Eastern Illinois University
The Keep

Faculty Research & Creative Activity

Biological Sciences

January 2010

Evaluating the Illinois Stream Valley Segment Model as an Effective Management Tool

Stephen S. Warrner
Eastern Illinois University

Robert U. Fischer
University of Alabama - Birmingham

Ann M. Holtrop
Illinois Department of Natural Resources

Leon C. Hinz Jr.
Illinois Natural History Survey

James M. Novak
Eastern Illinois University, jmnovak@eiu.edu

Follow this and additional works at: http://thekeep.eiu.edu/bio_fac

Part of the Biology Commons

Recommended Citation

Warrner, Stephen S.; Fischer, Robert U.; Holtrop, Ann M.; Hinz, Leon C. Jr.; and Novak, James M., "Evaluating the Illinois Stream Valley Segment Model as an Effective Management Tool" (2010). *Faculty Research & Creative Activity*. 210.
http://thekeep.eiu.edu/bio_fac/210

This Article is brought to you for free and open access by the Biological Sciences at The Keep. It has been accepted for inclusion in Faculty Research & Creative Activity by an authorized administrator of The Keep. For more information, please contact tabruns@eiu.edu.

Environmental Management (2010) 46:761–770
DOI 10.1007/s00267-010-9551-x

Evaluating the Illinois Stream Valley Segment Model as an Effective Management Tool

Stephen S. Warrner · Robert U. Fischer ·
Ann M. Holtrop · Leon C. Hinz Jr. ·
James M. Novak

Received: 23 August 2009 / Accepted: 12 August 2010 / Published online: 9 September 2010
© Springer Science+Business Media, LLC 2010

Abstract Stream habitat assessments are conducted to evaluate biological potential, determine anthropogenic impacts, and guide restoration projects. Utilizing these procedures, managers must first select a representative stream reach, which is typically selected based on several criteria. To develop a consistent and unbiased procedure for choosing sampling locations, the Illinois Department of Natural Resources and the Illinois Natural History Survey have proposed a technique by which watersheds are divided into homogeneous stream segments called valley segments. Valley segments are determined by GIS parameters including surficial geology, predicted flow, slope, and drainage area. To date, no research has been conducted to determine if the stream habitat within a valley segment is homogeneous and if different valley segments have varying habitat variables. Two abutting valley segments were randomly selected within 13 streams in the Embarras River watershed, located in east-central Illinois. One hundred meter reaches were randomly selected within each valley segment, and a transect method was used to quantify habitat characteristics of the stream channel. Habitat variables for each stream were combined through a principal components analysis (PCA) to measure environmental variation between abutting valley segments. A multivariate analysis of variance (MANOVA) was performed on PCA axes 1–3. The majority of abutting valley segments were significantly different from each other indicating that habitat variability within each valley segment was less than variability between valley segments ($5.37 \leq F \leq 245.13$; $P \leq 0.002$). This comparison supports the use of the valley segment model as an effective management tool for identifying representative sampling locations and extrapolating reach-specific information.

Keywords Valley segment · Stream habitat · Scale · Management

Introduction

Stream degradation resulting from channel reconfiguration, waterway impoundment, and riparian zone removal continues to impact the quality of North American streams (Rankin 1989; Zwick 1992; Karr and Chu 2000; Rogers and others 2002; USEPA 2002). These modifications, in conjunction with an often lack of best management practices (BMPs), have altered the chemical and physical properties of streams while degrading the quality of habitat available for aquatic communities (Karr 1981; Karr and others 1985; Crunkilton and others 1996; Carpenter and others 1998; Ney 1999; Sheehan and Rasmussen 1999; Meader and Goldstein 2003). Following the establishment of the Clean Water Act in 1972, national and state-wide water chemistry, bioassessment, and habitat assessment

S. S. Warrner · J. M. Novak
Department of Biological Sciences, Eastern Illinois University,
600 Lincoln Avenue, Charleston, IL 61920, USA

R. U. Fischer (✉)
Department of Biology, University of Alabama-Birmingham,
1300 3rd Avenue South, CH 109, Birmingham, AL 35294-1170,
USA
e-mail: rfischer@uab.edu

A. M. Holtrop
Watershed Protection Section, Illinois Department of Natural
Resources, One Natural Resources Way, Springfield, IL 62702,
USA

L. C. Hinz Jr.
Illinois Natural History Survey, One Natural Resources Way,
Springfield, IL 62702, USA

protocols were developed to detect deteriorating stream conditions as well as restore and maintain the physical integrity of waterways (Winger 1981; USEPA 1990; Karr 1991; Talmage and others 2002; Wang and others 2006).

Due to the vast number of streams in North America, managers lack the time and resources necessary to visit each stream reach to determine its ecological status utilizing currently available assessment procedures (Seelbach and others 2005; Wang and others 2006). Like many other state agencies, the Illinois Department of Natural Resources (IDNR), has selected stream reaches in which to conduct stream quality assessments using historical data, reach accessibility, proximity to point source pollution, relative location of tributaries, relative position within the watershed, and whether or not the reach is representative of the stream or entire watershed (IDNR 2002). However, determining if individual reaches are representative of conditions throughout a stream is often difficult, due to the inherent spatial variability of streams and the subjective criteria used to select potential sample reaches (Seelbach and Wiley 1997; Seelbach and others 1997; Palmer and Poff 1997; Montgomery and MacDonald 2002; Kilgour and Stanfield 2006).

In addition to selecting a representative sampling location, it is also difficult to determine the appropriate spatial scale for management objectives (Lammert and Allan 1999; Meader and Goldstein 2003; Wang and others 2006; Brenden and others 2008). Stream managers typically conduct field assessments at reach lengths less than 1,000 m; however, these reaches may not be sufficiently large to use as a basis for extrapolation to larger river segments (Bryce and Clarke 1996; Wang and others 2006). Because the majority of sampling efforts take place at relatively fine spatial scales, stream units representative of the entire stream reach should be selected to allow managers to effectively select, sample, and extrapolate information from representative reaches to a more course spatial scale (Frissell and others 1986; Bryce and Clarke 1996; Seelbach and others 1997).

To develop consistent and distinctly defined stream reaches for management and assessment the IDNR and Illinois Natural History Survey (INHS) have delineated valley segments from aggregations of adjacent stream sections with similar geomorphic, hydrologic, and landscape attributes. This concept has been promoted in several descriptions of riverine hierarchies (Frissell and others 1986; Hudson and others 1992; Maxwell and others 1995; Higgins and others 2005). The Illinois valley segment model was based on similar models developed in neighboring states (Wisconsin, Michigan, and Missouri; Seelbach and others 2006; Groundwater Conservation Advisory Council 2007; Sowa and others 2007). Confluence to confluence stream arcs were attributed within an ArcGIS environment as part of an earlier project (Holtrop and Dolan 2003; Brenden and others 2006). Using these data Illinois valley segments were delineated with the valley segment affinity search technique (VAST) developed by Brenden and others (2008). VAST is based on the cluster affinity search technique (CAST) a non-hierarchical agglomerative clustering routine developed by Ben-Dor and others (1999). However, VAST differs from CAST by allowing only spatially adjacent stream arcs to form clusters and in this manner individual arcs are removed from clustered segments (see Brenden and others 2008 for details).

Illinois streams were clustered using an affinity threshold of 0.6 and the following arc attributes: network catchment area, link number, local catchment slope, two measures of surficial geology (proportion of bedrock plus colluvium in the watershed, proportion of dune plus coarse lacustrine in the watershed), and predicted hydrologic and temperature classes. Hydrologic classes were developed from predicted annual median flow yield (Q_{50}/DA) based on multiple linear regression models that predict exceedence flows for each stream arc (Holtrop and others 2006). Stream arcs were attributed with a yield class of high (>20 cm/year), moderate (10–20 cm/year), low (5–10 cm/year) or very low (<5 cm/year) based on the average annual depth of water for each catchment basin that is converted to stream flow. Water temperature classes were based on the estimated mean temperature from a state-wide multiple linear regression model and group arcs based on expected mean daily water temperature for the month of July (cold <19°C, cool 19–22°C, warm 22–29°C, very warm >29°C) (Holtrop and others 2006).

For this project we differentiated between multiple arc valley segments (MAVS) that consist of two or more confluence to confluence arcs that were aggregated into a single valley segment and single arc valley segments (SAVS). SAVS are confluence to confluence arcs which were not similar enough to adjacent arcs to aggregate with neighbors. Based on these definitions, the valley segment model assumes that (1) stream composition (e.g., stream habitat, community structure) within the entire valley segment is fairly homogeneous, and (2) overall stream composition within each valley segment is more similar to abutting valley segments than to segments in other watersheds (Seelbach and others 1997; Seelbach and Wiley 1997).

The valley segment model should allow stream managers to more effectively select representative sample sites because valley segments closely approximate the spatial scale at which managers already sample stream habitat and biological communities while approximating the scale at which physical processes and aquatic communities function (Vannote and others 1980; Frissell and others 1986;

Seelbach and others 1997; Wang and others 2006; Brenden and others 2006). However, to date no research has been reported which tests the major assumptions of the valley segment model, particularly whether stream habitats are more homogeneous within a valley segment or among abutting valley segments.

The purpose of this research was to ask if this model was effective at delineating differences in stream habitat by combining or separating stream arcs among valley segments. Thus, the objective of this project was to determine if abutting valley segments have measurably different habitat variables. If the assumptions of the model hold true, stream valley segments determined by grouping similar GIS parameter values are true habitat divisions and are at a fine enough spatial scale to determine habitat differences between valley segments.

Study Sites

Thirteen streams in the upper Embarras River watershed located in east-central Illinois were sampled between May and August of 2007 (Fig. 1). Approximately 75% of streams within the watershed have been disturbed by agriculture practices while only 12% of streams have been classified as least disturbed (IDNR 1996). We selected streams throughout the upper portion of the watershed to test the valley segment model under a range of disturbance levels.

Methods

Valley Segment Selection

Within each stream, valley segments were chosen based on accessibility (i.e. number of bridges crossing in a valley segment) and total length. Valley segments greater than 1,600 m in total length were selected in order to properly space replicate reaches while encompassing habitat variability within each valley segment. Two abutting valley segments were sampled in each stream for a total of twenty-six valley segments. Seven of these streams contained one upstream MAVS and an abutting downstream SAVS, while the remaining six streams contained two abutting SAVS (Table 1). MAVS were selected to evaluate the stream arc merging routine, whereas abutting SAVS were selected to determine if these valley segments were effectively separated from each other.

Reach Selection

Using Arc GIS (ESRI 2006), each valley segment was divided into 400 m increments (Fig. 2), a distance chosen to ensure that sampled reaches were not in close proximity to each other as well as to provide adequate coverage within each valley segment. Depending on the length of the valley segment, three to twelve reaches were randomly selected and sampled within each valley segment arc to minimize bias (Table 1). In the field, each reach was

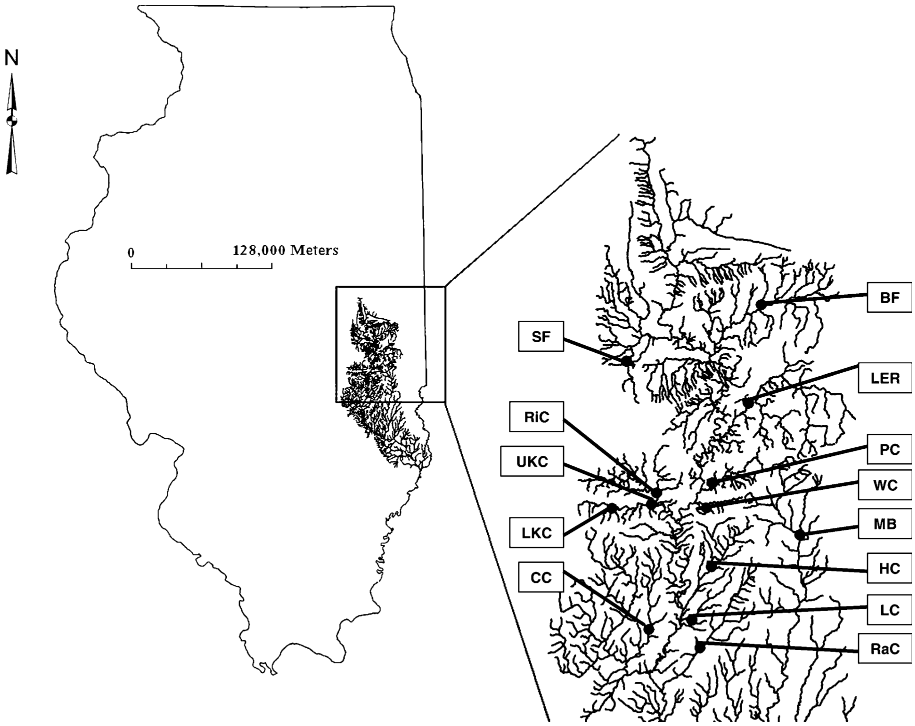

Fig. 1 The geographic location of the Embarras River watershed is designated within the map of Illinois. Thirteen streams, indicated by the circles on the inset map, were selected within the upper portion of the watershed in order to test the valley segment model. The streams selected within this watershed included Brushy Fork (BF), Cottonwood Creek (CC), Hurricane Creek (HC), Little Embarras River (LER), Lost Creek (LC), Lower Kickapoo Creek (LKC), McNary Branch (MB), Polecat Creek (PC), Ranger Creek (RaC), Riley Creek (RiC), Scattering Fork (SF), Upper Kickapoo Creek (UKC), and Whetstone Creek (WC)

Table 1 Summary characteristics for abutting valley segments sampled within the 13 streams of the upper Embarras River watershed

Stream	Location	Segment type	Total length (m)	Drainage area (km^2)	Reaches sampled
BF	Upstream	SAVS	10,474	186	3
	Downstream	SAVS	3,709	203	3
CC	Upstream	SAVS	3,426	67	3
	Downstream	SAVS	5,952	71	3
HC	Upstream	MAVS	14,908	87–98	6
	Downstream	SAVS	12,598	108	3
LER	Upstream	MAVS	31,191	183–277	12
	Downstream	SAVS	10,569	288	3
LC	Upstream	MAVS	18,027	27–37	6
	Downstream	SAVS	8,889	43	3
LKC	Upstream	SAVS	7,435	69	3
	Downstream	SAVS	3,980	77	3
MB	Upstream	SAVS	6,411	119	3
	Downstream	SAVS	3,978	157	3
PC	Upstream	SAVS	3,687	73	3
	Downstream	SAVS	6,874	75	3
RaC	Upstream	SAVS	9,618	99	3
	Downstream	SAVS	7,508	109	3
RiC	Upstream	MAVS	28,722	6–103	6
	Downstream	SAVS	6,965	166	3
SF	Upstream	MAVS	31,397	9–27	6
	Downstream	SAVS	11,768	35	3
UKC	Upstream	MAVS	18,364	17–25	6
	Downstream	SAVS	5,621	35	3
WC	Upstream	MAVS	18,776	2–21	6
	Downstream	SAVS	9,629	29	3

Valley segment location was designated as either upstream (initially selected valley segment) or downstream (abutting downstream valley segment). The streams selected within this watershed included Brushy Fork (BF), Cottonwood Creek (CC), Hurricane Creek (HC), Little Embarras River (LER), Lost Creek (LC), Lower Kickapoo Creek (LKC), McNary Branch (MB), Polecat Creek (PC), Ranger Creek (RaC), Riley Creek (RiC), Scattering Fork (SF), Upper Kickapoo Creek (UKC), and Whetstone Creek (WC)

located using a Garmin® Global Positioning System (GPS). Sampling reaches began at the top of the nearest channel unit (riffle, run, or pool) and progressed 100 m upstream, unless this location was within 200 m of a bridge, tributary, or beaver dam (research has documented that these factors may influence habitat quality and aquatic community structure; Minshall and others 1985; Montgomery and MacDonald 2002). All reaches within a stream were sampled at base flow conditions over a period of 3 days in order to minimize temporal habitat variability among sampled reaches. The same personnel collected habitat data for all reaches, minimizing observer variability.

Transect Habitat Sampling

It is important to test the valley segment model utilizing a set of variables that is not directly related to the GIS data incorporated into the model. Thus, stream habitat variables were selected because previous stream classification systems and research have indicated the importance of these variables for assessing habitat (Platts 1974; Schlosser 1982; Frissell and others 1986; Gregory and others 1991; Talmage and others 2002; Meader and Goldstein 2003). Geomorphic variables (e.g. bankfull width, slope) were not collected at each transect because they are indirectly related to the GIS data incorporated within the valley segment model (i.e. predicted hydrologic class and local catchment slope).

Within each reach, ten transects were systematically spaced every 10 m; at each transect, channel, bank, riparian, and floodplain data were collected. Measured channel characteristics included wetted width, thalweg depth, average depth across a transect, and substrate. Wetted width, thalweg depth, and average depth were measured to the nearest centimeter. Organic and inorganic substrate were collected by a modified Wolman pebble count and assigned a categorical rank (Wolman 1954; Table 2).

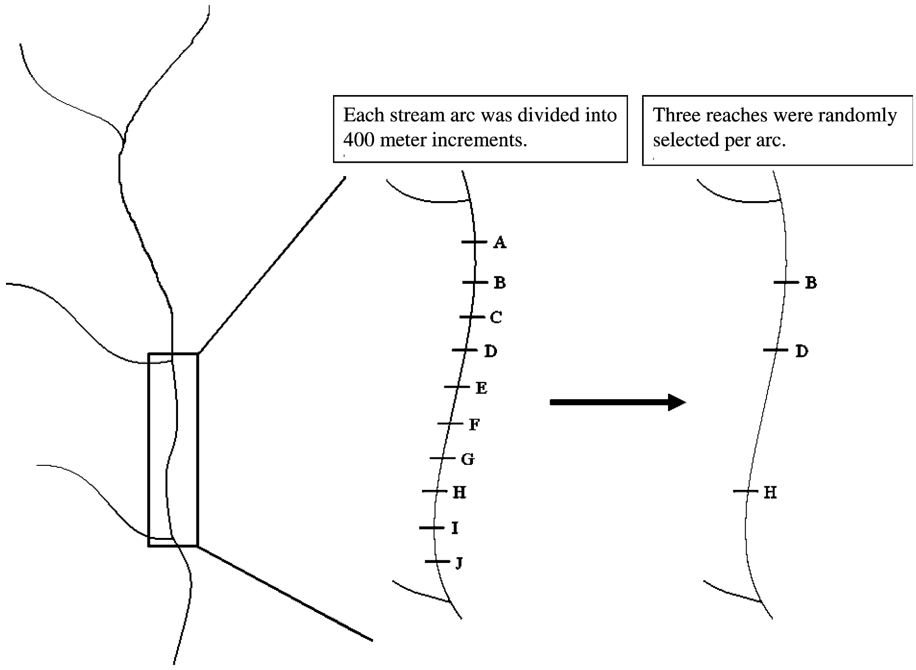

Fig. 2 Reach selection procedure implemented to identify reaches within valley segments. Every valley segment was divided into 400 m increments, with each increment being a potential sampling location. Three reaches per stream arc were then randomly selected for sampling. The number of randomly sampled reaches within each valley segment depended on the total length of each valley segment

Table 2 Rank category values associated with stream habitat variables collected during habitat assessments of sample reaches within each valley segment

Rank	Substrate type	Percent bank vegetation	Floodplain composition	Dominant riparian type
1	Clay	0–25	Forest	Herbaceous
2	Silt	26–50	Old field	Shrub
3	Sand	51–75	Cow pasture	Tree
4	Detritus	>75	Agriculture	Mix of types
5	Fine Gravel		Residential	
6	Gravel			
7	Cobble			
8	Boulder			
9	Bedrock			

Measured bank characteristics included bank angle, undercut bank, bank erosion, and bank vegetation type (percent bare, herbaceous, shrub, tree, bedrock). All four variables were determined for both left and right banks and results were averaged. Bank angle was measured with a clinometer to the nearest degree. Undercut bank distance was measured to the nearest centimeter. Bank erosion and bank vegetation type were ranked (Table 2). Measured riparian and floodplain characteristics included width of riparian zone (vegetation along the margins of the stream), percent canopy cover, dominant riparian vegetation type, and immediate floodplain composition (land use immediately adjacent to the riparian zone). All variables were determined for both left and right sides of the stream and results were averaged. Riparian width was measured to the nearest meter. Canopy cover was measured at the midpoint of each transect with a convex spherical densiometer model C (Lemmon 1956), and dominant riparian type and floodplain composition were categorically ranked (Table 2).

Statistical Analyses

We used statistical analysis software (SAS) to conduct a principal components analysis (PCA) of all stream habitat variables by transect within a valley segment to compare environmental variability between abutting valley segments. It was not the purpose of this project to ask how a single habitat variable varied between valley segments. Rather, we focused on how a suite of habitat variables described environmental variation between valley segments. If two habitat variables had a correlation greater than 0.60, one of the variables was removed from the PCA. A given principal component axis was selected for inclusion in the analysis only if it had an eigenvalue greater than one (McCune and Grace 2002).

Comparisons between abutting valley segments were conducted to determine if the VAST model properly combined or separated stream habitat into valley segments. We performed a PCA for each stream for a total of 13 PCAs. For streams containing MAVS, all stream arcs within each MAVS were combined and all habitat data within the resulting valley segments were compared to the downstream SAVS. The principal component axes with eigenvalues greater than one were used to characterize the environment at each valley segment. We used a multivariate analysis of variance (MANOVA) to determine if significant differences in environmental characteristics occurred between abutting valley segments. A Pillai's trace was used to calculate statistical significance at $\alpha = 0.05$ (Gotelli and Ellison 2004). We also used univariate ANOVA analyses to determine whether valley segments differed in PCA scores for one or more axes. Significance was assessed using a Pillai's trace at $\alpha = 0.05$.

Results

Comparing abutting valley segments for each stream, 49-73% of the variation was explained by the first three principal component axes. These three axes were used to compare environmental variability between valley segments. In 12 of 13 streams, abutting valley segments significantly differed from each other ($5.37 \leq F \leq 245.13$; $P \leq 0.002$; Table 3) across all three PCA axes (all $P < 0.05$). Overall, we observed that the influence of an individual stream habitat variable fluctuated among all streams; different combinations of habitat variables may have been responsible for the delineation of abutting valley segments. For example, in Cottonwood Creek wetted width, percent bank erosion, canopy cover, and riparian zone width were the dominant habitat variables that contributed the most to the delineation between abutting valley segments (Fig. 3). Lower Kickapoo Creek was the only stream in which abutting valley segments were not significantly different due to habitat variability.

Potential Longitudinal Pattern

The physical characteristics of a stream change along its longitudinal profile. Because we observed differences in stream habitat between valley segments, it was important to determine if the valley segment model delineation was due to model parameter values or if separation was a factor of changes along the longitudinal profile. Reaches within each stream were numbered sequentially, beginning at the upstream end. We then used a post hoc analysis of variance (ANOVA) on wetted width and thalweg depth, two variables predicted to increase longitudinally along the valley segments. While wetted width and thalweg depth were significantly different between several reaches within a stream ($P \leq 0.0367$ and $P \leq 0.0330$, respectively), Duncan post hoc tests indicated that habitat variables fluctuated unpredictably along the longitudinal gradient of each stream.

Table 3 MANOVA results abutting valley segments in the upper Embarras River watershed

Stream	Pillai's trace	*F*	NumDF	DenDF	*P*
BF	0.93	245.13	3	52	<0.0001
CC	0.47	15.03	3	51	<0.0001
HC	0.46	21.39	3	76	<0.0001
LER	0.15	7.52	3	132	0.0001
LC	0.20	6.51	2	79	0.0005
LKC	0.06	1.02	3	52	0.3923
MB	0.24	5.37	3	52	0.0027
PC	0.80	70.97	3	52	<0.0001
RaC	0.43	12.98	3	52	<0.0001
RiC	0.66	50.07	3	79	<0.0001
SF	0.58	36.04	3	79	<0.0001
UKC	0.62	42.00	3	77	<0.0001
WC	0.73	68.79	3	75	<0.0001

Overall significance was determined at a *P*-value less than 0.05. The streams selected for this analysis included Brushy Fork (BF), Cottonwood Creek (CC), Hurricane Creek (HC), Little Embarras River (LER), Lost Creek (LC), Lower Kickapoo Creek (LKC), McNary Branch (MB), Polecat Creek (PC), Ranger Creek (RaC), Riley Creek (RiC), Scattering Fork (SF), Upper Kickapoo Creek (UKC), and Whetstone Creek (WC). Lower Kickapoo Creek was the only stream in which abutting valley segments were not significantly different from each other

Discussion

At first glance, streams in the Embarras River watershed might appear fairly homogeneous with respect to stream habitat. A long history of agricultural disturbance has decreased habitat heterogeneity, making streams more similar in terms of substrate, water depth, stream width, percent canopy cover, etc. The Illinois valley segment model has identified numerous valley segments (over 1,000 in the Embarras River watershed alone), suggesting that stream quality may be more heterogeneous than originally thought. Our results confirm habitat heterogeneity across the system, even at the smallest scale between abutting valley segments. Among streams, we found entirely unique suites of environmental variables influencing differentiation. Both of these results support the utility of the Illinois valley segment model as an important tool that

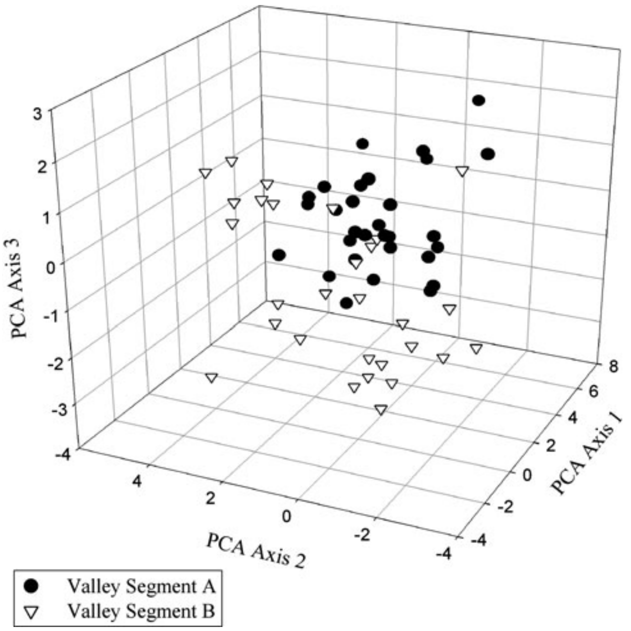

Fig. 3 Graph depicting habitat variability along principal component axes 1–3 for abutting valley segments sampled within Cottonwood Creek. On PCA axis one, the strongest loading positive habitat variables included thalweg (0.4994), average water depth (0.4985), wetted width (0.3933), and percent bank erosion (0.2930), while strongest negative variable was substrate (−0.3659). On PCA axis two, percent herbaceous bank (0.5157) and bank angle (0.3486) were the strongest loading positive variables while percent bare bank (−0.4425), canopy cover (−0.3070), percent tree bank (−0.2754), and percent bank erosion (−0.2723) were the strongest negative variables. On the third PCA axis, riparian zone width (0.5249) and dominant riparian type (0.5226) were the strongest loading positive variables while percent woody-shrub bank (−0.3926) and percent tree bank (−0.2968) were the strongest negative variables

encompasses spatial and temporal scales while integrating both structure and function into a relatively low cost procedure that allows consistent understanding among stream managers. The valley segment model is an effective management tool because it (1) is sensitive to the stream's natural ecological variation, (2) allows modeling and extrapolation of stream systems, and (3) allows both accurate and practical state-wide identification of representative sites and impaired segments.

Abutting Valley Segments

A consistent stream habitat pattern between abutting valley segments was observed in spite of the variety of streams used to test the valley segment model. Abutting valley segments differed from each other, indicating that environmental variation within valley segments was less than the environmental variation between valley segments. Among streams, no single stream habitat variable was predominantly responsible for separating abutting valley segments; rather, the importance of each habitat variable fluctuated among streams. For example, water depth was the most influential habitat variable for the Little Embarras River while riparian zone width was most influential for Whetstone Creek. When we combined habitat variables, differentiation among valley segments was clear. This differentiation is similar to the aggregate of GIS parameters utilized in the valley segment model. Thus, both stream habitat variables and valley segment model parameter aggregates appear to be evaluating the same fundamental characteristics that make valley segments unique.

Lower Kickapoo Creek was the only stream in which habitat variables did not differ between abutting valley segments. We attribute this lack of differentiation to the high degree of variability in Lower Kickapoo Creek. For example, water depth varied from 1 to 110 cm across the 6 sites (3 sites per valley segment) and canopy cover varied from 0 to 97%. Higher variability within sites makes it difficult to partition variation among sites, limiting our ability to objectively differentiate abutting valley segments using these environmental variables. It is also possible that correlated measures, a concern with all transect data, could explain the lack of differentiation between abutting valley segments in Lower Kickapoo Creek.

Streams are dynamic systems that are constantly changing across a landscape (Minshall 1988; Fisher 1997; Montgomery and Buffington 1998; Frothingham and others 2002). While stream habitat characteristics tend to be generalized across a coarse spatial scale such as an ecoregion, stream habitat variability is present within a smaller context such as a valley segment, and stream variability at this scale is influenced by factors such as local climate, geology, hydrology, and topography (Leopold and others 1964; Bryce and Clarke 1996; Meixler 1999; Montgomery 1999; Gomi and others 2002; Bisson and others 2006). Channel morphology can change over a relatively fine scale due to changes in geology and tributaries (Rosgen 1994; Perry and Schaeffer 1987); this parallels our observations between abutting valley segments.

While natural stream variation can influence habitat heterogeneity between valley segments, tributaries draining into these systems may also be a factor (Schlosser 1991; Roth and others 1996; Allan 2004). While agricultural practices continue to dominant overall landuse in the Embarras River watershed, landuse immediately adjacent to each stream was variable creating patches along the longitudinal profile of the stream. We hypothesize that landuse variability may contribute to habitat heterogeneity between valley segments. These observations parallel other studies which have documented that land use is often more variable at the valley segment spatial scale as compared to more coarse spatial scales such as sub-watersheds, leading to greater habitat heterogeneity between abutting valley segments (Roth and others 1996; Allan 2004).

Long-term temporal changes across the landscape can influence stream habitat heterogeneity (Harding and others 1998; Frothingham and others 2002). Sampling was completed within a very short time period; all sites within abutting valley segments were sampled within 3 days and at base flow conditions. There were no notable landscape alterations during this time period. However, long term temporal variation across the landscape may contribute to habitat heterogeneity between valley segments. This is particularly true in east-central Illinois where landuse has been altered gradually over time (Frothingham and others 2002). A recently disturbed landscape may influence stream habitat structure differently than historical landscape disturbance (Harding and others 1998; Allan 2004). Allan (2004) terms this the "legacy effect," in which past stream modifications continue to affect channel structure and hydrologic variability and contribute to stream habitat heterogeneity across valley segments. The legacy effect could be partially responsible for the habitat heterogeneity we observed between abutting valley segments; there were several situations in which abutting valley segments differed in their apparent disturbance history. For example, two sites within the Lower Kickapoo Creek had been channelized at some point in the past. A lack of sinuosity remained, but stream banks supported mature trees, suggesting that channelization occurred in the more distant past. Two other sites within the Lower Kickapoo Creek had more recent signs of disturbance, having had all woody vegetation removed recently, leaving only grassy shrubs along the bank. This illustrates the legacy effect, whereby different disturbance histories could be influencing the patterns of habitat heterogeneity that we observed between abutting valley segments.

Potential Longitudinal Pattern

It is important to determine whether the valley segment model is delineating valley segments based on model parameters or if valley segments encompass natural changes in the stream to explain why valley segment types differ from each other. Several studies have documented that the physical characteristics of a stream change as the stream progresses from a headwater stream to a larger river (Leopold and others 1964; Vannote and others 1980; Schaeffer and Perry 1986). While a longitudinal pattern may be a practical explanation for why valley segments differed from each other, this explanation is countered by our wetted width and thalweg depth data, two surrogates variables for stream size. As we progressed downstream along abutting valley segments, we expected to observe each reach get progressively wider and deeper. While there were differences in these variables between reaches in most streams, variables did not increase in the predicted longitudinal pattern along abutting valley segments.

The inability to detect a longitudinal pattern may be because valley segments represent a relatively small portion of the total stream length, and that over this finer spatial scale, stream width and depth fluctuate in an unpredictable fashion. Models like the River Continuum Concept predict these types of changes in habitat structure over a more coarse spatial scale (Vannote and others 1980). Frothingham and others (2002) argues that this longitudinal pattern operates at more coarse scales such as a watershed but are less evident at finer spatial scales. We conclude that a longitudinal pattern was not responsible for the differences between valley segments but that a combination of model parameters was responsible for successfully delineating valley segments.

Management Implications

Evaluating watershed condition is a common management practice. Watersheds are evaluated in order to identify high priority areas, monitor long term trends in stream quality, and target potential water quality problems (Miller and others 2006). Typically a manager will sample several reaches within a watershed in order to determine the overall condition of that watershed. We found that valley segments are relatively homogeneous, thus eliminating the need to sample multiple reaches within a valley segment. This will save valuable time and resources that could be appropriated to sampling additional valley segments, providing a better estimate of watershed-wide habitat diversity. In addition, more thorough sampling of valley segments would help to identify those that warrant protection and/or restoration, allowing for more efficient allocation of limited management resources. We demonstrated that the valley segment model effectively partitions stream habitat variation, and valley segments are an appropriate unit for evaluating, monitoring, and managing stream condition.

Acknowledgments This project was funded cooperatively by the Illinois Department of Natural Resources and the United States Fish and Wildlife Service through the State Wildlife Grant Program (T-25). Additional funding and equipment was provided by the Illinois Wildlife Preservation Fund and the Department of Biological Sciences and Graduate School at Eastern Illinois University. The authors wish to thank Dr. Scott Meiners, Dr. Karen Gaines, Danyelle Dehner, Laura Sass, Chris Gensler, Dave Closson, and Erin Mandel from Eastern Illinois University for their assistance during data collection and analysis.

References

Allan JD (2004) Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Reviews of Ecology, Evolution, and Systematics 35:257–284

Bailey RC, Norris R, Reynoldson TB (2003) Bioassessment of freshwater ecosystems: using the reference condition approach. Springer, New York

Ben-Dor A, Shamir R, Yahkini Z (1999) Clustering gene expression patterns. Journal of Computational Biology 6:281–297

Bisson PA, Montgomery DR, Buffington JM (2006) Valley segments, stream reaches, and channel units. In: Hauer FR, Buffington JM (eds) Methods in stream ecology, 2nd edn. Academic Press, San Diego, pp 23–49

Brenden TO, Cark RD, Cooper AR, Seelbach PW, Wang L, Aichele SS, Bissell EG, Stewart JS (2006) A GIS framework for collecting, managing, and analyzing multi-scale landscape variables across large regions for river conservation and management. In Hughes RM, Wang L, Seelbach PW (eds) Landscape influences on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland, pp 49–74

Brenden TO, Wang L, Seelbach PW, Clark RD (2008) A spatially-constrained clustering program for river valley segment delineation from GIS river networks. Environmental Modeling and Software 23:638–649

Bryce SA, Clarke SE (1996) Landscape-level ecological regions: linking state-level ecoregion frameworks with stream habitat classifications. Environmental Management 20:297–311

Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH (1998) Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8:559–568

Crunkilton R, Kleist J, Ramcheck J, DeVita W, Villeneueve D (1996) Assessment of the response of aquatic organisms to long-term *in situ* responses to urban runoff. In: Roesner LA (ed) Effects of watershed development and management on aquatic ecosystems. American Society of Civil Engineers, New York, pp 95–111

ESRI (2006) Arc/Info user's manual. Environmental Systems Research Institute, Redlands

Fisher SG (1997) Creativity, idea generation, and the functional morphology of streams. Journal of the North American Benthological Society 16:305–318

Frissell CA, Liss WJ, Warren CE, Hurley MD (1986) A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199–214

Frothingham KM, Rhoads BL, Herricks EE (2002) A multi-scale conceptual framework for integrated ecogeomorphological research to support stream naturalization in the agricultural Midwest. Environmental Management 29:16–33

Gomi T, Sidle RC, Richardson JS (2002) Understanding processes and downstream linkages of headwater systems. BioScience 52:905–916

Gotelli NJ, Ellison AM (2004) A primer of ecological statistics. Sinauer Associates, Inc, Sunderland

Gregory SV, Swanson FJ, McKee WA, Cummins KW (1991) An ecosystem perspective of riparian zones. BioScience 41:540–551

Groundwater Conservation Advisory Council (2007) Report to the Michigan legislature in response to 2006 public act 34

Harding JS, Benfield EF, Bolstad PV, Helfman GS, Jones EBD (1998) Stream biodiversity: the ghost of land use past. Proceedings of the National Academy of Science of the United States of America 95:14843–14847

Higgins JV, Bryer MT, Khoury ML, Fitzhugh TW (2005) A freshwater classification approach for biodiversity conservation planning. Conservation Biology 19:432–445

Holtrop AM, Dolan C R (2003) Assessment of streams and watersheds in Illinois: development of a stream classification system and fish sampling protocols. Illinois Natural History Survey Aquatic Ecology technical report 03/15

Holtrop AM, Hinz LC, Epifanio J (2006) Ecological classification of rivers for environmental assessment and management: model development and risk assessment (T-02-P-001). Project completion report to the Illinois Department of Natural Resources. Illinois Natural History Survey technical report 2006/12

Hudson PL, Griffith RW, Wheaton TJ (1992) Review of habitat classification schemes appropriate to streams, rivers, and connecting channels in the Great Lakes drainage basin. In: Busch WDN, Sly PG (eds) The development of a aquatic habitat classification system for lakes. CRC Press, Boca Raton, pp 73–107

Illinois Department of Natural Resources (1996) Inventory of resource rich areas in Illinois: an evaluation of ecological resources. IDNR, Center for Wildlife Ecology, Springfield

Illinois Department of Natural Resources (2002) Fisheries stream sampling guidelines. IDNR, Division of Fisheries, Springfield

Inoue N, Masanori M (2002) Effects of longitudinal variation in stream habitat structure on fish abundance: an analysis based on subunit-scale habitat classification. Freshwater Biology 47:1594–1607

Karr JR (1981) Assessment of biotic integrity using fish communities. Fisheries 6:21–27

Karr JR (1991) Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1:66–84

Karr JR, Chu EW (2000) Sustaining living rivers. Hydrobiologia 422(423):1–14

Karr JR, Toth LA, Dudley DR (1985) Fish communities of Midwestern streams: a history of degradation. BioScience 35: 90–95

Kilgour BW, Stanfield LW (2006) Hindcasting reference conditions in streams. In Hughes RM, Wang L, Seelbach PW (eds) Landscape influences on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland, pp 623–639

Lammert H, Allan JD (1999) Assessing the biotic integrity of streams: effects of scale in measuring the influence of land use/cover and habitat structure on fish and macroinvertebrates. Environmental Management 23:257–270

Lemmon PE (1956) A spherical densiometer for estimating forest understory density. Forest Science 2:314–320

Leopold LB, Wolman MG, Miller JP (1964) Fluvial processes in geomorphology. Freeman, San Francisco

Maxwell, JR, Edwards CJ, Jensen ME, Paustain SJ, Parrot H, Hills DM (1995) A hierarchical framework for aquatic ecological units in North America (Neartic Zone). General technical report NC-176. U.S. Department of Agriculture Forest Service, North Central Forest Experimental Station, St. Paul

McCune B, Grace JB (2002) Analysis of ecological communities. MjM Sofware Design, Gleneden Beach

Meader MR, Goldstein RM (2003) Assessing water quality at large geographic scales: relations among land use, water physicochemistry, riparian condition, and fish community structure. Environmental Management 31:504–517

Meixler MS (1999) Regional setting. In: Bain MB, Stevenson NJ (eds) Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, pp 11–24

Miller MA, Colby ACC, Kanehl P (2006) Report on the regional monitoring and assessment program study of wadeable streams in the driftless area ecoregion of western Wisconsin. U.S. Environmental Protection Agency, Office of Research and Development, EPA 600/R-06/165, Washington, DC

Minshall GW (1988) Stream ecosystem theory: a global perspective. Journal of the North American Benthological Society 7:263–288

Minshall GW, Cummins KW, Peterson RC, Cushing CE, Bruns DA, Sedell JR, Vannote RL (1985) Developments in stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Sciences 42:1045–1055

Montgomery DR (1999) Process domains and the river continuum. Journal of the American Water Resources Association 35: 397–410

Montgomery DR, Buffington JM (1998) Channel processes, classification, and response. In: Naiman RJ, Bilby RE (eds) River ecology and management: lessons learned from the Pacific coastal region. Springer, New York, pp 13–42

Montgomery DR, MacDonald LH (2002) Diagnostic approach to stream channel assessment and monitoring. Journal of the American Water Resources Association 38:1–16

Ney JJ (1999) Practical use of biological statistics. In: Kohler CC, Hubert WA (eds) Inland fisheries management in North America, 2nd edn. American Fisheries Society, Bethesda, pp 167–191

Palmer MA, Poff NL (1997) The influence of environmental heterogeneity on patterns and processes in streams. Journal of the North American Benthological Society 16:169–173

Perry JA, Schaeffer DJ (1987) The longitudinal distribution of riverine benthos-a river discontinuum? Hydrobiologia 148:257–268

Platts WS (1974) Geomorphic and aquatic conditions influencing salmonids and stream classification—with application to ecosystem classification. US Forest Service, Inter-mountain Forest and Range Experiment Station, Boise

Rankin ET (1989) The qualitative habitat evaluation index (QHEI): rationale, methods, and application. Ohio Environmental Protection Agency, Division of Water Quality Planning and Assessment, Columbus

Rogers CE, Brabander DJ, Barbour MT, Hemond HF (2002) Use of physical, chemical, and biological indices to assess impacts of contaminants and physical habitat alteration in urban streams. Environmental Toxicology and Chemistry 21:1156–1167

Rosgen DL (1994) A classification of natural rivers. Catena 22: 169–199

Roth NE, Allan JD, Erickson DL (1996) Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecology 11:141–156

Schaeffer DJ, Perry JA (1986) Gradients in the distribution of riverine benthos. Freshwater Biology 16:745–767

Schlosser IJ (1982) Fish community structure and function along two habitat gradients in a headwater stream. Ecological Monographs 52:395–414

Schlosser IJ (1991) Stream fish ecology: a landscape perspective. BioScience 41:704–712

Seelbach PW, Wiley MJ (1997) Overview of the Michigan rivers inventory (MRI) project. Michigan Department of Natural Resources, Fisheries Division. Fisheries technical report 97-3, Lansing, MI

Seelbach PW, Wiley MJ, Kotanchik JC, Baker ME (1997) A landscape-based ecological classification system for river valley segments in lower Michigan (MI-SEV Version 1.0). Michigan Department of Natural Resources, research report 2036, Lansing, MI

Seelbach PW, Wang L, Clark RD, Brenden T, Cooper A, Wiley MJ, Allan D, Hinz L, Wehrly KE, Zorn T, Baker E, Stevenson RJ, Pijanowski B, Lyons J, Mitro M, Holtrop A, Day D, DePhilip M (2005) Ecological classification for environmental assessment: demonstration, validation, and application to regional assessment across Illinois, Michigan, and Wisconsin. United States Environmental Protection Agency Grant Number R-83059601-0. Ann Arbor, MI

Seelbach PW, Wiley MJ, Baker ME, Wehrly KE (2006) Initial classification of river valley segments across Michigan's lower peninsula. American Fisheries Society Symposium 48:25–48

Sheehan RJ, Rasmussen JL (1999) Large rivers. In: Kohler CC, Hubert WA (eds) Inland fisheries management in North America, 2nd edn. American Fisheries Society, Bethesda, pp 431–454

Sowa SP, Annis G, Morey ME, Diamond DD (2007) A gap analysis and comprehensive conservation strategy for riverine ecosystems. Ecological Monographs 77:301–334

Talmage PJ, Perry JA, Goldstein RM (2002) Relation of instream habitat and physical conditions to fish communities of agricultural streams in the northern Midwest. North American Journal of Fisheries Management 22:825–833

United States Environmental Protection Agency (1990) Biological criteria: national program for guidance for surface waters. USEPA, Office of Water Regulations and Standards, EPA-440/5-90-004, Washington, DC

United States Environmental Protection Agency (2002) National water quality inventory: report to congress, 2002 reporting cycle. USEPA, Office of Water, EPA-841-R-07-001, Washington, DC

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE (1980) The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130–137

Walters DM, Leigh DS, Freeman MC, Freeman BJ, Pringle CM (2003) Geomorphology and fish assemblages in a Piedmont river basin, USA. Freshwater Biology 48:1950–1970

Wang L, Seelbach PW, Hughes RM (2006) Introduction to landscape influences on stream habitats and biological assemblages. In Hughes RM, Wang L, Seelbach PW (eds) Landscape influences on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, pp 1–23

Winger PV (1981) Physical and chemical characteristics of warmwater streams: a review. In: Warmwater streams symposium, American Fisheries Society, pp 32–44

Wolman MG (1954) Method of sampling coarse level substrate. Transactions of the American Geophysical Union 35:951–956

Zwick P (1992) Stream habitat fragmentation: a threat to biodiversity. Biodiversity and Conservation 1:80–97