Knox, the cause of the episodic Holocene history of changing floods, and its associated history of alluvial deposits, is change in climate. For example, in the study discussed above, the variations in Holocene bankfull discharges link to climatic changes: The small floods of the early Holocene are associated with a warm and dry period, the larger floods since 3000 BP with cooler and wetter conditions. In addition, Knox argued, the linkage between fluvial and atmospheric systems occur at differing scales, embracing not only floods with relatively short recurrence intervals, such as the bankfull discharges discussed above, but also larger floods that occur only rarely (i.e., with long recurrence intervals).

Knox focused on such high-magnitude floods in an evaluation of the sensitivity of flood regimes to climate change in southwestern Wisconsin (Knox 1993). In this study (which earned him the Grove Karl Gilbert Award for Excellence in Geomorphological Research from the AAG's Geomorphology Specialty Group), he used the coarsest cobbles and boulders in dated overbank flood deposits. By quantifying the relationship between the size of the sediments and the depth of flow required to transport them, he was able to reconstruct a 7000-year history of the large floods that were capable of moving such large material. From about 5000 to 3300 years BP, high-discharge floods were smaller than during the period after 3300 BP; particularly high floods occurred after about 1000 BP. Independent climate reconstructions indicate that the climate variability over these time periods was relatively modest: Mean annual temperatures were only 1 to 2°C higher and annual precipitation only

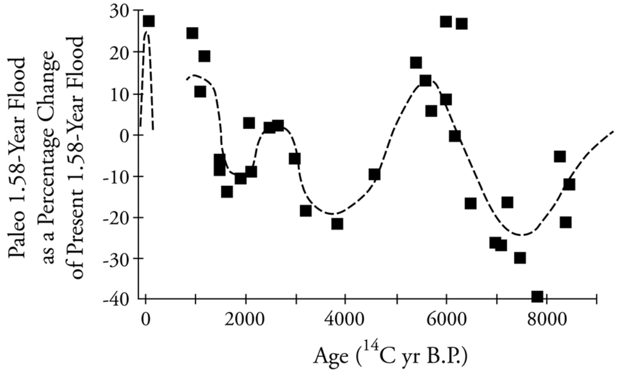

Fig. 1. Long-term variations in the magnitude of 1.58-year floods in southwestern Wisconsin, expressed as a percentage larger or smaller than modern 1.58-year floods. Simplified and redrawn from Knox (1985, Figure 5).

10 to 20% lower during the 5000 to 3300 BP low-flood episode compared with the time since 3300 BP.

The important lesson, as Knox pointed out, is that small change in climate may generate major changes in flooding, with an obvious message regarding the effects of the ongoing greenhouse warming of the atmosphere. High-magnitude, low-frequency floods result from heavy precipitation that renders non-climate factors irrelevant, as Knox frequently noted. For lesser floods, however, he did invoke such non-climate factors, bringing us to our next topic.

Vegetation… in Which Climate Change Influences Vegetation, Which, in Turn, Influences Flood Histories….

Vegetation may influence both flood magnitude and slope erosion. In the preceding two papers discussed, Knox worked with situations that minimized the importance of vegetation and its influence. In the first paper, the relatively long episodes of the Holocene allowed an emphasis on recurring bankfull discharges associated with stable conditions of climate and vegetation. In the second, high-magnitude floods were caused by short-term weather/climate events during which vegetation cover was rendered unimportant by unusually heavy precipitation. If these observations hold true, vegetation as a hydrologic factor might become particularly important over time periods that bracket episodes with differing climate-vegetation systems and with times of transition between those episodes.

Knox investigated just such situations in a study focused on Blockhouse Creek in southwestern Wisconsin (not far, incidentally, from the Knox family farm settled by his ancestors in the 1830s) (Knox 1972). Alluvial fills on Blockhouse Creek reveal a three-part sequence common throughout the Driftless Area. First, the lowest, basal deposit is a meter or more thickness of coarse gravelly sediment with radiocarbon dates of about 6000 BP; this was interpreted as bed load material deposited by streams toward the end of the dry climatic episode of early to mid-Holocene time. Second, stratigraphically above the gravels lies a 1 to 2 meter accumulation of much finer silt and clay that Knox saw as material eroded from slopes during the transition from the dry period to the more humid conditions of the later Holocene. This material seems to have accumulated rather quickly at the time of climatic shift, because a (now buried) soil at the top of this layer suggests that a lengthy period of stability followed this alluviation, allowing for soil development. Third, an accumulation of relatively recent alluvium tops off the sequence. These uppermost silts and clays were deposited after 1830 and represent sediments delivered to streams as a consequence of accelerated slope erosion caused by initial Euro-American clearing and plowing for agriculture.

The two upper units of alluvium, then, were deposited during short periods when vegetation on slopes was reduced relative to precipitation: the first when a more humid climate was suddenly imposed on a sparse vegetation of drier conditions (before the vegetation cover, slow to respond to climate change, increased in response to greater moisture) and the second when clearing for Euro-American agriculture dramatically increased slope erosion.

Knox articulated these relationships in what he termed the biogeomorphic response model (Figure 2), which is worth a detailed consideration, as he suggested it as a generalizable phenomenon, whose application was not limited to Blockhouse Creek or to Wisconsin's Driftless Area (although the details of similar relationships in other environments have certainly inspired debate, e.g., Graf 1983). The starting point for the model (as for so much of his work) was climate change. Knox noted that transitions between relatively arid and humid climatic regimes were likely to be abrupt (Figure 2A). Vegetation cover increases during humid periods, but it is slower to reach a maximum, as it takes time for new plants to become

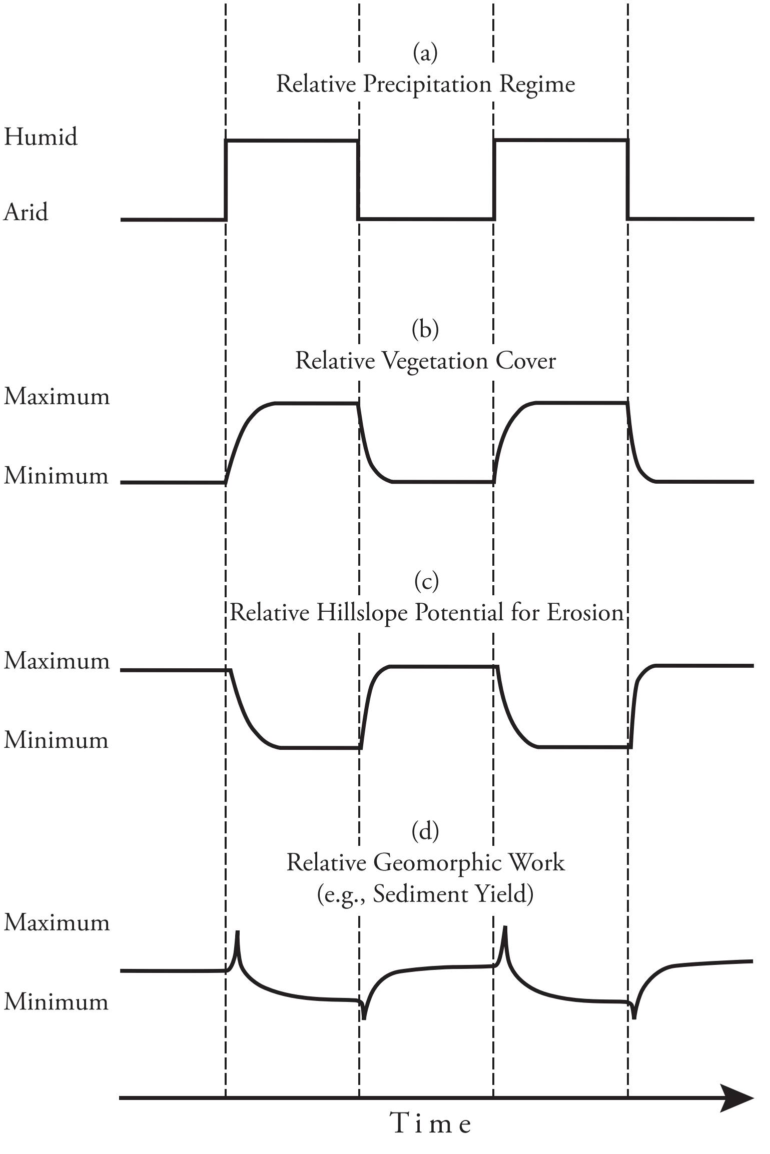

Fig. 2. Biogeomorphic response model showing impact of abrupt changes in climatic regimes. Redrawn from Knox (1972, Figure 6).

established in response to the added water (Figure 2B). Because of the protective role of vegetation, the vulnerability of hillslopes to erosion varies as an inverse of vegetation cover, increasing during sparsely vegetated arid periods and declining when vegetation expands during humid periods (Figure 2C). Sediment yield (ultimately derived from sediments washed down hillslopes) is likely to be greatest when high rainfall is combined with sparse vegetation (little protection). Knox pointed out that this occurs at the beginning of humid periods (Figure 2D), as rainfall is already high (Figure 2A), yet vegetation cover is still limited (Figure 2B) so that erosion potential is still high (Figure 2C). The period of high maximum hillslope erosion is quite brief (Figure 2D), because vegetation cover is increasing in response to the increased precipitation, reducing the erosion potential. The rapid accumulation of the middle depositional unit at

Blockhouse Creek, then, represents an example where rapid hillslope erosion and valley alluviation accompanied the transition to humid late Holocene conditions. In keeping with the biogeomorphic response model, that geomorphic activity was short-lived, allowing the valley floor to stabilize and soil development to proceed.

Knox limited this study to Blockhouse Creek and other similarly small (30 km^2 or less drainage area) southwest Wisconsin streams because he recognized that the fluvial response to environmental change would play out differently downstream in larger valleys. This concern suggests the next environmental factor to be presented—spatial or topographic variations within a drainage network.

Topographic or Spatial Situation… in Which Fluvial Activity Varies Spatially…

Knox repeatedly considered topographic position, or, more pointedly, location within the drainage network, in his fluvial work. He had to, because flood magnitudes, and thus their channel and alluvial signatures, vary with stream order. This necessitates some standardization to isolate temporal environmental factors as influences on flood discharges. Such standardization was accomplished in the 1993 paper on climate-flood links, discussed above, by using a ratio of bankfull flood to high-magnitude flood, thereby creating a measure of the deviations from modal floods, and in the 1972 paper on vegetation change, also above, by restricting sampling to fifth-order and sixth-order streams. Moreover, Knox recognized early the distinctive reaction of different parts of streams to Holocene environmental changes:

> Although it is quite clear that physical changes in runoff and sediment yield within the watershed would disturb any existing balance between the channel-forming hydraulic variables that include discharge, sediment, and slope, the exact response of each variable would vary systematically with topography down through the drainage hierarchy (Knox 1972, p. 405).

Knox focused at a much broader scale on position within a drainage network as an influence on fluvial behavior in a paper linking the Upper and Lower Mississippi Rivers (UMV and LMV; Knox 1996). In this paper, he first synthesized the stratigraphic evidence gathered by a multitude of scholars (himself included) regarding the late Quaternary flood history of the Upper Mississippi (in the Upper Midwest) and its tributaries. He identified four major episodes in the past 25,000 years. The first of these lasted until about 14,000 BP and was primarily characterized by aggradation (from glacially derived sediment) in the UMV. At the same time, periglacial conditions in the smaller unglaciated Driftless Area tributaries caused extensive weathering and hillslope erosion, storing sediment in those tributary valleys. The second episode, from 14,000 BP to 9000 BP featured numerous very large floods, as large proglacial lakes trapped between the retreating continental glacier and the moraines deposited when the glacier was further South periodically overflowed and eroded drains through those barriers. The enormous discharges of these floods, with relatively low sediment concentrations, had a net erosive impact, incising through much of the alluvium deposited during the previous period and causing significant shifts in the course of the Mississippi River itself. The third episode comprised most of the Holocene, from 9000 BP to about 150–200 years ago, and saw renewed aggradation in the UMV as tributaries remobilized the sediment from the extensive hillslope erosion that had occurred during the first episode and delivered it to the main valley. The final episode was a period of major human influence, following the arrival of Euro-American settlers.

We see in this synthesis a distinction between events in the main stem of the UMV and its tributaries, as the Mississippi River was affected by proglacial floods while most of the tributaries were not. There is also connection, however, as the tributaries responded to their Late Pleistocene sediment input by subsequently moving alluvium into the main valley through the Holocene. But this is prologue to connection at an even broader scale, as Knox then looked to link the Holocene history in the two areas (Upper and Lower) of the Mississippi River Valley.

Knox prefaced this section by arguing that focusing on particular types of river behavior, aggradation and degradation, for example, might be counterproductive because different parts of the drainage network often respond differently to the same environmental change. Instead, he looked at the timing of changes, which he termed "discontinuities," from one sort of behavior to another. In the upper valley, he identified seven such discontinuities from about 8000 to 800 BP (here, discontinuities separate major episodes of aggradation or degradation). In the lower valley, two sorts of fluvial activity show correspondence to the upper valley discontinuities. First, five sets of meander are belts preserved in the LMV, and Knox interprets the transition from each to the next as discontinuities; all four such discontinuities correlate closely to the times of upper valley discontinuities. Second, five times at which new lobes of the Mississippi River Delta were initiated, also interpreted as lower valley discontinuities, correlate to five discontinuities in the upper valley.

Traditional interpretations of Holocene changes in the LMV focus primarily on changes in sea level associated with glacial advances and retreats and secondarily on tectonic influences. Knox argued that sea level change was probably most important near the mouth of the river. He noted that more than 80% of the mean annual discharge and mean annual sediment load of the Mississippi River is contributed by the part of the watershed above the confluence of the Mississippi and Ohio Rivers and suggested that it is only logical to suspect that fluvial changes in the UMV would have significant impacts on the behavior of the river in the LMV. It was a provocative argument, but one that finds support in the temporally correlated discontinuities in the upper and lower valleys, and one that highlights the importance of the interconnections among places throughout the drainage network.

While Knox noted the importance of human impacts (they account for the fourth major UMV episode), he excluded discussion of that period in this paper because of space limitations. Certainly, though, human impacts are a recurring emphasis in Knox's fluvial work, the final topical section of our own discussion.

Human Impacts… in Which Land Uses Influence the Other Variables…

From early in his research career, Knox was interested in the impacts of Euro-American agriculture on the streams of southwestern Wisconsin. We speculate that this curiosity may have derived from his childhood on the family farm set in the deep valley of the Little Platte River (near Platteville, Wisconsin), perhaps hearing stories of his ancestors who a century earlier settled in the Driftless Area and dealt with its environment. This interest appeared in a paper that we discussed earlier (Knox 1972), a report that found agricultural clearing and plowing had increased erosion on hillslopes and caused the deposition of post-settlement alluvium in valley bottoms.

A much later treatment added decades of research to the story (Knox 2006). Here, Knox was specifically concerned with the impact of Euro-American agricultural practices, particularly during the period between about 1830 (when extensive Euro-American settlement began) and 1950 (when modern conservation practices significantly reduced agricultural impacts). During this period, the land-use changes that allowed for accelerated hillslope erosion also increased surface runoff (itself a substantial cause of the erosion) so that the delivery of both water and sediment to the channel was increased.

This combination caused a substantial increase in overbank flooding and alluviation in the upstream reaches of major Driftless Area streams, with rates of floodplain aggradation reaching 10 to 100 times pre-settlement rates (Figure 3). The raised valley floors meant higher stream banks and deeper channels, so that by the 1890s, much deeper (and higher-energy) flood discharges occurred. Because the streambeds are "armored" by late Pleistocene/early Holocene gravels too large to be moved by even these augmented floods of the early agricultural period, the streams responded to the increase in energy not by incising but rather by eroding laterally. This lateral channel migration gradually created meander belts inset within the floodplains—which, combined with the raising of the aggradation of the early historical floodplains effectively left those floodplains behind as terraces, because the cross-section area of the meander belts is sufficient to contain any flows smaller than the 50- to 100-year flood. In one typical example presented by Knox, the combination of overbank deposits raising the (initial) historical valley floor and lateral erosion widening the meander belt within it increased the cross-section area that could contain flows before they spill onto the historical valley floor from $3.6\,m^2$ to $24.8\,m^2$, an almost seven-fold increase.

In downstream reaches of these same streams, closer to the base-level constraint imposed by confluence with the Mississippi River, low gradients did not allow for such high-energy floods. As a result, the large downstream floodplains did not develop the same prominent inset meander belts that had formed in their headwaters, so overbank flooding continued (and continues) to occur both along the downstream reaches of the tributaries and on the floodplain of the Mississippi River itself (note again the importance of varied fluvial responses among different parts of the drainage network, as discussed in the previous section). As Knox summarized the spatial pattern of fluvial response to Euro-American agriculture:

> large capacities of the meander belt channels remain and efficiently deliver water and sediment downstream. In turn, this delivery maintains anomalously high rates of overbank sedimentation on lower tributary floodplains where historical meander belts have not developed… (Knox 2006, p. 307)

Fig. 3. Jim Knox points to laminated silts and clays that were deposited since the beginning of Euro-American agriculture in the Driftless Area. The dark layer below is the A Horizon of the pre-settlement soil, which serves as a marker that the aggradation above that level occurred since approximately 1830. Photo courtesy David W. May.

Knox further noted that because of this spatially varied response, with overbank flooding and sedimentation continuing in the lowest tributary reaches and in the main stem Mississippi Valley itself, the impacts of early Euro-American agricultural practices have been and will continue to be seen for many decades after the replacement of those practices by more conservation-oriented agricultural methods.

This paper illustrates two additional points about Knox and his career. First, the methodology reflects the rich array of sources and techniques that Knox employed, from historical channel resurveys and land survey notes to particle size and heavy metal analyses to calculations of flood statistics and hydraulic modeling. Second, the paper includes voluminous citations of the works of more than a dozen of his graduate students, who made their own major contributions to the understanding of the Quaternary history of the Driftless Area. This latter point leads to our concluding comments.

Concluding Comments

We have highlighted five papers to represent the breadth of the research work of James C. Knox and that are arranged to illustrate the links that he saw between fluvial activity and other variables in the environment. Although they are a limited sample from a very large body of work, they represent an approach to the interpretation of the specific hydrological and geomorphic behavior of rivers, at timescales from decades to millennia and at spatial scales from a few square kilometers to half a continent. That approach always emphasized the environmental context, understanding the river as being organically and inextricably connected to a broad range of natural and human factors in the surrounding environment and indeed in all of the environment upstream.

This breadth of vision carried over into other aspects of his academic career. Throughout his 40 years at the University of Wisconsin, Knox taught students at all levels, from graduates in seminars to undergraduates in advanced geomorphology classes to entering freshmen in large survey courses in physical geography; he felt teaching to be an important part of the job at Madison, and he never attempted to restrict himself to the research lab. His effectiveness in inspiring and advising graduate students is attested to by the dozens of scientists whom he launched into careers both within and outside of academe. Nor did his efforts end when students graduated, as he was an active mentor and advocate for his advisees long after they embarked on their own careers. He also participated in a full range of service responsibilities—in his department, across campus, and more broadly in the profession—where his expertise and wisdom were always sought, yet he shunned a career trajectory into administration (a role often offered to him), instead remaining committed to research and teaching.

An anecdote serves to illustrate Knox's commitment to the triple responsibilities of academic life. About two decades ago, a college dean asked Knox (whose effective leadership abilities were well known) to assume chair responsibilities for a department (not his own nor even an earth science unit) undergoing serious internal discord. The dean offered freedom from teaching as an inducement. Knox agreed to the service position but not at the expense of teaching; he continued his full classroom responsibilities (including handling an introductory-level course) but accepted funding to support a graduate student as a research assistant. He thus assumed responsibility for onerous service duty without sacrificing teaching albeit with some aid to ensure that his research would continue unabated.

Finally, Knox felt that a strong geography department could best be maintained with a breadth of perspectives. In both physical and human geography, he saw the ideal faculty as one of competent people who could, with tolerance, recognize the value of those with other interests; he worked as an advocate within his own department for such a mix. It is quite a legacy: research, teaching, and service—all pursued with eager generosity.

We are struck that the lessons that James Clarence Knox learned about the interconnections of environmental variables in the Driftless Area may have contributed to his vision of interconnections in the academic world. It is, at any rate, a perspective that could enlighten us all.

Acknowledgement

We thank Joseph W. Stoll of the Syracuse University Cartographic Laboratory for assistance in preparing the figures and David W. May for providing Figure 3. David W. May, Michael G. Commons, and two anonymous reviewers provided helpful comments on various drafts of the manuscript.

Short Biographies

Jacob Bendix has been on the Geography faculty at Syracuse University for almost 20 years. His research is in plant biogeography and fluvial geomorphology, with particular interest in disturbance ecology and the interactions between ecological and geomorphological processes and patterns. He holds a BA from the University of California, Berkeley, MS from the University of Wisconsin-Madison (where Jim Knox was his advisor), and PhD from the University of Georgia.

Thomas Vale, Wisconsin colleague to and personal friend of Jim Knox for nearly forty years, taught and wrote about physical geography, biogeography, natural resources, nature protection, and the American West. His BA, MA, and PhD are from the University of California, Berkeley.

Notes

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† *Editor's note*—this paper, along with others to appear in future issues, was invited to honor and review the legacy of Geomorphologist Dr. James C. Knox, who passed away 6 October 2012. Dr. Knox's research exemplified the spirit of this section of *Geography Compass*. His scholarship brought together the best practices in both hydrology and geomorphology and inspired many students and current professionals in these fields. Dr. Knox is already greatly missed by his students, peers, and friends, and it is intended that these papers in his honor will appeal to a wide audience of geography scholars, in venues such as geographic thought courses, and for those pursuing research in hydrology and geomorphology.—*Sheryl Luzzadder-Beach, Hydrology and Geomorphology Section Editor*, slbeach@austin.utexas.edu.

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