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Longitudinal Structuring of Turtle Assemblages in an Altered River in Central Illinois, USA: Implications for Conservation

Robert D. Bluett[1, 2], Wade E. Louis[1], Daniel A. Newhouse[1], Carl J. Handel, Jr.[1], and John H. Kube[3]
[1]Illinois Department of Natural Resources, Division of Wildlife Resources, One Natural Resources Way, Springfield, Illinois, 62702, USA
[2]Corresponding author; e-mail: bob.bluett@illinois.gov
[3]305 W. Harris St., Petersburg, Illinois, 62675, USA

ABSTRACT

Longitudinal gradients in stream conditions affect structuring of assemblages of many aquatic organisms. Common patterns include downstream additions of species and shifts in functional groups. We speculated these patterns would be evident in turtle assemblages of the Sangamon River in central Illinois. Using baited hoop nets, we captured 1,060 turtles during 441 trap-nights along a 357-km reach of the river. Number of species captured increased from two in the fourth stream order (Snapping Turtle, *Chelydra serpentina*; Spiny Softshell, *Apalone spinifera*) to eight in the seventh. Two generalists (Painted Turtle, *Chrysemys picta*; Red-eared Slider, *Trachemys scripta*) became established near an impoundment in the fifth stream order and were encountered regularly thereafter. Two lotic specialists (Smooth Softshell, *Apalone mutica*; Ouachita Map Turtle, *Graptemys ouachitensis*) first appeared in lower reaches of the fifth stream order, and another (Northern Map Turtle, *Graptemys geographica*) in the seventh. Longitudinal structuring calls for basin-wide approaches to conservation because threats such as siltation and pollution can originate in terrestrial settings and accumulate downstream.

Key Words: turtle; assemblage; river; lotic; longitudinal; conservation; Illinois; Sangamon

INTRODUCTION

Longitudinal gradients in stream conditions affect structuring of assemblages of aquatic organisms. For example, diversity of fishes increases from a river's headwaters to its terminus (Smith and Kraft 2005). This pattern is caused by addition of species (i.e., few species drop out of assemblages located downstream from their first appearance) and is accompanied by shifts in relative importance of members composing assemblages (Sheldon 1968). Exceptions to these patterns are common enough to warrant mention (e.g., Mathews 1986; Palic et al. 2007). However, most debates concern processes driving patterns rather than their tendency to occur in a wide range of ecological settings (e.g., Naiman et al. 1987; Edds 1993) and taxonomic groups such as fishes, mussels (Haag and Warren 1998), gastropods (Minton et al. 2008) and macroinvertebrates (Heino et al. 2005).

Evidence of longitudinal structuring in assemblages of turtles is sparse. Moll and Moll (2004) supported the concept, but noted difficulty distinguishing effects of longitudinal structuring from climatic, geologic, evolutionary and anthropogenic influences on distributions of species in the Mississippi River. DonnerWright et al. (1999) found strong relationships between structuring of assemblages and gradients in stream morphology on a 100-km reach of the St. Croix River, including addition of one species near the downstream extent of their study area. Support for longitudinal structuring can also be inferred from distributions of individual species of turtles that vary with velocity and depth of water, substrate, availability of basking sites, and other traits that change along a river's course (Shively and Jackson 1985; Fuselier and Edds 1994; Reese and Welsh 1998; Lindeman 1999; Riedle et al. 2009; Kornilev et al. 2010).

Our study area spanned 357 of 386 km of the main channel of the Sangamon River in four of its seven stream orders. This allowed us to sample assemblages in a wide range of stream conditions to assess longitudinal changes without confounding effects of other factors that shape distributions of species. Our hypotheses mirrored prevailing theories: diversity varies positively with stream order; changes in the composition of assemblages are caused by additions of species; and changes in the composition of assemblages are accompanied by shifts in functional groups. Our findings have implications for conservation of turtles in the Sangamon River, which has been altered dramatically by human activities.

MATERIALS AND METHODS

Methods

We captured turtles in hoop nets (diameter 60.96 cm; mesh 3.81cm; single throat). Fresh frozen fish (400–600 g) was placed in a nylon-mesh bag attached to the hoop farthest from the throat, which faced downstream when set. We replaced baits daily when we checked nets, recorded the number of each species captured and released turtles unharmed. We did not mark turtles because we anticipated too few recaptures for robust estimates of abundance.

Sampling occurred from May–September, 2006–2011. We did not sample stream orders 1–3 (Fig. 1) because private ownership limited access and depths were generally too shallow to set nets with openings of throats underwater. We attempted to distribute effort proportionately to length and width of the channel in each of the remaining stream orders. Effort in the fourth stream order was meager, but turtles were likely to encounter our nets in the narrow channel (Fig. 2) and species we captured were typical of streams in the region (Major et al. 2009).

Each trapping session consisted of 8–24 nets set for 2–3 nights. Sampling locations within a stream order were chosen opportunistically based on ease and legality of

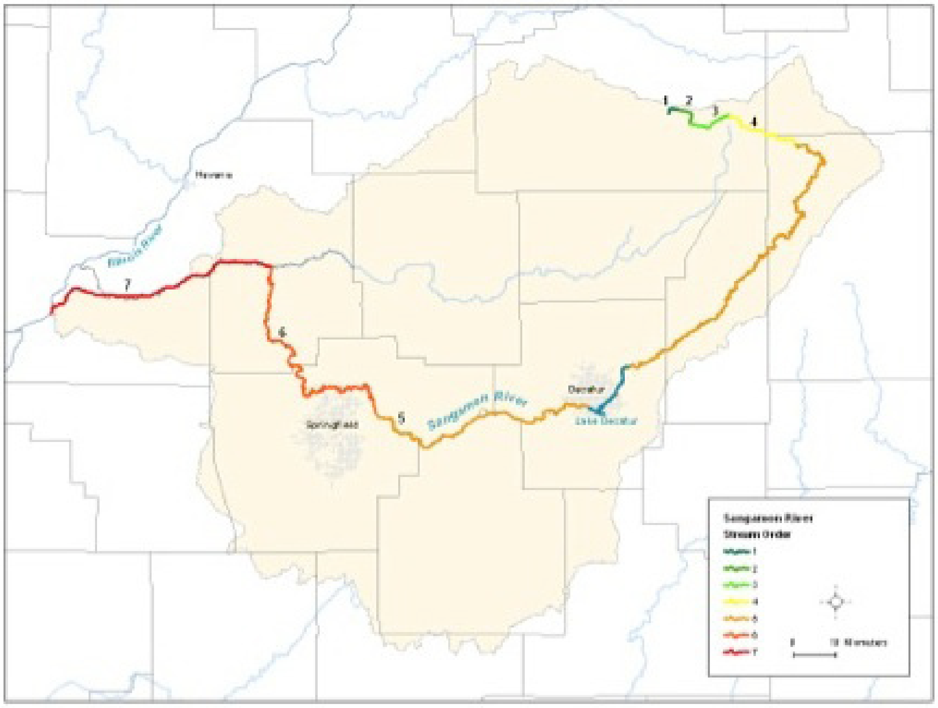

Figure 1. Stream orders of the Sangamon River in central Illinois, USA.

Figure 2. The Sangamon River is narrow and wadeable in its fourth stream order.

access. Some portions of our study area (stream orders 4–5) were accessible only by foot; others (stream orders 5–7) were sampled from a canoe or motorboat. We set nets in diverse habitats representative of each reach (e.g., pools and runs in the open channel and near features such as sandbars, logjams, deadwood and confluences of tributaries).

Metrics used to describe assemblages were derived from Krebs' (1989) calculations for observed species richness (S_{obs}), Horn's index of overlap (R_0) and Shannon-Wiener functions for diversity (H') and evenness (J'). We did not attempt to correct S_{obs} because estimators perform poorly when the number of species in an assemblage is small (e.g., <15–20; Melo et al. 2003). This was the case in our study area, where we captured all but one species known to occur in lotic habitats of the lower Illinois River basin (Phillips et al. 1999). Collecting representative samples of assemblages (i.e., proportionate to each species' relative abundance) is difficult because probabilities of capture vary among species (Cagle 1942). We acknowledge this problem, but note bias was consistent among stream orders, allowing for valid comparisons.

Study Area

The Sangamon River originates in McLean County, Illinois. Its main stem flows 386 km before emptying into the Illinois River (Illinois Department of Natural Resources 2000a). This 7th-order stream drains 14,985 km^2 (c.a. 10% of the state; Illinois Department of Natural Resources 2001).

Substrates in our study area varied from clay to cobble. Upper reaches were generally dominated by gravel or sand and gravel whereas substrates in lower reaches were mostly sand. Banks were incised deeply (1–5 m) and bordered by a narrow, intermittent riparian corridor along much of the study area (Fig. 3).

Figure 3. A reach of the sixth stream order of the Sangamon River in central Illinois, USA. Photo by Chris Young.

Our study was the first inventory of turtles inhabiting the Sangamon River. Based on distributions and habitat preferences (Phillips et al. 1999), we considered nine species to be possible residents: Snapping Turtle (*Chelydra serpentina*), Painted Turtle (*Chrysemys picta*), Northern Map Turtle (*Graptemys geographica*), Ouachita Map Turtle (*Graptemys ouachitensis*), False Map Turtle (*Graptemys pseudogeographica*), Red-eared Slider (*Trachemys scripta*), Eastern Musk Turtle (*Sternotherus odoratus*), Smooth Softshell (*Apalone mutica*) and Spiny Softshell (*Apalone spinifera*). All records of map turtles (*Graptemys* spp.) and *A. mutica* were from the Illinois River, so we were unsure about residency in the Sangamon.

Human activities have altered nearly every aspect of the ecology of the Sangamon River. These changes began in the early to mid-1800s and were entrenched by the early 1900s (Herget 1978; Illinois Department of Natural Resources 1994, 2000b; Prince 1997). Approximately 28% of the Sangamon River's main stem is channelized (Mattingly et al. 1993). Levees occur along 12% of the river's channel, with a disproportionate amount in lower reaches (Mattingly et al. 1993).

Crops such as corn and soybeans are produced in 76% of the river basin (Illinois Department of Natural Resources 2001). Silt and nutrients carried by run-off from farm fields affect the river (Illinois Environmental Protection Agency 1995; Illinois Department of Natural Resources 2000a) and its fauna (Smith 1971; Schanzle and Cummings 1991). Sub-surface drainage (i.e., tiling) is a common practice (Zucker and Brown 1998) that contributes to nutrient loads (Wiley et al. 1990) and abrupt changes in water levels (Sangunett 2005). An agricultural matrix supports high densities of nest predators such as raccoons (*Procyon lotor*; Gehrt et al. 2002). Exotic species are problematic in both terrestrial and aquatic environments [e.g., Amur honeysuckle (*Lonicera maackii*), common carp (*Cyprinus carpio*); Illinois Department of Natural Resources 2000b; Carney 2010].

Springfield (population 116,250), Decatur (population 76,122) and smaller cities along the main stem of the Sangamon River affect its water quality, which is classified as "fair" (Illinois Environmental Protection Agency 1995). The main stem of the Sangamon River was dammed in 1922 to provide a municipal water supply for Decatur. Low-head dams that once occurred at Springfield, Petersburg and New Salem are no longer functional. Impoundments on major tributaries such as Salt Creek, Clear Creek, Sugar Creek, and South Fork of the Sangamon River supply water for cities and power plants.

RESULTS

We captured 1,060 turtles during 441 trap-nights. Observed species richness increased with stream order (Table 1), as did diversity (Table 2). Evenness was high in all stream orders. Community overlap differed greatly between uppermost and lowermost stream orders but not adjacent or intervening stream orders (Table 3).

Table 1. Capture effort (no. trap-nights) and observed species richness (S_{obs}) on four stream orders of the Sangamon River in central Illinois, USA, 2006–2011.

		S_{obs}	
Stream order	Effort	Based on all captures	Based on captures of ≥2 individuals per species
4	16	2	2
5	163	6	4
6	124	6	6
7	138	8	8

Some patterns we observed on reaches within stream orders were noteworthy. One was absence of *C. picta* and near absence of *T. scripta* (1 capture during 107 trap-nights of effort) in all but the last reach of the 5th stream order we sampled above Lake Decatur; both species were encountered regularly in reaches sampled below the lake. We first observed *A. mutica* and *G. ouachitensis* in the second-to-last (but not the last) downstream reach sampled in the 5th stream order; both species were represented by captures of one individual. We first encountered *G. geographica* in the last reach of the 7th stream order near the Sangamon's confluence with the Illinois River.

DISCUSSION

Longitudinal Structuring

Patterns of diversity and community overlap were indicative of longitudinal structuring of assemblages. We did not observe a shift in functional groups, as the number of species with morphological adaptations to flowing water (e.g., flattened carapace)

Table 2. Numbers of turtles captured, relative abundances (in parentheses), diversity, and evenness on four stream orders of the Sangamon River in central Illinois, USA, 2006–2011.

	Stream order				
Species	4	5	6	7	Total
Apalone spinifera	19 (0.679)	238 (0.515)	42 (0.186)	126 (0.366)	425 (0.401)
Chelydra serpentina	9 (0.321)	80 (0.173)	13 (0.058)	19 (0.055)	121 (0.114)
Trachemys scripta	--	129 (0.279)	119 (0.527)	113 (0.328)	361 (0.341)
Chrysemys picta	--	13 (0.028)	15 (0.066)	6 (0.017)	34 (0.032)
Apalone mutica	--	1 (0.002)	33 (0.146)	31 (0.090)	65 (0.061)
Graptemys ouachitensis	--	1 (0.002)	4 (0.018)	40 (0.116)	45 (0.042)
Graptemys geographica	--	--	--	6 (0.017)	6 (0.006)
Sternotherus odoratus	--	--	--	3 (0.009)	3 (0.003)
Total captures	28 (0.026)	462 (0.436)	226 (0.209)	334 (0.315)	1060
Species diversity (H')	0.628	1.129	1.347	1.543	1.443
Evenness (J')	0.906	0.630	0.752	0.742	0.694

Table 3. Percent change in species diversity, evenness and community overlap among four reaches of the Sangamon River in central Illinois, USA.

Community descriptor	Percent change among stream orders					
	4-5	4-6	4-7	5-6	5-7	6-7
Species diversity	79.8	114.5	145.7	19.3	36.7	14.6
Evenness	-30.5	-17.0	-18.1	19.4	17.8	-1.3
Community overlap (R_0)	0.903	0.598	0.080	0.813	0.857	0.870

matched those without in each stream order. "True river turtles" (e.g., *G. ouachitensis*, *A. mutica*; Lindeman 2000) were absent from the 4th stream order, first appeared in lower reaches of the 5th, and were captured with increasing frequency in higher stream orders. This pattern was consistent with reach-scale studies that found "feathered" rather than sharp limits of upstream distribution for lotic specialists (*Graptemys* spp.; Shively and Jackson 1985; DonnerWright et al. 1999; Killebrew et al. 2002).

Detection of *S. odoratus* in the 7th stream order was not surprising given the species' preference for slow-moving water (Ernst et al. 1994) and presence in the broader landscapes of the Illinois and Sangamon rivers (Moll 1977; Tucker et al. 2008; Bluett et al. 2011a). Captures of *G. geographica* in the last reach of the 7th stream order might have reflected a change in suitability of the Sangamon River, proximity to the Illinois River or both. Admixtures of assemblages of fishes are often observed for short distances (c.a. 20 km) upstream from the confluence of a tributary with a larger stream or river (Thornbrugh and Gido 2010).

Lake Decatur was a clear "break point" for *C. picta* and *T. scripta*. Major et al. (2009) observed a similar phenomenon in streams of west-central Illinois, where *C. picta* and *T. scripta* joined *C. serpentina* and *A. spinifera* near impoundments. Relationships between the dam's location and our first encounters of *A. mutica* and *G. ouachitensis* were equivocal, partly because of gaps in sampling.

Table 4. Observed species richness (S_{obs}) reported for assemblages of turtles in Midwestern rivers (USA).

River	Vicinity	S_{obs}	Study
Mississippi	Itasca, MN	2	Moll and Moll (2004)
Mississippi	Lake City, MN	7	Moll and Moll (2004)
Mississippi	LaCrosse, WI	7	Moll and Moll (2004)
Mississippi	Bellevue, IA	7	Moll and Moll (2004)
Mississippi	Alton, IL	9	Moll and Moll (2004)
Mississippi	Cape Girardeau, MO	7	Moll and Moll (2004)
Mississippi	Tiptonville, TN	6	Moll and Moll (2004)
Mississippi	St. Louis, MO to Cairo, IL	6	Barko et al. (2004)
Mississippi	Hamilton, IL	6	Anderson et al. (2002)
Illinois	Havana, IL	7	Paglia (2004)
Illinois	Havana, IL	7[a]	Moll (1977)
Illinois	Havana, IL	9	Tucker et al. (2008)
Big Muddy	Grand Tower, IL	7	Bluett et al. (2011b)
Embarras	Charleston, IL	6	Douros (2010)
Wabash	Allendale/Mt. Carmel, IL	5	Pierce (1992)
St. Croix	Danbury, WI to Stillwater, MN	7	DonnerWright et al. (1999)
Des Moines	Not specified	5	Vandewalle & Christiansen (1996)
Missouri	Not specified	5	Vandewalle & Christiansen (1996)
Sangamon	Beardstown, IL	8	This study

[a]Study did not distinguish *Graptemys pseudogeographica* from *G. ouchitensis*; presumably both occurred for a total of 8 species.

Implications for Conservation

We encountered 53% of species of freshwater turtles native to Illinois, and approximately 17% of those in North America. Species richness in the 7th order of the Sangamon was greater than that reported for all but two Midwestern rivers, both of which are larger than the Sangamon (Table 4). Thus, the Sangamon River is a significant resource despite channelization, isolation from its floodplain, alteration of hydrological regimes, urban development and intensive agricultural production. We conclude altered rivers should not be overlooked when developing regional or continental strategies for conservation of freshwater turtles.

The diverse assemblage we observed in the last stream order of the Sangamon is a product of ecological processes that begin in its headwaters (Saunders et al. 2002; Meyer et al. 2007) and extend past its confluence with the Illinois River (Osborne and Wiley 1992). As with fishes, this widens the scope of turtle conservation to the whole basin as well as reaches and sites (Saunders et al. 2002; Wang et al. 2002; Allen 2004; Cowx and van Zyll de Jong 2004). Past achievements suggest this goal is attainable. For example, regulatory provisions of the Clean Water Act of 1972 have reduced point sources of pollution (e.g., untreated sewage, industrial waste), and innovations in agricultural practices have mediated non-point sources (e.g., silt, nutrients) through widespread adoption of conservation tillage (Illinois Department of Agriculture 2006), targeted applications of chemicals, and use of pesticides with brief environmental persistence (Yates et al. 2006; Renwick et al. 2008). Positive changes in water quality have aided recovery of native fishes and mussels in the Illinois River (Sietman et al. 2001; Pegg and McClelland 2004) and Salt Creek, a tributary of the Sangamon (Retzer 2005).

Agricultural policies have benefitted turtles since 1985, when the Food Securities Act first offered financial incentives to producers who converted highly erodible croplands to permanent vegetative cover for the life of easements, typically 10–15 years [i.e., Conservation Reserve Program (CRP); Gray 2009)]. During 2011, 5,527 ha of cropland in the Sangamon River Basin were enrolled in CRP with 1,803 ha protected by permanent easements under the Conservation Reserve Enhancement Program (Illinois Department of Natural Resources, unpubl. data). Restoration of riparian forests, wetlands and stream banks on lands enrolled in CRP is good for turtles (Burke and Gibbons 1995; Bodie 2001; Moll and Moll 2004; Nowalk 2010; Sterrett et al. 2010) and the broader environment (Haufler 2007; Marshall et al. 2008; United States Department of Agriculture 2010).

CONCLUSION

Our findings provide a benchmark for evaluating responses of turtle assemblages to changes in environmental quality of the Sangamon River. Monitoring programs should include stream network position (e.g., stream order or link) as a stratum when sampling assemblages of turtles and their environment. Characterizing spatial and temporal attributes of a complex and dynamic ecosystem is a challenging task (Thorp et al. 2006). For example, early reports of longitudinal structuring of assemblages of fishes led to more attempts to document the pattern (Platts 1979). Confirmations, exceptions and variations were noted, as were possible causes (Mathews 1986; Hitt and Angermeier 2006). This fostered an appreciation for spatial and temporal scales, theories to describe relationships, models to test them, and integration with broader aspects of stream ecology (Lammert and Allan 1999; Grenouillet et al. 2004; Smith and Kraft 2005; Thorp et al. 2006; Parsons and Thoms 2007). Progress in other fields of study will aid chelonian ecologists as they seek causes of longitudinal structuring and refine strategies for conservation to suit life cycles of turtles.

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LITERATURE CITED

Allen, J.D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. Annual Review of Ecology, Evolution and Systematics 35:257–284.

Anderson, R.V., M.L. Gutierrez, and M.A. Romano. 2002. Turtle habitat use in a reach of the upper Mississippi River. Journal of Freshwater Ecology 17:171–177.

Barko, V.A., J.T. Briggler, and D.E. Ostendorf. 2004. Passive fishing techniques: a cause of turtle mortality in the Mississippi River. Journal of Wildlife Management 68:1145–1150.

Bluett, R.D., E.M. Schauber, C.K. Bloomquist, and D.A. Brown. 2011a. Sampling assemblages of turtles in central Illinois: a case study of capture efficiency and species coverage. Transactions of the Illinois State Academy of Science 104:127–136.

Bluett, R.D., D.A. Woolard, J.G. Palis, and J.A. Kath. 2011b. Survey for *Macrochelys temminckii* in southern Illinois: implications for recovery actions. Transactions of the Illinois State Academy of Science 104:63–70.

Bodie, J.R. 2001. Stream and riparian management for freshwater turtles. Journal of Environmental Management 62:443–455.

Burke, V.J., and J.W. Gibbons. 1995. Terrestrial buffer zones and wetland conservation: a case study of freshwater turtles in a Carolina bay. Conservation Biology 9:1365–1369.

Cagle, F.R. 1942. Turtle populations in southern Illinois. Copeia 1942:155–162.

Carney, D. 2010. Trends in the lower Sangamon River basin fish community, 1981 to 2008. Illinois Department of Natural Resources, Springfield, Illinois, USA. 22 p.

Cowx, I.G., and M. van Zyll de Jong. 2004. Rehabilitation of freshwater fisheries: tales of the unexpected? Fisheries Management and Ecology 11:243–249.

DonnerWright, D.M., M.A. Bozek, J.R. Probst, and E.M. Anderson. 1999. Responses of turtle assemblages to environmental gradients in the St. Croix River in Minnesota and Wisconsin, USA. Canadian Journal of Zoology 77:989–1000.

Douros, D.L. 2010. Population ecotoxicology of the common snapping turtle in agriculturally impacted lotic ecosystems. M.Sc. Thesis, Eastern Illinois University, Charleston, Illinois, USA. 53 p.

Edds, D.R. 1993. Fish assemblage structure and environmental correlates in Nepal's Gandaki River. Copeia 1993:48–60.

Ernst, C.H., J.E. Lovich, and R. Barbour. 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington, D.C., USA.

Fuselier, L., and D. Edds. 1994. Habitat partitioning among three sympatric species of map turtles, genus *Graptemys*. Journal of Herpetology 28:154–158.

Gehrt, S.D., G.F. Hubert, Jr., and J.A. Ellis. 2002. Long-term population trends of raccoons in Illinois. Wildlife Society Bulletin 30:457–463.

Gray, R. 2009. Field guide to the 2008 Farm Bill for fish and wildlife conservation. U.S. National Bird Conservation Initiative Committee and Intermountain West Joint Venture, Washington, D.C., USA. 44 p.

Grenouillet, G., D. Pont, and C. Hérissé. 2004. Within-basin fish assemblage structure: the relative influence of habitat versus stream spatial position on local species richness. Canadian Journal of Fisheries and Aquatic Sciences 61:93–102.

Haag, W.R., and M.L. Warren, Jr. 1998. Role of ecological factors and reproductive strategies in structuring freshwater mussel communities. Canadian Journal of Fisheries and Aquatic Sciences 55:297–306.

Haufler, J.B. (Ed.). 2007. Fish and wildlife response to Farm Bill conservation practices. The Wildlife Society Technical Review 07-1. Bethesda, Maryland, USA. 113 p.

Heino, J., J. Parviainen, R. Paavola, M. Jehle, and P. Louhi. 2005. Characterizing macroinvertebrate assemblage structure in relation to stream size and tributary position. Hydrobiologia 539:121–130.

Herget, J.E. 1978. Taming the environment: the drainage district in Illinois. Journal of the Illinois State Historical Society 71:107–118.

Hitt, N.P., and P.L. Angermeier. 2006. Effects of adjacent streams on local fish assemblage structure in western Virginia: implications for biomonitoring. American Fisheries Society Symposium 48:75–86.

Illinois Department of Agriculture. 2006. 2006 Illinois soil conservation transect survey summary. Illinois Department of Agriculture, Springfield, Illinois, USA. 16 p.

Illinois Department of Natural Resources. 1994. The changing Illinois environment: critical trends. Illinois Department of Natural Resources, Springfield, Illinois, USA. 89 p.

Illinois Department of Natural Resources. 2000a. Lower Sangamon River area assessment. Volume 2: water resources. Illinois Department of Natural Resources, Springfield, Illinois, USA. 75 p.

Illinois Department of Natural Resources. 2000b. The heart of the Sangamon: an inventory of the region's resources. Illinois Department of Natural Resources, Springfield, Illinois, USA. 22 p.

Illinois Department of Natural Resources. 2001. Critical trends in Illinois ecosystems. Illinois Department of Natural Resources, Springfield, Illinois, USA. 112 p.

Illinois Environmental Protection Agency. 1995. Fact sheets #1–33. Illinois Environmental Protection Agency, Springfield, Illinois, USA. 11 p.

Killebrew, F.C., W.J. Rogers, and J.B. Babitzke. 2002. Assessment of instream flow and habitat requirements for Cagle's Map Turtle (*Graptemys caglei*). West Texas A&M University, Canyon, Texas, USA. 59 p.

Kornilev, Y.V., C.K. Dodd, Jr., and G.R. Johnston. 2010. Linear home range, movement, and spatial distribution of the Suwannee cooter (*Pseudemys concinna suwanniensis*) in a blackwater river. Chelonian Conservation and Biology 9:196–204.

Krebs, C.J. 1989. Ecological Methodology. HarperCollins Publishers, Inc., New York, New York, USA.

Lammert, M., and J.D. Allan. 1999. Assessing biotic integrity of streams: effects of scale in measuring the influence of land use/cover and habitat structure on fish and macroinverbrates. Environmental Management 23:257–270.

Lindeman, P.V. 1999. Surveys of basking map turtles *Graptemys* spp. in three river drainages and the importance of deadwood abundance. Biological Conservation 88:33–42.

Lindeman, P.V. 2000. Resource use of five sympatric turtle species: effects of competition, phylogeny, and morphology. Canadian Journal of Zoology 78:992–1008.

Major, P.D., R.D. Bluett, and A.C. Hulin. 2009. Turtles of Bond, Macoupin and Montgomery counties, Illinois, 2006–2008. Transactions of the Illinois State Academy of Science 102:191–198.

Marshall, D.W., A.H. Fayram, J.C. Panuska, J. Baumann, and J. Hennessy. 2008. Positive effects of agricultural land use changes on coldwater fish communities in southwest Wisconsin streams. North American Journal of Fisheries Management 28:944–953.

Mathews, W.J. 1986. Fish faunal 'breaks' and stream order in the eastern and central United States. Environmental Biology of Fishes 17:81–92.

Mattingly, R.L., E.E. Herricks, and D.M. Johnston. 1993. Channelization and levee construction in Illinois: review and implications for management. Environmental Management 17:781–795.

Melo, A.S., R.A.S. Pereira, A.J. Santos, G.J. Shepherd, G. Machado, H.F. Medeiros, and R.J. Sawaya. 2003. Comparing species richness among assemblages using sample units: why not use extrapolation to standardize different sample sizes? Oikos 101:398–410.

Meyer, J.L., D.L. Strayer, J.B. Wallace, S.L. Eggert, G.S. Helfman, and N.E. Leonard. 2007. The contribution of headwater streams to biodiversity in river networks. Journal of the American Water Resources Association 43:86–103.

Minton, R.L., J.D. White, D.M. Hayes, M.S. Chenoweth, and A.M. Hill. 2008. Diversity and distribution of freshwater gastropods in the Bayou Bartholomew drainage, Arkansas, USA. American Malacological Bulletin 26:171–177.

Moll, D.L. 1977. Ecological investigations of turtles in a polluted ecosystem: the central Illinois River and adjacent floodplain lakes. Ph.D. Dissertation, Illinois State University, Normal, Illinois, USA. 179 p.

Moll, D., and E.O. Moll. 2004. The Ecology, Exploitation, and Conservation of River Turtles. Oxford University Press, Inc., New York, New York, USA.

Naiman, R.J., J.M. Melillo, M.A. Lock, T.E. Ford, and S.R. Reice. 1987. Longitudinal patterns of ecosystem processes and community structure in a subarctic continuum. Ecology 68:1139–1156.

Nowalk, M. 2010. The effect of stream restoration on turtle species assemblages in the Piedmont region of North Carolina, USA. M.Sc. Thesis, Duke University, Durham, North Carolina, USA. 40 p.

Osborne, L.L., and M.J. Wiley. 1992. Influence of stream spatial position on structure of warmwater fish communities. Canadian Journal of Fisheries and Aquatic Sciences 49:671–681.

Paglia, S.J. 2004. Changing turtle communities of the Illinois River. M.Sc. Thesis, Eastern Illinois University, Charleston, Illinois, USA. 43 p.

Palic, D., L. Helland, B.R. Pedersen, J.R. Pribil, R.M. Grajeda, A.K. Loan-Wilsey, and C.L. Pierce. 2007. Fish assemblages of the upper Little Sioux River Basin, Iowa, USA: relationships with stream size and comparison with historical assemblages. Journal of Freshwater Ecology 22:69–79.

Parsons, M., and M.C. Thoms. 2007. Hierarchical patterns of physical-biological associations in river ecosystems. Geomorphology 89:127–146.

Pegg, M.A., and M.A. McClelland. 2004. Spatial and temporal patterns in fish communities along the Illinois River. Ecology of Freshwater Fish 13:125–135.

Phillips, C.A., R.A. Brandon, and E.O. Moll. 1999. Field Guide to Amphibians and Reptiles of Illinois. Manual 8, Illinois Natural History Survey, Champaign, Illinois, USA. 282 p.

Pierce, L. 1992. Diet content and overlap of six species of turtle among the Wabash River. M.Sc. Thesis, Eastern Illinois University, Charleston, Illinois, USA. 124 p.

Platts, W.S. 1979. Relationships among stream order, fish populations and aquatic geomorphology in an Idaho river drainage. Fisheries 4:5–9.

Prince, H. 1997. Wetlands of the American Midwest: a historical geography of changing attitudes. University of Chicago Press, Chicago, Illinois, USA.

Reese, D.A., and H.H. Welsh, Jr. 1998. Comparative demography of *Clemmys marmota* populations in the Trinity River of California in the context of dam-induced alterations. Journal of Herpetology 32:505–515.

Renwick, W.H., M.J. Vanni, Q. Zhang, and J. Patton. 2008. Water quality trends and changing agricultural practices in a Midwest U.S. watershed, 1994–1996. Journal of Environmental Quality 37:1862–1874.

Retzer, M.E. 2005. Changes in the diversity of native fishes in seven basins in Illinois, USA. American Midland Naturalist 153:121–134.

Riedle, J.D., P.A. Shipman, S.E. Fox, and D.M. Leslie, Jr. 2009. Habitat associations of aquatic turtle communities in eastern Oklahoma. Proceedings of the Oklahoma Academy of Science 89:11–21.

Sangunett, B.M. 2005. Reference conditions for streams in the Grand Prairie Natural Division of Illinois. M.Sc. Thesis, University of Illinois, Urbana, Illinois, USA. 83 p.

Saunders, D.L., J.J. Meeuwig, and C.J. Vincent. 2002. Freshwater protected areas: strategies for conservation. Conservation Biology 16:30–41.

Schanzle, R.W., and K.S. Cummings. 1991. A survey of the freshwater mussels (Bivalvia: Unionidae) of the Sangamon River Basin, Illinois. Illinois Natural History Survey Biological Notes 137. Illinois Natural History Survey, Champaign, Illinois, USA. 25 p.

Sheldon, A.L. 1968. Species diversity and longitudinal succession in stream fishes. Ecology 49:193–198.

Shively, S.H., and J.E. Jackson. 1985. Factors limiting the upstream distribution of the Sabine map turtle. American Midland Naturalist 114:292–303.

Sietman, B.E., S.D. Whitney, D.E. Kelner, K.D. Blodgett, and H.L. Dunn. 2001. Post-extirpation recovery of the freshwater mussel (Bivalva: Unionidae) fauna in the upper Illinois River. Journal of Freshwater Ecology 16:273–281.

Smith, P.W. 1971. Illinois streams: a classification based on their fishes and an analysis of factors responsible for the disappearance of native species. Illinois Natural History Survey Biological Notes, No. 76. Illinois Natural History Survey, Urbana, Illinois, USA. 14p.

Smith, T.A., and C.E. Kraft. 2005. Stream fish assemblages in relation to landscape position and local habitat variables. Transactions of the American Fisheries Society 134:430–440.

Sterrett, S.C., L.L. Smith, S.W. Golladay, S.H. Schweitzer, and J.C. Maerz. 2010. The conservation implications of riparian land use on river turtles. Animal Conservation 2010:1–9.

Thornbrugh, D.J., and K.B. Gido. 2010. Influence of spatial positioning within stream networks on fish assemblage structure in the Kansas River basin, USA. Canadian Journal of Fisheries and Aquatic Sciences 67:143–156.

Thorp, J.H., M.C. Thoms, and M.D. Delong. 2006. The riverine ecosystem synthesis: biocomplexity in river networks across space and time. River Research and Applications 22:123–147.

Tucker, J.K., S.A. Gritters, and R.A. Hrabik. 2008. Turtle communities in the Upper Mississippi River System. Illinois Natural History Survey Technical Report 2008(30), Illinois Natural History Survey, Champaign, Illinois, USA. 63 p.

United States Department of Agriculture. 2010. Effects of conservation practices on cultivated cropland in the Upper Mississippi River Basin. Natural Resources Conservation Service, Washington, D.C., USA. 146 p.

Vandewalle, T.J., and J.L. Christiansen. 1996. A relationship between river modification and species richness of freshwater turtles in Iowa. Journal of the Iowa Academy of Sciences 103:1–8.

Wang, L., J. Lyons, and P. Kanehl. 2002. Effects of watershed best management practices on habitat and fish in Wisconsin streams. Journal of the American Water Resources Association 38:663–680.

Wiley, M.J., L.L. Osborne, and R.W. Larimore. 1990. Longitudinal structure of an agricultural prairie river system and its relationship to current stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Sciences

47:373–384.

Yates, A.G., R.C. Bailey, and J.A. Schwindt. 2006. No-till cultivation improves stream ecosystem quality. Journal of Soil and Water Conservation 61:14–19.

Zucker, L.A., and L.C. Brown (Eds.). 1998. Agricultural drainage: water quality impacts and subsurface drainage studies in the Midwest. Ohio State University Extension Bulletin 871. The Ohio State University, Columbus, Ohio, USA.