DENNIS STREICHER

City of Elmhurst, Illinois
209 North York Street
Elmhurst, Illinois 60126
630.530.3046

EDUCATION and CERTIFICATION

B.S. in Biology from Northern Illinois University.

Illinois Class 1 Sewage Treatment Works Operator

Illinois Class "A" Public Water Supply Operator

WORK EXPERIENCE

City of Elmhurst, May 1972 to present

1972-1981	WWTP Chemist
1981-1982	Assistant Superintendent
1982-1990	Superintendent
1991-2000	Assistant Director of Public Works/ Water and Wastewater.
2000-Present	Director of Water & Wastewater

PROFESSIONAL ACTIVITIES

Member of the A.W.W.A.
Member Water Environment Federation
Member of Central States Water Environment Assoc.
Chairman of the Central States Education Committee
Past president of the Central States Illinois Section
Vice-president of the Illinois Association of Wastewater Agencies
Served as the northeast representative on the Operators Certification Committee for six years.

AWARDS

2000 Illinois EPA Operator of the Year
1996 CSWEA Operations Award

INTERESTS

Active in local environmental groups especially bird watching (birding) organizations. Wildlife photography especially birds in wild habitats. Natural history studies.

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April 2, 2004

Mr. Dennis P. McKenna
Deputy Administrator
Illinois Department of Agriculture
P.O. Box 19281
Springfield, IL 62794-9281

Re: Illinois Association of Wastewater Agencies Dissolved Oxygen Study

Dear Dennis,

As a follow up on our conversation of April 1, 2004, I'd like to thank you for your interest in the Illinois Association Wastewater Agencies (IAWA) dissolved oxygen study. As you are aware IAWA is very interested in implementing this study and modifying the Illinois water quality standards as regards to dissolved oxygen. It is our opinion that many other water quality standards will be enhanced by a scientifically well founded dissolved oxygen standard in Illinois. We feel the study has followed closely the USEPA protocols and builds upon the previous water quality standard. In addition it incorporates the special features of the Illinois warm water chemistry. Note that the study specifically excludes Lake Michigan and wetlands from consideration for DO limits changes.

The IAWA commissioned this study with the goal of incorporating a previous study by Chapman in 1986; then adding new data that has been developed since that time. The final draft will then make recommendations to modify Illinois water quality standards for DO based on natural fluctuations in aquatic systems and physiological tolerances of native aquatic life. The most significant recommendations are the incorporation of seven day running averages for the mean and minimum DO concentrations. The mean would be 7-d mean of 6.0 mg/L when most early life stages of fish are present and a 7-d mean minimum of 4.0 mg/L when most early life stages of fish are absent. This feature alone adds significantly to the standards as it recognizes the seasonality of the natural aquatic systems in Illinois. The recommended standards are either equivalent to or more conservative than the previously established national dissolved oxygen standards.

I have transmitted a copy of the report to you; we would appreciate your thoughts on the study. Also, please don't hesitate to share the study with others in the agricultural communities to elicit their responses as well. The goal of IAWA is to include comments

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of all interested stakeholders. Further we wish to sure that the concerns of the agricultural community are answered before the IAWA makes the move to ask the pollution control board to modify the standards in Illinois.

Once again it was enjoyable speaking with you and if you have any questions don't hesitate to give me a call at (630) 530-3046.

Sincerely,

Dennis Streicher
Director of Water & Wastewater
630.530.3046 office
630.834.0298 fax

Cc: IAWA DO file

June 14, 2004

Ms. Nancy Erickson
Director of Natural and Environmental Research
Illinois Farm Bureau
1701 Towanda Avenue
Bloomington, IL 61701

Re: Illinois Association of Wastewater Agencies Dissolved Oxygen Study
IPCB Docket Number R04-25

Dear Ms. Erickson,

As a follow up to our conversation of May 25, 2004, I'd like to thank you for your interest in the Illinois Association Wastewater Agencies (IAWA) dissolved oxygen study. Earlier in April of 2004 I had transmitted a copy of the study to you for comments.

As you are aware IAWA is very interested in implementing this study and modifying the Illinois water quality standards as regards to dissolved oxygen. It is our opinion that many other water quality standards will be enhanced by a scientifically well founded dissolved oxygen standard in Illinois. We feel the study has followed closely the USEPA protocols and builds upon the previous water quality standard. In addition it incorporates the special features of the Illinois warm water chemistry. Note that the study specifically excludes Lake Michigan and wetlands from consideration for DO limits changes.

The IAWA commissioned this study with the goal of incorporating a previous study by Chapman in 1986; then adding new data that has been developed since that time. The final draft will then make recommendations to modify Illinois water quality standards for DO based on natural fluctuations in aquatic systems and physiological tolerances of native aquatic life. The most significant recommendations are the incorporation of seven day running averages for the mean and minimum DO concentrations. The mean would be 7-d mean of 6.0 mg/L when most early life stages of fish are present and a 7-d mean minimum of 4.0 mg/L when most early life stages of fish are absent. This feature alone adds significantly to the standards as it recognizes the seasonality of the natural aquatic systems in Illinois. The recommended standards are either equivalent to or more conservative than the previously established national dissolved oxygen standards.

At this time the IAWA has filed a petition with the Illinois Pollution Control Board (IPCB) to incorporate the studies results into Illinois general use water standards. The IPCB has agreed to hear the petition and has set dates in June and August to receive testimony from interested stakeholders. We would appreciate your thoughts on the study. Also, please don't hesitate to share the study with others in the agricultural communities to elicit their responses as well. The goal of IAWA is to include comments of all interested stakeholders.

Once again it was enjoyable speaking with you and if you have any questions don't hesitate to give me a call at (630) 530-3046.

Sincerely,

Dennis Streicher
Director of Water & Wastewater
630.530.3046 office
630.834.0298 fax

Cc: IAWA DO file

April 2, 2004

Alec Messina
IL Environmental Regulatory Group
3150 Roland Avenue
Springfield, IL 62703

Re: Illinois Association of Wastewater Agencies Dissolved Oxygen Study

Dear Alec,

As a follow up on our conversation of April 2, 2004, I'd like to thank you for your interest in the Illinois Association Wastewater Agencies (IAWA) dissolved oxygen study. As you are aware IAWA is very interested in implementing this study and modifying the Illinois water quality standards as regards to dissolved oxygen. It is our opinion that many other water quality standards will be enhanced by a scientifically well founded dissolved oxygen standard in Illinois. We feel the study has followed closely the USEPA protocols and builds upon the previous water quality standard. In addition it incorporates the special features of the Illinois warm water chemistry. Note that the study specifically excludes Lake Michigan and wetlands from consideration for DO limits changes.

The IAWA commissioned this study with the goal of incorporating a previous study by Chapman in 1986; then adding new data that has been developed since that time. The final draft will then make recommendations to modify Illinois water quality standards for DO based on natural fluctuations in aquatic systems and physiological tolerances of native aquatic life. The most significant recommendations are the incorporation of seven day running averages for the mean and minimum DO concentrations. The mean would be 7-d mean of 6.0 mg/L when most early life stages of fish are present and a 7-d mean minimum of 4.0 mg/L when most early life stages of fish are absent. This feature alone adds significantly to the standards as it recognizes the seasonality of the natural aquatic systems in Illinois. The recommended standards are either equivalent to or more conservative than the previously established national dissolved oxygen standards.

I have transmitted a copy of the report to you; we would appreciate your thoughts on the study. Also, please don't hesitate to share the study with others that you represent to elicit their responses as well. The goal of IAWA is to include comments of all interested stakeholders. Further we wish to sure that the concerns of the industrial discharger community are answered before the IAWA makes the move to ask the pollution control board to modify the standards in Illinois.

Once again it was enjoyable speaking with you and if you have any questions don't hesitate to give me a call at (630) 530-3046.

Sincerely,

Dennis Streicher
Director of Water & Wastewater
630.530.3046 Office
630.834.0298 fax

Cc: IAWA DO file

April 12, 2004

Dr. Edward Krug
Illinois State Water Survey
2204 Griffith Dr
Champaign, IL 61820

Re: Illinois Association of Wastewater Agencies Dissolved Oxygen Study

Dear Dr. Krug,

As a follow up on our conversation of April 12, 2004, I'd like to thank you for your interest in the Illinois Association Wastewater Agencies (IAWA) dissolved oxygen study. As you are aware IAWA is very interested in implementing this study and modifying the Illinois water quality standards as regards to dissolved oxygen. It is our opinion that many other water quality standards will be enhanced by a scientifically well founded dissolved oxygen standard in Illinois. We feel the study has followed closely the USEPA protocols and builds upon the previous water quality standard. In addition it incorporates the special features of the Illinois warm water chemistry. Note that the study specifically excludes Lake Michigan and wetlands from consideration for DO limits changes.

The IAWA commissioned this study with the goal of incorporating a previous study by Chapman in 1986; then adding new data that has been developed since that time. The final draft will then make recommendations to modify Illinois water quality standards for DO based on natural fluctuations in aquatic systems and physiological tolerances of native aquatic life. The most significant recommendations are the incorporation of seven day running averages for the mean and minimum DO concentrations. The mean would be 7-d mean of 6.0 mg/L when most early life stages of fish are present and a 7-d mean minimum of 4.0 mg/L when most early life stages of fish are absent. This feature alone adds significantly to the standards as it recognizes the seasonality of the natural aquatic systems in Illinois. The recommended standards are either equivalent to or more conservative than the previously established national dissolved oxygen standards.

I have transmitted a copy of the report to you; we would appreciate your thoughts on the study. Also, please don't hesitate to share the study with others that you represent to elicit their responses as well. The goal of IAWA is to include comments of all interested stakeholders. Further we wish to sure that the concerns of the industrial discharger community are answered before the IAWA makes the move to ask the pollution control board to modify the standards in Illinois.

Once again it was enjoyable speaking with you and if you have any questions don't hesitate to give me a call at (630) 530-3046.

Sincerely,

Dennis Streicher
Director of Water & Wastewater
630.530.3046 Office
630.834.0298 fax

Cc: IAWA DO file

Short Curriculum Vita

Name	James E. Garvey
Title	Assistant Professor
Address	Fisheries and Illinois Aquaculture Center Department of Zoology Southern Illinois University – Carbondale jgarvey@siu.edu http://www.science.siu.edu/zoology/garvey/index.html
Degrees	1997 Ph.D., Zoology, The Ohio State University, Ohio 1992 M.S., Zoology, The Ohio State University, Ohio 1990 B.A., *cum laude*, Zoology, Miami University, Ohio

Experience

2000-	Assistant Professor, Department of Zoology, Southern Illinois University
1998-2000	Assistant Professor, Division of Biology, Kansas State University
1997-1998	Postdoctoral Fellow, Department of Biology, Queen=s University, Ontario
1997	Research Associate, Department of Zoology, The Ohio State University
1996-1997	Presidential Fellow, Graduate School, The Ohio State University
1990-1996	Graduate Research Associate, Department of Zoology, The Ohio State University
1990-1996	Graduate Teaching Associate, Department of Zoology, The Ohio State University
1988-1990	Research Technician, Department of Zoology, Miami University
1988	Student Researcher, School for Field Studies, St. John, U.S. Virgin Islands

Fields of Research Competence

Aquatic ecology, fish ecology, basic and applied fish biology, limnology, food web dynamics, bioenergetics, life history modeling

Honors and Awards

2001	Best Oral Presentation, Annual Meeting of the Illinois Chapter of the American Fisheries Society, February 2001
2000	Best Oral Presentation, 2000 Annual Meeting of the Kansas Chapter of the American Fisheries Society, Manhattan, Kansas
1999	Article titled ACompetition between larval fishes in reservoirs: the role of

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	relative timing of appearance@ (co-author, R.A. Stein) was among 5 nominated by a selection committee for Best Paper in Transactions of the American Fisheries Society (out of –100 articles)
1999	American Society of Limnology and Oceanography=s DIALOG III Symposium, Bermuda, October 1999
1998	Graduate Faculty Status, Kansas State University, November 1998
1996	Best Poster, Annual Meeting of the American Fisheries Society, Dearborn, Michigan, August 1996
1996	University Presidential Fellowship, July 1996
1995	Honorable Mention, Best Oral Presentation, Annual Meeting of the American Fisheries Society, Tampa, Florida, August 1995

Student Awards

2004	Dean Sherman, Honorable Mention, Best Poster Award, Undergraduate Research Forum, Southern Illinois University, Carbondale, March 2004
2004	Laura Csoboth, Student Travel Award, Illinois American Fisheries Society Meeting, Champaign, Illinois, March 2004

Selected Professional Service (last five years)

2004	Reviewer, National Science Foundation proposal, Ecology Panel (RUI proposal)
2004	Member, Skinner Award Committee, American Fisheries Society (second term)
2004	North Central Representative, Early Life History Section, American Fisheries Society.
2003	Workshop Presenter, Analysis of Fisheries Data, Illinois Chapter of the American Fisheries Society Continuing Education Workshop, Springfield, Illinois, April 2003
2003	Moderator, River Session, Illinois Chapter of the American Fisheries Society, Rend Lake, IL, February 2003
2002	Reviewer, National Science Foundation proposal, Ecology Panel, August 2002
2002	Chair, Student Judging of Oral Presentations, National American Fisheries Society Meeting, Baltimore, Maryland, August 2002
2002-present	Associate Editor, *Transactions of the American Fisheries Society* (handle ~ 10 manuscripts per year)
2001-2003	Judge, Regional Science Fair, SIUC campus, February 2001-2003
1999-2001	Member, Skinner Award Committee, American Fisheries Society (first term)
2001	Reviewer, National Science Foundation proposal, Ecology Panel, February 2001
2001	Moderator, Fisheries Session, Illinois Renewable Natural Resources Meeting, February 2001
2000	Judge, Student Paper Presentations, American Fisheries Society

	National Meeting, August 2000
1994-present	Peer Reviewer, *Behaviour, Biological Invasions, Canadian Journal of Zoology Transactions of the American Fisheries Society, North American Journal of Fisheries Management, Ecology, Ecological Applications, Great Basin Naturalist, American Midland Naturalist, Prairie Naturalist, Journal of Plankton Research, Animal Behaviour, Journal of the North American Benthological Society, Northwest Science, North American Journal of Aquaculture, Proceedings of the Royal Academy of Science –Great Britain*

Current Society Memberships

2003-present	Honorary Member, American Institute of Biological Sciences
1990-present	Ecological Society of America
1990-present	American Fisheries Society
1990-1996, 1999-present	North American Benthological Society
2001-present	Illinois Chapter of the American Fisheries Society
1999-present	Full Member, Sigma Xi

Invited Presentations

2003	Upper Mississippi Conservation Committee, Prairie du Chien, Wisconsin, August 2003
2002	Ecology Consortium, Southern Illinois University, Carbondale, November 2002
2000	Sam Parr Biological Station, Illinois Natural History Survey, June 2000
2000	Northeast Division Meeting of the American Fisheries Society, April 2000
2000	Department of Zoology, University of Wisconsin - Madison, February 2000
1999	Department of Biology, William Jewell College, Missouri, September 1999
1998	Department of Biology, Queen=s University, Kingston, Ontario, January 1998
1997	Apple Valley Fishing Club, Apple Valley, Ohio, October 1997
1996	Department of Biological Sciences, University of Pittsburgh, December 1996.

Technical Reports

Garvey, J.E., and M.R Whiles. 2003. An assessment of national and Illinois dissolved oxygen water quality criteria. Illinois Association of Wastewater Agencies. 52 pages

Garvey, J.E., B.D. Dugger, M.R. Whiles, S.R. Adams, M.B. Flinn, B.M. Burr, and R.J.

Sheehan. 2003. Responses of fish, waterbirds, invertebrates, vegetation, and water quality to environmental pool management: Mississippi River Pool 25. U.S. Army Corps of Engineers. 181 pages.

Garvey, J.E. 2002. Winter habitat used by fishes in Smithland Pool, Ohio River. U.S. Fish and Wildlife Service and U.S. Army Corps of Engineers, 90 pages.

Garvey, J.E., and R.J. Sheehan. 2001. Winter habitat associations of riverine fishes: predictions for the Ohio River, U.S. Fish and Wildlife Service and U.S. Army Corps of Engineers, 39 pages.

Garvey, J.E., R.A. Wright, R.A. Stein, E.M. Lewis, K.H. Ferry, and S.M. Micucci. 1998. Assessing the influence of size on overwinter survival of largemouth bass in Ohio on-stream impoundments. Ohio Division of Wildlife Final Report. Federal Aid in Sport Fish Restoration Program 29, 288 pages.

Stein, R.A., and **J.E. Garvey**. 1996. A review of a technical report prepared for the Cuyahoga River (Ohio) Community Planning Organization by EnvironScience Inc.

Theses and Dissertations

Garvey, J.E. 1997. Strong interactors and community structure: testing predictions for reservoir food webs, Ph.D. dissertation, 235 pages.

Garvey, J.E. 1992. Selective predation as a mechanism of crayfish species replacement in northern Wisconsin lakes. M.S. thesis, The Ohio State University, 88 pages.

Book Chapters

S.R. Chipps, and **J.E. Garvey.** In press. Assessment of food habits and feeding patterns. *In* M.L. Brown and C.S. Guy, editors. Analysis and Interpretation of Freshwater Fisheries Data. 41 MS pages, 2 tables, 4 figures, 13 boxes. 1 April 2001.

Book Reviews

Garvey, J.E. 2003. Searching for scales in fisheries. Review of "Hierarchical Perspectives on Marine Complexities: Searching for Systems in the Gulf of Maine" by Spencer Apollonio. Columbia University Press, New York. 2002. 229 pp. Appeared in BioScience 53(10):1004-1006. (Invited)

Peer-Reviewed Publications (Selected Abstracts at http://www.science.siu.edu/zoology/garvey/pubs.html)

Garvey, J.E., K.G. Ostrand, and D.H. Wahl. In press. Interactions among allometric scaling, predation and ration affect size-dependent growth and mortality of fish during winter. Ecology. Aug. 2003.

Ostrand, K.G., S.J. Cooke, **J.E. Garvey**, and D.H. Wahl. In press. The energetic impact of overwinter prey assemblages on age-0 largemouth bass. Environmental Biology of Fishes.

Colombo, R.E., P.S. Wills, and **J.E. Garvey**. 2004. Use of ultrasound imaging to determine sex of shovelnose sturgeon *Scaphirhynchus platorynchus* from the Middle Mississippi River. North American Journal of Fisheries Management 24:322-326.

Roberts, M.R., JE. Wetzel, III, R.C. Brooks, and **J.E. Garvey**. 2004. Daily incrementation in the otoliths of the red spotted sunfish, *Lepomis miniatus*. North American Journal of Fisheries Management 24:270-274.

Garvey, J.E., and E.A. Marschall. 2003. Understanding latitudinal trends in fish body size through models of optimal seasonal energy allocation. Canadian Journal of Fisheries and Aquatic Sciences 60(8):938-948.

Micucci, S.M., **J.E. Garvey**, R.A. Wright, and R.A. Stein. 2003. Individual growth and foraging responses of age-0 largemouth bass to mixed prey assemblages during winter. Environmental Biology of Fishes 67(2):157-168.

Garvey, J.E., J.E. Rettig, R.A. Stein, D.M. Lodge, and S.P. Klosiewski. 2003. Scale-dependent associations among fish predation, littoral habitat, and distributions of native and exotic crayfishes. Ecology 84(12): 3339-3348.

Whiles, M.J., and **J.E. Garvey**. In press. Aquatic resources of the Shawnee and Hoosier National Forests, USDA Forest Service.

Garvey, J.E., R.A. Stein, R.A. Wright, and M.T Bremigan. 2003. Largemouth bass recruitment in North America: quantifying underlying ecological mechanisms along environmental gradients Black bass: ecology, conservation and management. Edited by D. Philipp and M. Ridgway. American Fisheries Society Symposium 31:7-23.

Garvey, J.E., D.R. DeVries, R.A. Wright, and J.G. Miner. 2003. Energetic adaptations along a broad latitudinal gradient: implications for widely distributed communities. BioScience 53(2):141-150.

Garvey, J.E., T.P. Herra, and W.C. Leggett. 2002. Protracted reproduction in sunfish: the temporal dimension in fish recruitment revisited. Ecological Applications 12:194-205.

Garvey, J.E., R.A. Wright, K.H. Ferry, and R.A. Stein. 2000. Evaluating how local- and regional- scale processes interact to regulate growth of age-0 largemouth bass. Transactions of the American Fisheries Society 129:1044-1059.

Fullerton, A.H., **J.E. Garvey**, R.A. Wright, and R.A. Stein. 2000. Overwinter growth and survival of largemouth bass: interactions among size, food, origin, and winter duration. Transactions of the American Fisheries Society 129:1-12.

Wright, R.A., **J.E. Garvey**, A.H. Fullerton, and R.A. Stein. 1999. Using bioenergetics to explore how winter conditions affect growth and consumption of age-0 largemouth bass. Transactions of the American Fisheries Society 128:603-612.

Garvey, J.E., and R.A. Stein. 1998. Competition between larval fishes in reservoirs: the role of relative timing of appearance. Transactions of the American Fisheries Society 127:1023-1041.

Garvey, J.E., R.A. Wright, and R.A. Stein. 1998. Overwinter growth and survival of age-0 largemouth bass: revisiting the role of body size. Canadian Journal of Fisheries and Aquatic Sciences 55:2414-2424.

Garvey, J.E., N.A. Dingledine, N.S. Donovan, and R.A. Stein. 1998. Exploring spatial and temporal variation within reservoir food webs: predictions for fish assemblages. Ecological Applications 8:104-120.

Garvey, J.E., and R.A. Stein. 1998. Linking bluegill and gizzard shad assemblages to growth of age-0 largemouth bass in reservoirs. Transactions of the American Fisheries Society 127:70-83.

Lodge, D.M., R.A. Stein, K.M. Brown, A.P. Covich, C. Brönmark, **J.E. Garvey**, and S.P. Klosiewski. 1998. Predicting impact of freshwater exotic species on native biodiversity: challenges in spatial and temporal scaling. Australian Journal of Ecology 23:53-67.

Garvey, J.E., E.A. Marschall, and R.A. Wright. 1998. From star charts to stoneflies: detecting relationships in continuous bivariate data. Ecology 79(2):442 447.

Schaus, M.H., M.J. Vanni, T.E. Wissing, M. Bremigan, **J.E. Garvey**, and R.A. Stein. 1997. Nitrogen and phosphorus excretion by the detritivorous gizzard shad (*Dorosoma cepedianum*) in a reservoir ecosystem. Limnology and Oceanography 42(6):1386-1397.

Garvey, J.E., R.A. Stein, and H.M. Thomas. 1994. Assessing how fish predation and interspecific prey competition influence a crayfish assemblage. Ecology 75:532-547.

Garvey, J.E., and R.A. Stein. 1993. Evaluating how chela size influences the invasion potential of an introduced crayfish, *Orconectes rusticus*. American Midland Naturalist 129:172-181.

Garvey, J.E., H.A. Owen, and R.W. Winner. 1991. Toxicity of copper to the green alga, *Chlamydomonas reinhardtii* (Chlorophycea), as affected by humic substances of terrestrial and freshwater origin. Aquatic Toxicology 19:89-96.

Oral Presentations and Posters (Last Five Years)

Williamson, C.J., and **J.E.** Garvey. Growth and mortality of silver carp: implications for its rise to dominance in the Middle Mississippi River. Illinois Chapter of the American Fisheries Society, Champaign, IL, March 2004. (Oral presentation by Williamson)

Koch, B.T., **J.E. Garvey**, and M. Lydy. The effects of land use on organochlorine accumulation in middle Mississippi River shovelnose sturgeon: intersexuality and reproductive consequences. Illinois Chapter of the American Fisheries Society, Champaign, IL, March 2004. (Oral presentation by Koch)

Csoboth, L.A., D.W. Schultz, K. DeGrandChamp, **J.E. Garvey**, and R.M. Neumann. Fish response at a backwater-river interchange: the Swan Lake rehabilitation and enhancement project. Illinois Chapter of the American Fisheries Society, Champaign, IL, March 2004. (Poster presentation)

Colombo, R.E., **J.E. Garvey**, and R.C. Heidinger. Comparing demographics of channel catfish in fished and un-fished reaches of the Wabash River. 64th Meeting of the Midwest Fish and Wildlife Conference. Kansas City, December 2003. (Oral presentation by Colombo)

Spier, T., **J.E. Garvey**, R.C. Heidinger, R.J. Sheehan, P. Wills, K. Hurley, R.E. Colombo, R.C. Brooks. Pallid and shovelnose sturgeon movement and habitat usage in the middle Mississippi River. 64th Meeting of the Midwest Fish and Wildlife Conference. Kansas City, December 2003 (Oral presentation by Spier)

Marschall, E.A., and **J.E. Garvey**. Understanding latitudinal trends in fish body size through models of optimal seasonal energy allocation. 88th Meeting of the Ecological Society of America, Savannah, Georgia, July 2003 (Oral presentation by Marschall)

Braeutigam, B.J., and **J.E. Garvey**. Winter habitat used by fish in Smithland Pool, Ohio River. Ohio River Research Review, Indiana, August 2003. (Oral presentation by Braeutigam)

Garvey, J.E. Importance of flood-plain connectivity to fish assemblages in the Mississippi River. Middle Mississippi River Workgroup Meeting, Carbondale, IL, June 2003. (Oral presentation by Garvey)

O'Neill, B.J., **J.E. Garvey**, M.R. Whiles, and K.R. Lips. Scale-dependent interrelationships among, fish, landscape characteristics, and ambystomatid salamanders in forest ponds. Annual Meeting of the American Society of Ichthyologists and Herpetologists, Manaus, Brazil, June 2003 (Oral presentation by O'Neill)

Spier, T., **J. Garvey**, R. Heidinger, R. Sheehan, P. Wills, and K. Hurley. Demographics and habitat usage of pallid sturgeon in the Middle Mississippi River. Meeting of the Illinois Chapter of American Fisheries Society, Rend Lake, IL, February 2003 (Oral presentation by Spier)

Jackson, N.D., **J.E. Garvey**, R.C. Heidinger, and R.J. Sheehan. Age and mortality of shovelnose sturgeon, *Scaphirhynchus platorynchus*, in the Middle Mississippi River and Lower Wabash Rivers, Illinois. Meeting of the Illinois Chapter of American Fisheries Society, Rend Lake, IL, February 2003 (Oral presentation by Jackson)

Flinn, M.B., S. R. Adams, M.R. Whiles, **J.E. Garvey**, B.M. Burr, and R.J. Sheehan. Fish and macroinvertebrate responses to environmental pool management in Mississippi River Pool 25. Meeting of the Illinois Chapter of American Fisheries Society, Rend Lake, IL, February 2003 (Oral presentation by Flinn)

Colombo, R.E., **J.E. Garvey**, R.C. Heidinger and R.J. Sheehan. Population demographics of channel catfish *Ictalurus punctatus* in the Wabash River. Meeting of the Illinois Chapter of American Fisheries Society, Rend Lake, IL, February 2003 (Oral presentation by Colombo)

Garvey, J.E. Early growth of centrarchids along a productivity gradient: setting the stage for future interactions. American Fisheries Society Meeting, Baltimore, MD, August 2002 (Oral presentation)

Ostrand, K.G., S.J. Cooke, **J.E. Garvey**, D.H. Wahl. Age-0 largemouth bass: the overwinter effects of prey type on growth and spring swimming performance. American Fisheries Society Meeting, Baltimore, MD, August 2002 (Oral presentation by Ostrand)

Garvey, J.E., S.M. Micucci, R.A. Wright, and R.A. Stein. Prey assemblage structure during winter influences the condition of age-0 largemouth bass. Midwest Fish and Wildlife Meeting, Des Moines, IA, December 2001 (Oral presentation)

Garvey, J.E. Using optimal allocation models to explain latitudinal trends in recruitment of largemouth bass. Illinois Renewable Natural Resources Conference, Peoria, IL, February 2001 (Oral presentation; received Best Oral Presentation)

Bremigan, M.T., R.A. Stein, and **J.E. Garvey**. Variable gizzard shad recruitment and its effects along a reservoir productivity gradient. American Society of Limnology and Oceanography Meeting - Copenhagen, Denmark, June 2000 (Poster presentation).

Evans-White, M., W.K. Dodds, and **J.E. Garvey**. Crayfish biomass, growth, and production in a tallgrass prairie stream. North American Benthological Society Meeting, Colorado, May 2000 (Oral presentation by Dodds).

Garvey, J.E. Patterns of sportfish recruitment in natural lakes and reservoirs: do generalities exist? Kansas Chapter of the American Fisheries Society Meeting, February 2000 (Oral presentation; received Best Oral Presentation).

Garvey, J.E. From fish in lakes to crayfish in prairie streams: searching for general recruitment mechanisms and ecosystem consequences. KSU Ecology Research Seminar Series, November 1999 (Oral presentation).

Garvey, J.E., T.P. Herra, and W.C. Leggett. Mechanisms underlying the spatial distribution of larval sunfish (*Lepomis* spp.) in Lake Opinicon, Ontario. American Fisheries Society Meeting - Charlotte, North Carolina, August 1999 (Oral presentation).

Garvey, J.E. Interactions between ecosystems and life histories: predicting fish community structure in lakes. Kansas EPSCoR Conference, Topeka, KS, April 1999 (Poster presentation).

MATT ROWLAND WHILES

Department of Zoology
Southern Illinois University
Carbondale, Illinois 62901-6501
Phone: (618) 453-7639

PERSONAL INFORMATION

Born December 4, 1964; Kansas City, Missouri.

Married 1998, 1 daughter and 1 son

EDUCATION

9/91-6/95 University of Georgia, Athens, Georgia; **Ph.D. Ecology.**
Dissertation: Disturbance, recovery, and invertebrate communities in southern Appalachian headwater streams.

9/88-9/91 University of Georgia, Athens, Georgia; **M.S. Entomology.**
Thesis: First-year recovery of a southern Appalachian headwater stream following an insecticide induced disturbance.

8/84-8/88 Kansas State University, Manhattan, Kansas; **B.S. Biology.**

AREAS OF SPECIALIZATION

Ecosystem ecology with emphasis on freshwater ecosystem structure and function (mainly streams and wetlands), the role of invertebrates in ecosystems, ecosystem-level consequences of extinctions, energetic linkages between aquatic and terrestrial systems, the role of disturbance, and biological assessment of freshwater habitats.

PROFESSIONAL EXPERIENCE

2003- **Associate Professor of Zoology**, Southern Illinois University
Teaching Freshwater Invertebrates, Stream Ecology, and General Ecology.
Advising graduate research in freshwater ecosystem ecology.

2000- **Assistant Professor of Zoology**, Southern Illinois University
Teaching Freshwater Invertebrates, Stream Ecology, and General Ecology.
Advising graduate research in freshwater ecosystem ecology.

2000- **Adjunct Assistant Professor of Entomology**, Kansas State University
Serving as a graduate committee member for students pursuing studies in the area of aquatic invertebrate ecology

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KGM R01-25

PROFESSIONAL EXPERIENCE (continued)

1997-00	**Assistant Professor of Entomology** (non-tenure track), Kansas State University Taught Insect Ecology, Insects and People, Economic Entomology, and an interdisciplinary Environmental Concerns course. Advised graduate research in invertebrate ecology.
1995-97	**Assistant Professor of Biology**, Wayne State College Taught Introductory Zoology, Invertebrate Zoology, Entomology, Vertebrate Zoology, Ecology, and General Biology (majors and non-majors). Advised undergraduate research in freshwater invertebrate ecology.
1996-	**Adjunct Graduate Faculty**, University of Memphis Graduate committee member for students working in aquatic ecology.
1989-95	**Graduate Teaching Assistant**, University of Georgia Instructed numerous laboratory courses including General Biology, Entomology, Animal Behavior, Aquatic Entomology, General Ecology, and Insect Ecology.
1994	**Laboratory Coordinator**, University of Georgia Instructed, scheduled, and supervised graduate teaching assistants for the General Biology program.
1988-94	**Research Assistant**, University of Georgia Investigated the role of aquatic invertebrates in stream ecosystem function. Participated in all aspects of a long-term study including sampling and processing of invertebrate communities, organic matter, and water chemistry.
1987-88	**Research Assistant**, Kansas State University Investigated effects of nutrient enrichment on algal growth and invertebrate grazer densities in streams on LTER sites across the country.
1987-87	**Undergraduate Research Assistant**, Kansas State University Investigated small mammal behavior on islands in the Sea of Cortez with and without reptilian predators.
1985-87	**Undergraduate Research Assistant**, Kansas State University Examined macroinvertebrate community dynamics in streams with contrasting hydrologic regimes on the Konza Prairie Research Natural Area.

HONORS AND AWARDS

1997	Professor of the Year, Math and Sciences Division, Wayne State College.
1996	Professor of the Year, Math and Sciences Division, Wayne State College.
1995	Outstanding Teaching Assistant, University of Georgia.
1994-1995	University-Wide Assistantship Award, University of Georgia.
1994-1995	Merit Assistantship Award; Outstanding Teaching and Research, Univ. of GA.
1993-1994	Merit Assistantship Award; Outstanding Teaching and Research, Univ. of GA
1988	Nominee for Outstanding Senior Biology Student, Kansas State University.
1987	Hydrolab Award; best poster, North American Benthological Society meetings
1984	Designated Kansas State Scholar.

PROFESSIONAL PUBLICATIONS

Dodds, W. K., and **M. R. Whiles**. *In press*. Factors related to quality and quantity of suspended particles in rivers: general continent-scale patterns in the United States. *Environmental Management:*

Whiles, M. R., J. B. Jensen, J. G. Palis, and W. G. Dyer. *In press*. Diets of larval flatwoods salamanders, *Ambystoma cingulatum*, from Florida and South Carolina. *Journal of Herpetology*.

Whiles, M. R., and J. E. Garvey. *In press*. Freshwater resources within the Shawnee-Hoosier Ecological Assessment Region. Special Publication of the USDA Forest Service:

Dodds, W. K., K. Gido, **M. R. Whiles**, K. M. Fritz, and W. J. Matthews. 2004. Life on the Edge: Ecology of Prairie Streams. *Bioscience* 54: 205-216

Ranvestel, A. W., K. R. Lips, C. M. Pringle, **M. R. Whiles**, and R. J. Bixby. 2004. Neotropical tadpoles influence stream benthos: evidence for ecological consequences of amphibian declines. *Freshwater Biology* 49: 274-285.

Webber, J. A., K. W. J. Williard, **M. R. Whiles**, M. L. Stone, J. J. Zaczek, and K. D. Davie. 2004. Watershed scale assessment of the impact of forested riparian zones on stream water quality. Pages 114-120 In: Van Sambeek, J.W.; J.O. Dawson; F. Ponder, Jr.; E.F. Loewenstein; and J.S. Fralish, eds. Proceedings, 13th Central Hardwood Forest Conference; Urbana, IL. Gen. Tech. Rep. NC-234. St. Paul, MN: USDA Forest Service, North Central Research Station.

Evans-White, M. A., W. K. Dodds, and **M. R. Whiles**. 2003. Ecosystem significance of crayfishes and central stonerollers in a tallgrass prairie stream: functional differences between co-occurring omnivores. *Journal of the North American Benthological Society*: 22: 423-441.

Callaham, M. A., Jr., J. M. Blair, T. C. Todd, D. J. Kitchen, and **M. R. Whiles**. 2003. Macroinvertebrates in North American tallgrass prairie soils: Effects of fire, mowing, and fertilization on density and biomass. *Soil Biology and Biochemistry* 35:1079-1093.

Whiles, M. R., and W. K. Dodds. 2002. Relationships between stream size, suspended particles, and filter-feeding macroinvertebrates in a Great Plains drainage network. *Journal of Environmental Quality* 31: 1589-1600.

Jonas, J., **M. R. Whiles**, and R. E. Charlton. 2002. Aboveground invertebrate responses to land management differences in a central Kansas grassland. *Environmental Entomology* 31: 1142-1152.

Stagliano, D. M., and **M. R. Whiles**. 2002. Macroinvertebrate production and trophic structure in a tallgrass prairie headwater stream. *Journal of the North American Benthological Society* 21: 97-113.

Callaham, M. A., **M. R. Whiles**, and J. M. Blair. 2002. Annual fire, mowing, and fertilization effects on two annual cicadas (Homoptera: Cicadidae) in tallgrass prairie. *American Midland Naturalist* 148: 90-101.

Meyer, C. K., **M. R. Whiles**, and R. E. Charlton. 2002. Life history, secondary production, and ecosystem significance of acridid grasshoppers in annually burned and unburned tallgrass prairie. *American Entomologist* 48: 52-61.

PROFESSIONAL PUBLICATIONS (continued)

Whiles, M. R., and B. S. Goldowitz. 2001. Hydrologic influences on insect emergence production from central Platte River wetlands. *Ecological Applications* 11: 1829-1842.

Whiles, M. R. M. A. Callaham, C. K. Meyer, B. L. Brock, and R. E. Charlton. 2001. Emergence of periodical cicadas from a Kansas riparian forest: densities, biomass, and nitrogen flux. *American Midland Naturalist* 145: 176-187.

Schrank, S. J., C. S. Guy, **M. R. Whiles**, and B. L. Brock. 2001. Assessment of Physicochemical and watershed features influencing Topeka shiner *Notropis topeka* distribution in Kansas streams. *Copeia* 2001: 413-421.

Dodds, W. K., M. A. Evans-White, N. M. Gerlanc, L. J. Gray, D. A.Gudder, M. J. Kemp, A. L. López, D. Stagliano, E. A. Strauss, J. L. Tank, **M. R. Whiles**, W. M. Wollheim. 2001. Quantification of the nitrogen cycle in a prairie stream. *Ecosystems*: 3: 574-589.

Whiles, M. R., B. L. Brock, A. C. Franzen, and S. Dinsmore II. 2000. Stream invertebrate communities, water quality, and land use patterns in an agricultural drainage basin of northen Nebraska. *Environmental Management*: 26: 563-576.

Jensen, J. B., and **M. R. Whiles.** 2000. Diets of sympatric *Plethodon petraeus* and *Plethodon glutinosus*. *Journal of the Elisha Mitchell Scientific Society* 116: 245-250.

Callaham, M. A., Jr., **M. R. Whiles**, C. K. Meyer, B. L. Brock, and R. E. Charlton. 2000. Feeding ecology and emergence production of annual cicadas (Homoptera: Cicadidae) in tallgrass prairie. *Oecologia* 123: 535-542.

Alexander, K. A., and **M. R. Whiles**. 2000. A new species of *Ironoquia* Banks (Trichoptera: Limnephilidae) from the central Platte River, Nebraska. *Entomological News*: 111: 1-7.

Whiles, M. R., B. S. Goldowitz, and R. Charlton. 1999. Life history and production of a semi-terrestrial limnephilid caddisfly in a Platte River wetland. *Journal of the North American Benthological Society* 18: 533-544.

Goldowitz, B. S., and **M. R. Whiles**. 1999. Investigations of fish, amphibians, and aquatic invertebrates within the middle Platte River system. Published final Report, Platte Watershed Program, Cooperative Agreement X99708101, USEPA.

Whiles, M. R., and B. S. Goldowitz. 1998. Biological responses to hydrologic fluctuation in wetland sloughs of the central Platte River. *In* Lingle, G. (ed.) *Proceedings of the Ninth Platte River Basin Ecosystem Symposium*. USFWS and USEPA Region VII.

Whiles, M. R., and J. B. Wallace. 1997. Litter decomposition and macroinvertebrate communities in headwater streams draining pine and hardwood catchments. *Hydrobiologia* 353: 107-119.

Wallace, J. B., T. F. Cuffney, S. L. Eggert, and **M. R. Whiles**. 1997. Stream organic matter inputs, storage, and export for Satellite Branch at Coweeta Hydrologic Laboratory, North Carolina, USA. *Journal of the North American Benthological Society* 16: 67-74.

Whiles, M. R. and J. B. Wallace. 1996. Macroinvertebrate production in a headwater stream during recovery from anthropogenic disturbance and hydrologic extremes. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 2402-2422.

Wallace, J. B., J. W. Grubaugh, and **M. R. Whiles**. 1996. The influence of coarse woody debris on stream habitats and invertebrate biodiversity. *In* McMinn, J. W. and D. A. Crossley, Jr.

(eds.). Biodiversity and coarse woody debris in southern forests. Gen. Tech. Rept. SE-94. USDA Forest Service, Southeastern Forest Experiment Station.

PROFESSIONAL PUBLICATIONS (continued)

Wallace, J. B., J. W. Grubaugh, and **M. R. Whiles**. 1996. Biotic indices and stream ecosystem processes: results from an experimental study. *Ecological Applications* 6: 140-151

Whiles, M. R. and J. W. Grubaugh. 1996. Coarse woody debris and amphibian and reptile biodiversity in southern forests. *In* McMinn, J. W. and D. A. Crossley, Jr. (eds.). Biodiversity and coarse woody debris in southern forests. Gen. Tech. Rept. SE-94. USDA Forest Service, Southeastern Forest Experiment Station.

Wallace, J. B., **M. R. Whiles**, S. Eggert, T. F. Cuffney, G. J.Lugthart, and K. Chung. 1995. Long-term dynamics of coarse particulate organic matter in three Appalachian Mountain streams. *Journal of the North American Benthological Society* 14: 217-232.

Whiles, M. R., K. Chung, and J. B. Wallace. 1993. Influence of *Lepidostoma* (Trichoptera: Lepidostomatidae) on leaf litter processing in disturbed streams. *American Midland Naturalist* 130: 356-363.

Wallace, J. B., **M. R. Whiles**, J. R. Webster, T. F. Cuffney, G. J. Lugthart, and K. Chung. 1993. Dynamics of particulate inorganic matter in headwater streams: linkages with invertebrates. *Journal of the North American Benthological Society* 12: 112-125.

Whiles, M. R. and J. B. Wallace. 1992. First-year benthic recovery of a southern Appalachian stream following three years of insecticide treatment. *Freshwater Biology* 28: 81-91.

Hooker, K. L. and **M. R. Whiles**. 1988. A technique for collection and study of subterranean invertebrates. *Southwestern Naturalist* 33: 375-376.

ORAL PRESENTATIONS

Meyer, C. K., **M. R. Whiles**, S. G. Baer, and B. S. Goldowitz. 2004. Macroinvertebrate communities and ecosytem function in backwater sloughs of the central Platte River: influence of hydrologic gradients and restoration activities. Invited symposia: Entomology in Prairie Ecosystems. Annual meetings of the North Central Branch of the Entomological Society of America, Kansas City, MO.

Regester, K.J., K. R. Lips, and **M. R. Whiles**. 2004. The significance of pond-breeding salamanders to energy flow and subsidies in an Illinois forest ecosystem. Midwest Ecology and Evolution Conference, University of Notre Dame, March 5-7.

Walther, D. A., **M. R. Whiles**, D. W. Butler, and M. B. Flinn. 2004. Community level estimation of non-predatory chironomid production in a southern Illinois stream. Annual meetings of the North Central Branch of the Entomological Society of America, Kansas City, MO.

Meyer, C. K., **M. R. Whiles**, and S. G. Baer. 2003. Aboveground production and belowground biomass in natural and restored Platte River slough wetlands. Annual meetings of the Society for Ecological Restoration, Austin, TX.

Whiles, M. R. 2003. Freshwater macroinvertebrate communities and disturbance: tools for basic and applied investigations in freshwater ecosystems. Invited seminar speaker, Purdue University Department of Forestry, Fisheries, and Wildlife.

Callaham, M.A., Jr., **M.R. Whiles**, P.F. Hendrix, and J.M. Blair. 2003. Using natural abundance stable isotopes to examine the feeding ecology of cicadas in tallgrass prairie. Invited symposium presentation, Entomological Society of America Annual Meetings, Cincinnati OH.

Whiles, M. R. 2003. Biological responses to hydrologic variability and restoration activities in central Platte River backwater wetlands. Invited seminar speaker, Eastern Illinois University Dept. of Biology.

Callaham, M.A., Jr., P.F. Hendrix, J.M. Blair, and **M.R. Whiles**. 2003. Natural abundance and tracer applications of stable isotopes for examination of soil invertebrate feeding ecology. Invited symposium presentation at Soil Science Society of America Annual Meetings, Denver, CO.

Whiles, M. R. 2003. Biological responses to hydrologic variability in Platte River backwater wetlands. Invited seminar speaker, University of Illinois Dept. of Natural Resources and Environmental Sciences.

Flinn, M. B., **M. R. Whiles**, and S. R. Adams. 2003. Response of aquatic macroinvertebrates to environmental pool management and vegetation in Mississippi River backwater wetlands. Annual Meetings of the North American Benthological Society, Athens, GA.

Stone, M. L., **M. R. Whiles**, J. A. Webber, and K. J. Williard. 2003. Influence of riparian vegetation on water quality, in-stream habitat, and macroinvertebrates in southern Illinois agricultural streams. Annual Meetings of the North American Benthological Society, Athens, GA.

Oneill, B. J., J. E. Garvey, **M. R. Whiles**, and K. A. Lips. 2003. Scale-dependent interrelationships among fish, landscape characteristics, and ambystomatid salamanders in forest ponds. Joint meeting of ichthyologists and herpetologists, Manaus, Brazil.

Flinn, M. B., S. R. Adams, **M. R. Whiles**, J. E. Garvey, B. M. Burr, and R. J. Sheehan. 2003. Fish and macroinvertebrate responses to environmental pool management in Mississippi River pool 25. Illinois Chapter of the American Fisheries Society, Rend Lake, IL.

Adams, S. R. M. B. Flinn, B. M. Burr, R. J. Sheehan, and **M. R. Whiles**. 2002. Larval ecology of blue sucker (*Cycleptus elongatus*) in the Mississippi River. American Society of Ichthyologists and Herpetologists meetings, Kansas City, MO.

Whiles, M. R. 2002. Ecology and ecosystem significance of cicadas in a tallgrass prairie landscape. Invited seminar speaker, Dept. of Biology, University of Memphis.

Whiles, M. R., and B. S. Goldowitz. 2002. Influence of hydrology and fish on macroinvertebrate communities in backwater sloughs of the central Platte River, Nebraska. Annual Meetings of the North American Benthological Society, Pittsburgh.

Whiles, M. R., M. L. Stone, J. Webber, and K. Williard. 2001. The influence of forested riparian buffers on water quality and stream invertebrates in Sugar Creek drainage, Illinois. Governor's Conference on Management of the Illinois river system, Peoria, Il.

Webber, J. A., K. W. Williard, **M. R. Whiles**, and M. L. Stone. 2001. Watershed-scale assessment of the impact of forested riparian buffer strips on stream water quality and biotic integrity. Ecological Society of America 2nd International Nitrogen Conference, Potomac, MD.

Evans-White, M. A., W. K. Dodds, and **M. R. Whiles**. 2001. Trophic basis of production of crayfish and central stonerollers in a prairie stream. Annual Meetings of the North American Benthological Society, Lacrosse, WI.

Whiles, M. R., and W. K. Dodds. 2001. Relationships between stream size, suspended particles, and filter-feeding macroinvertebrates in a Great Plains river system. Annual Meetings of the North American Benthological Society, Lacrosse, WI.

Whiles, M. R. and M. L. Stone. 2001. Relationships between riparian zone vegetation, water quality, and stream invertebrate communities. Midwestern Renewable Natural Resources Conference, Peoria, Illinois.

Jensen, J. B., C. Camp, J. L. Marshall, and **M. R. Whiles**. 2001. Recent advances in the knowledge of distribution and natural history of the Pigeon Mountain salamander (*Plethodon petraeus*). Joint annual meeting of the Herpetologists League and the Society for the Study of Amphibians and Reptiles, Indianapolis, Indiana.

Stagliano, D. M. and **M. R. Whiles**. 2000. Aquatic invertebrate trophic structure and secondary production in a tallgrass prairie stream. Annual Meetings of the North American Benthological Society, Keystone, Colorado.

Meyer, C. K., **Whiles, M. R.**, and R. E. Charlton. 2000. Secondary production and energetics of grass-feeding acridids in tallgrass prairie. Annual meetings of the Southwestern Branch of the Entomological Society of America, Dallas, TX.

Jonas, J. L., **M. R. Whiles**, and R. E. Charlton. 2000. Land use patterns and insect diversity in a central Kansas grassland. Annual meetings of the Southwestern Branch of the Entomological Society of America, Dallas, TX.

Dodds, W. K., M. Evans-White, N. M. Gerlanc, L. Gray, D. Gudder, M. J. Kemp, A. Lopez, D. M. Stagliano, E. A. Strauss, J. L. Tank, **M. R. Whiles**, and W. M. Wollheim. 2000. Quantification of the nitrogen cycle in a prairie stream: Konza LINX. Annual Meetings of the North American Benthological Society, Keystone, Colorado.

Whiles, M. R., and B. S. Goldowitz. 1999. Influence of hydrology on aquatic insect emergence production from backwater sloughs of the central Platte River, Nebraska. Annual meetings of the North American Benthological Society, Duluth, MN.

Meyer, C. K., **M. R. Whiles**, and R. E. Charlton. 1999. Secondary production and energetics of a dominant grass-feeding grasshopper in tallgrass prairie. Annual meetings of the Entomological Society of America, Atlanta.

Stagliano, D., **M. R. Whiles**, and R. E. Charlton. 1999. Aquatic insect production and functional structure in a tallgrass prairie headwater stream. Annual meetings of the Entomological Society of America, Atlanta.

Whiles, M. R. 1999. Natural History and emergence production patterns of cicadas (Homoptera: Cicadidae) on the Konza Prairie Research Natural Area, Kansas. Invited seminar speaker, University of Kansas, November 4, 1999.

Jeffrey, J. D., and **M. R. Whiles**. 1999. Effects of the PGA-class Colbert Hills golf course construction on prairie amphibians. 26th meetings of the KS Herp. Society, Pratt.

Whiles, M. R. 1999. Ecology and significance of cicadas in a tallgrass prairie ecosystem. Invited seminar speaker, University of Maine, October 21, 1999.

Evans-White, M. A., W. K. Dodds, M. J. Kemp, L. A. Gray, A. Lopez, J. L. Tank, and **M. R. Whiles**. 1999. Patterns of nitrogen cycling in a prairie stream food web. Annual meetings of the North American Benthological Society, Duluth, MN.

Goldowitz, B. S., and **M. R. Whiles**. 1999. Influence of hydrologic fluctuations on aquatic vertebrate communities in central Platte River Wetlands. Annual meetings of the Ecological Society of America, Spokane, WA.

Whiles, M. R. 1999. Significance of arthropods to prairie ecosystem function. Invited symposium speaker, annual meetings of the Central States Entomological Society, Manhattan, KS.

Whiles, M. R. 1999. Aquatic invertebrate communities and disturbance: tools for basic and applied investigations. Invited seminar speaker, Southern Illinois University.

Whiles, M. R., A. Franzen, S. Dinsmore, and B. L. Brock. 1998. Use of invertebrate rapid bioassessment for identification of stream reaches contributing to water quality degradation in a northeast Nebraska reservoir. Joint meetings of the Association of Limnologists and Oceanographers and the Ecological Society of America, St. Louis, MO.

Evans-White, M. A., W. K. Dodds, M. J. Kemp, L. A. Gray, J. L. Tank, **M. R. Whiles**, and A. Lopez. 1998. Nitrogen transfer through a prairie stream food web. Annual meetings of the Great Plains Limnological Society, Pittsburg, KS.

Whiles, M. R. and B. S. Goldowitz. 1998. Biological responses to hydrologic fluctuation in wetland sloughs of the central Platte River. The 9th Platte River Basin Ecosystem Symposium, Kearney, NE.

Whiles, M. R. 1997. Invertebrate bioassessment: advantages, techniques, and applications. Invited speaker, ann. meetings of the Nebraska Natural Resource Districts, Kearney, NE.

Whiles, M. R. 1997. Invertebrate communities and ecosystem processes in disturbed lotic systems. Invited seminar speaker, Kansas State University, Manhattan, KS.

Whiles, M. R. 1996. Disturbance, invertebrate communities, and stream ecosystem processes in southern Appalachian streams. Invited seminar speaker, Texas Tech University, Lubbock.

Whiles, M. R. 1995. Stream ecosystem research at Coweeta Hydrologic Laboratory. Invited seminar speaker, Southeastern Oklahoma State University, Durant, Oklahoma.

Whiles, M. R., and J. Bruce Wallace. 1995. Leaf litter decomposition and shredder communities in streams draining mixed hardwood and white pine watersheds. Annual meetings of the North American Benthological Society, Keystone, Colorado.

Wallace, J. B., J. W. Grubaugh, and **M. R. Whiles**. 1995. Biotic indices and stream ecosystem processes: results from an experimental study. Annual meetings of the North American Benthological Society, Keystone, Colorado.

Whiles, M. R. 1995. Disturbance and aquatic invertebrate communities in southern Appalachian Mountain streams. Invited seminar speaker, University of Tennessee at Chattanooga.

Whiles, M. R. 1994. Recovery dynamics of invertebrate communities and litter processing in southern Appalachian streams following disturbance. Invited seminar, Berry College, Mount Berry, Georgia.

Whiles, M. R. and J. B. Wallace. 1994. Long-term measurements of coarse particulate organic matter export from headwater streams. Annual meeting of the North American Benthological Society, Orlando, Florida.

Grubaugh, J. W., Wallace, J. B., and **M. R. Whiles**. 1994. 1956-57 versus 1991-92: A comparison of macroinvertebrate communities and potential effects of changing land usage in a Georgia piedmont river. Annual meeting of the North American Benthological Society, Orlando, Florida.

Whiles, M. R. 1993. Coarse woody debris and amphibian and reptile diversity in southern forests. Conference on coarse woody debris in southern forests: effects on biodiversity, University of Georgia, Institute of Ecology.

Whiles, M. R., and G. J. Lugthart. 1993. Secondary production in a headwater stream during record dry and wet years. Annual meeting of the North American Benthological Society, Calgary, Alberta, Canada.

Whiles, M. R., Wallace, J. B., and K. Chung 1992. Use of a refractory litter species by a caddisfly: the role of *Lepidostoma* in stream recovery from disturbance. Annual meeting of the North American Benthological Society, Louisville, Kentucky.

Whiles, M. R., and J. B. Wallace 1991. First-year macroinvertebrate community recovery in a southern Appalachian stream following an insecticide induced disturbance. Annual meeting of the North American Benthological Society, Santa Fe, New Mexico.

Whiles, M. R., Tate, C. M., and K. L. Hooker 1988. The influence of nutrient enrichments and grazers on periphyton growth in Konza Prairie streams. Annual Division of Biology Graduate Student Forum, Kansas State University.

Tate, C.M., **Whiles, M.R.**, and K. L. Hooker 1988. Influence of nutrients and grazers on periphyton biomass in prairie streams. Annual meeting of the North American Benthological Society, Tuscaloosa, Alabama.

Tate, C.M., Hooker, K.L., and **M. R. Whiles** 1987. Seasonal response of periphyton to nutrient enrichment in prairie streams. Annual meeting of the North American Benthological Society, Orono, Maine.

POSTER PRESENTATIONS

Rowlett, J. H., D. A. Walther, and **M. R. Whiles**. 2004. A comparison of macroinvertebrate community structure on artificial rock riffles to snag and exposed streambed habitats in Cache River, Illinios. Annual meetings of the North Central Branch of the Entomological Society of America, Kansas City, MO.

Whiles, M. R., D. W. Butler, D. A. Walther, and M. B. Flinn. 2003. Temperature-dependent growth rates of non-predatory chironomids from a southern Illinois stream. Annual meeting of the North American Benthological Society, Athens, GA.

Stone, M. L., **M. R. Whiles**, J. A. Webber, and K. Williard. 2002. Relationships between riparian vegetation, water chemistry, and stream invertebrates in a southern Illinois agricultural landscape. Annual meeting of the North American Benthological Society, Pittsburgh.

Flinn, M. B., R. Adams, **M. R. Whiles**, B. Burr, and R. Sheehan. 2002. Feeding ecology of larval blue suckers (*Cycleptus elongatus*): a direct benefit of riverine backwater invertebrates to a main channel fish. Annual meeting of the North American Benthological Society, Pittsburgh.

Flinn, M. B., R. Adams, **M. R. Whiles**, B. Burr, and R. Sheehan. 2002. Feeding ecology of larval blue suckers in Mississippi River backwaters. Mississippi River Research Consortium meetings, LaCrosse, WI.

Meyer, C. K., **M. R. Whiles**, and R. E. Charlton. 2001. Secondary production and energetics of grasshoppers as affected by annual burning in tallgrass prairie. Annual meetings of the North Central Branch of the Entomological Society of America, Fort Collins, CO.

Callaham, M. A., J. M. Blair, T. C. Todd, D. J. Kitchen, and **M. R. Whiles**. 2001. Fire, mowing, and fertilization effects on macroinvertbrate assemblages in tallgrass prairie soils. Soil Ecology Society Conference, Atlanta, Georgia.

Whiles, M. R., M. A. Callaham, Jr., C. K. Meyer, and J. M. Blair. 2000. Land Management Influences on Grassland Cicada Emergence Dynamics. Ecological Society of America All Scientists meetings, Snowbird, Utah.

Corum, R. A., W. K. Dodds, and **M. R. Whiles**. 2000. Distribution of filter-feeding invertebrates in central Kansas rivers and streams. Midwest Limnological Society Meetings, Lawrence, KS.

Whiles, M. R., D. M. Stagliano, and R. E. Charlton. 2000. Bioassessment of disturbed prairie streams: problems with traditional fish and aquatic invertebrate metrics. Annual Meetings of the North American Benthological Society, Keystone, Colorado.

Callaham, M. A., **M. R. Whiles**, C. K. Meyer, B. L. Brock, and R. E. Charlton. 1999. Emergence production and ecology of annual cicadas (Homoptera: Cicadidae) in tallgrass prairie. Annual meetings of the Entomological Society of America, Atlanta, GA.

Callaham, M. A., **M. R. Whiles**, C. K. Meyer, B. L. Brock, and R. E. Charlton. 1999. Feeding ecology of cicadas (Homoptera: Cicadidae) in tallgrass prairie. Soil Ecology Society Conference, Chicago, IL.

Jonas, J. L., **M. R. Whiles**, and R. E. Charlton. 1999. Influence of land use patterns on insect diversity in a central Kansas grassland. Annual meetings of the Entomological Society of America, Atlanta, GA.

Whiles, M. R., M. A. Callaham, C. K. Meyer, B. L. Brock, and R. E. Charlton. 1998. Periodical cicada emergence production in a northeast Kansas riparian forest. Annual meetings of the Entomological Society of America, Las Vegas, NV.

Stagliano, D., R. E. Charlton, and **M. R. Whiles**. 1998. Assessing environmental impacts on Colbert Hills using fish and aquatic insect communities. Kansas State Research and Extension Annual Conference, Manhattan, KS.

Alexander, K. A. and **M. R. Whiles**. 1998. A new species of *Ironoquia* Banks (Trichoptera: Limnephilidae) from backwaters of the central Platte River, Nebraska. North American Prairie Conference, Kearney, NE.

Dinsmore, S., **M. R. Whiles**, and R. Roberts. 1997. Use of bioassessment for identification of stream reaches contributing to eutrophication of a northeast Nebraska reservoir. Annual meetings of the Southwestern Association of Naturalists, Fayetteville, Arkansas.

Dinsmore, S., **M. R. Whiles**, and R. Roberts. 1996. Biological and chemical analysis of agriculturally impacted streams in northeast Nebraska. 31st regional meetings of the American Chemical Society, Sioux Falls, SD.

Whiles, M. R. 1993. Secondary production in a headwater stream during wet and dry years. Annual meetings of the Coweeta LTER site, Athens, Georgia.

Whiles, M. R. and K. L. Hooker 1987. Subterranean invertebrates from an artesian spring on Konza Prairie. Annual meeting of the NA Benthological Soc., Orono, Maine.

GRANT REVIEWER

NSF, USDA, USEPA, USGS-BRD, Illinois Groundwater Consortium (IGC)
EPA STAR Fellowships, invited review panel member (2002)

BOOK REVIEWER

Fundamentals of Ecology, 5th ed., E. P. Odum and G. Barrett
Ecology, Concepts and Applications, 2nd ed., M. C. Molles
Freshwater Ecology, W. K. Dodds

MANUSCRIPT REVIEWER

BioScience, Ecology, Ecological Applications, Limnology and Oceanography
Archiv fur Hydrobiologie, Journal of the North American Benthological Society
Environmental Management, Prairie Naturalist, American Entomologist
Environmental Entomology, Journal of Insect Science, Journal of Ecology
Journal of the Kansas Entomological Society, Bulletin of Marine Science
Journal of Cave and Karst Studies, Wetlands, Environmental Toxicology and Chemistry,
New Zealand Journal of Marine and Freshwater Research, Restoration Ecology

PROFESSIONAL SERVICE and MEMBERSHIPS

2002-03	Program Committee, North American Benthological Society
2002-03	Membership Director, American Water Resources Assoc., Illinois chapter
2000-	Entomological Society of America
1997-	Sigma Xi
1986-	North American Benthological Society

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:)
)
PROPOSED AMENDMENTS TO) **R 02-19**
AMMONIA NITROGEN STANDARDS) **(Rulemaking – Water)**
35 Ill. Adm. Code)

WRITTEN TESTIMONY OF ROBERT J. SHEEHAN

Justification and Approach for Adoption of the United States Environmental Protection Agency's Approach for Setting Ambient Water Quality Criteria for Ammonia in Illinois Surface Waters

I am Robert J. Sheehan, Professor of Fisheries in Zoology and Assistant Director of the Fisheries and Illinois Aquaculture Center, Southern Illinois University Carbondale. My purpose here today is to explain the justification and approach for what I believe Illinois should use to establish water quality criteria for the state's surface waters. I believe that recent information indicates that current ammonia water quality criteria used by Illinois appear to not be protective enough under certain circumstances and they appear to be overly protective under other circumstances. I believe that Illinois should use methods described by the United States Environmental Protection Agency (USEPA) in their latest National Criteria Document for ammonia, the 1999 Update of Ambient Water Quality Criteria for Ammonia ("1999 Ammonia Update").

I. Professional Credentials:

I base my testimony on more than 15 years of experience with ammonia toxicity issues. For example, colleagues and I published in the international journal *Hydrobiologia* what is to my knowledge the first paper examining the tolerance of larval (glochidia) unionid mussels to ammonia (Goudreau et al. 1993). This paper was considered in the 1999 Ammonia Update. A colleague and I also published in

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Transactions of the American Fisheries Society a study (Sheehan and Lewis 1986) that was also included as part of the database upon which the 1999 Ammonia Update was based. This work was the basis for two best paper awards conferred on us by the American Fisheries Society. I was selected by the Cadmus Group, a consulting firm employed by USEPA, to be one of the five national reviewers for the 1999 Ammonia Update; I was the only biologist among the reviewers (Cadmus 1997). I have taught a graduate level class (Zoology 565, Environmental Physiology of Fishes) for more than ten years that covers in depth the methods for calculation of numeric and narrative water quality criteria. I have also taught these methods in the University of Illinois' Envirovet curriculum; Envirovet is a program for training veterinarians in aquatic animal health. I am the Illinois Chapter of the American Fisheries Society's representative to the Illinois Environmental Protection Agency's (IEPA) Total Maximum Daily Load Work Group. I am a member of IEPA's Science Committee for developing water quality standards for nutrients.

Other indications of my professional stature include the more than $2,000,000 of funding I have received for research in aquatic systems. This funding was obtained from approximately twenty different sources. Most of this research has been directed at Illinois surface waters, and in particular rivers and streams, but some has been international (e.g., Amazon River) in scope. I have authored more than twenty-five peer-reviewed publications on river and stream organisms. These include: 1) invited author of the "Large Rivers" chapter (Sheehan and Rasmussen 1993) in the American Fisheries Society's textbook on fisheries management, *Inland Fisheries Management in North America*—an updated revision of that work has recently been completed (Sheehan and

Rasmussen 1999); and 2) invited author of the chapter on "Wetlands and Fisheries Resources of the Mississippi River" in the Pennsylvania Academy of Science book, *Ecology of Wetlands and Associated Systems.* I serve as a member of numerous government agency teams or committees, such as the Mississippi River Coordination Team and the Lower Platte River Task Force. I have been an expert witness for the Washington University Environmental Law Clinic at a hearing before the Missouri Clean Water Commission. I have also been an expert witness in a hearing before the Illinois Pollution Control Board that concerned ammonia in the Galesburg Sanitary District discharge. Lastly, I was appointed to the Pallid Sturgeon Recovery Team by the Director of the U.S. Fish and Wildlife Service; this is the only federally listed endangered fish species in the Mississippi River.

II. Justification

As Mr. Callahan testified, ammonia exists in solution in a dynamic equilibrium in two forms, as ammonium ion (NH_4^+) and as an unionized molecule (NH_3). Current water quality standards for Illinois are derived from the U.S. Environmental Protection Agency's National Criteria Document, *Ambient Water Quality Criteria for Ammonia—1984,* which was published in 1985 (hereafter referred to as "1985 Ammonia Guidance"). The 1985 Ammonia Guidance was formulated under the so-called joint toxicity theory, which holds that unionized ammonia is the more toxic form, but ionized ammonia is also toxic. Further, as pH, temperature or both decrease, the proportion of the toxicity attributable to ionized ammonia will increase, due to the effects of temperature and pH on the ammonia equilibrium. Toxicity appears to increase as pH, temperature, or both decrease if one only considers unionized ammonia concentrations, because more ionized ammonia will be found in lower pH and/or lower temperature solutions. Thus, the 1985 Ammonia Guidance expressed water quality criteria in terms of unionized ammonia with corrections for the effects of temperature and pH on ammonia toxicity. It was noted in the 1985 Ammonia Guidance that the joint toxicity model did not appear to be consistent with some data sets that were available at that time.

In the 1999 Ammonia Update, USEPA concluded that a definitive, thorough theoretical approach for describing pH effects on ammonia toxicity is lacking. Further, USEPA concluded in the 1999 Ammonia Update that there is no adequate theoretical basis or scientific understanding for specifying how temperature adjustments to unionized ammonia criteria can be made. Rather than trying to make "square-peg" data fit into the "round-hole" joint toxicity theory, the 1999 Ammonia Update took an empirical approach to describe how pH and temperature affect ammonia toxicity. This meant that in the opinion of USEPA in the 1999 Ammonia Update, the approach used in the 1985 Ammonia Guidance was flawed because it was formulated based on the belief in the joint toxicity theory, a belief that seemed to be refuted, especially when applied to temperature effects on ammonia toxicity.

Application of the 1999 Ammonia Update to Illinois water quality laws is warranted at this time. The 1999 Ammonia Update is superior to the 1985 Ammonia Guidance approach for a number of reasons. First, the 1999 Ammonia Update recognizes that the effects of temperature on ammonia toxicity are not strongly indicative of joint toxicity. Second, models used to describe the effects of pH on ammonia toxicity use empirical components in recognition of the incomplete knowledge of joint toxicity effects. Third, expressing ammonia toxicity on the basis of total ammonia eliminated the need for a temperature correction for ammonia Criterion Maximum Concentrations. Fourth, using total ammonia to express ammonia toxicity generally resulted in reduced variability among data sets and better fit to existing data sets. Fifth, permit limits are usually expressed in total ammonia, so expressing criteria on the basis of total ammonia would eliminate conversions to unionized ammonia. Sixth, another water quality criterion that 1999 Ammonia Update believes is necessary to protect aquatic life will be established, wherein the highest four-day average will not be allowed to exceed 2.5 times the chronic criterion. Lastly, the results of more than 40 new scientific studies with a number of additional species were added to the ammonia toxicity data base. Studies representing a broad range of species are necessary for developing adequately protective water quality criteria. More data in general reduces the risk of criteria being overprotective as well as under protective.

III. Proposed changes to Part 302, Subpart B, Section 302.212:

Methods for calculating water quality criteria are taken from the 1999 Ammonia Update. All criteria will be on the basis of total ammonia. The 1999 Ammonia Update provides two relationships for calculating the Criterion Maximum Concentration (CMC) or acute criterion for ammonia. One equation is used when salmonid fishes are present and the other when they are absent. Since no reproducing salmonid populations are found in Illinois waters that receive NPDES point source discharges, the salmonid fishes absent approach is warranted in Illinois.

The 1999 Ammonia Update provides two relationships for calculating the Criterion Continuous Concentration (CCC) or chronic criterion for ammonia. One relationship is to be used when early life history stages of fish are present and the other when they are not. The equation used when early life history stages are present results in a more protective water quality criterion, which is necessary to protect fishes during sensitive developmental stages.

I compiled a list of spawning dates for fish species in Illinois to determine when the "early life history stages present" water quality criteria should be applied. These spawning dates may be found as IAWA's Exhibit 11. Spawning dates were derived from many sources and based on the best information available. Although spawning dates have been reported for most species, information specific to Illinois is not available for many species, so professional judgment was also used. Primary sources of spawning date information included *Fishes of Illinois* (Smith 1979), *The Fishes of Missouri* (Pflieger 1997), and *Fishes of Wisconsin* (Becker 1983).

I consulted with Dr. Brooks Burr, an ichthyologist at my institution. I also consulted with Mr. Brian Thompson of the U.S. Environmental Protection Agency, Region V. It is my understanding that Mr. Thompson then consulted with a colleague in his office, Mr. Ed Hammer. Mr. Hammer is knowledgeable of fishes in Illinois. To the best of my knowledge, the following rationale for determining periods when early life history stages of fishes are present in Illinois waters is representative of and consistent with the outcome of those consultations.

Most Illinois fish species spawn in the spring and summer seasons, so the months of April through August are without doubt within the "early life history stages present" period. The earliest spawning species in Illinois' inland waters is the harlequin darter *Etheostoma histrio,* which is believed to spawn as early as February. The harlequin darter is found in Illinois in the Embarras River between the towns of Charleston and

Newton and in the Wabash River between Beall Woods State Park and the town of Rising Sun. It is reasonable that the "early life history stages present" should be considered to begin in February in these two river reaches to afford protection to the harlequin darter, unless this species proves to be relatively tolerant to ammonia.

Elsewhere in the waters of Illinois, exclusive of Lake Michigan, the earliest spawning species are most probably members of the Esocidae, the grass pickeral *Esox americanus* and the northern pike *E. lucius*. These two esocids probably typically initiate spawning in most of their Illinois range in March. Consequently, designating March as the beginning of the "early life history stages present" period in waters where the harlequin darter is not found is warranted.

Illinois fish species that spawn as late in the year as September include the sand shiner *Notropis ludibundus,* banded killifish *Fundulus diaphanous*, and mosquitofish *Gambusia affinis*. However, time should be permitted for the young of these species to grow out of the most sensitive developmental stages, so it appears justifiable to extend the "early life history stages present" period through October.

Two species that reportedly spawn in winter were not used to determine when early life history stages are present for the following reasons. The burbot *Lota lota* has been found in the Illinois River. It is thought to spawn during the winter, but it is doubtful that this species reproduces in any Illinois waters with the exception of Lake Michigan. The spring cavefish *Chologaster agassizi* may spawn at various times of the year, including winter, but this species is subterranean and unlikely to be affected by ammonia in discharges.

In summary, the "early life history stages not present" period should be considered to be November through February in most of the state. In waters where the harlequin darter occurs, however, the "early life history stages present" period should be considered to be November through January unless it can be shown that this species is relatively tolerant to ammonia. The "early life history stages not present" period could be extended through February in harlequin darter waters if this species is not very sensitive to ammonia.

The 1999 Ammonia Update suggests the use of a third criterion, a 4-day average that should not exceed 2.5 times the CCC. I believe that there is justification for this "subchronic" ammonia criterion. It will afford an additional level of protection for the state's aquatic biota that is not present in the existing law.

IV. Use of the 50th percentile pH to calculate chronic effluent standards:

Stephan et al. (1984) defined USEPA's general guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. This document established USEPA's intent in regard to water quality criteria development. The 1999 Ammonia Update is an example of the mechanics of water quality criteria development for a particular toxic—ammonia. According to Stephan et al. (1984), ". . . the concentration of a pollutant in a body of water can be above the CCC without causing an unacceptable effect if (a) the magnitudes and durations of the excursions above the CCC are appropriately limited and (b) there are compensating periods of time during which the concentration is below the CCC." The 1999 Ammonia Update approach establishing a subchronic standard effectively accomplishes (a) above—it limits the magnitudes and durations of excursions above the CCC. This protection is not present under current law.

Since unionized ammonia is considered the more toxic form, solutions become more toxic at elevated pH values. This is an important consideration when protecting organisms from lethal concentrations. Thus, a very conservative 75th percentile pH is used to calculate effluent standards to meet acute criteria. However, chronic effects deal with important yet less harmful responses, such as effects on growth. The intent of the CCC is to prevent unacceptable chronic effects, such as unacceptable effects on growth. By using the 50th percentile pH, excursions above the CCC will be completely compensated for by periods when pH is below the 50th percentile. Thus, a chronic effect, such as reduced growth, will be no worse on average than is considered acceptable, based on the CCC.

The establishment of the subchronic criterion will provide the level of protection against extended duration and high magnitude excursions above the CCC as described by Stephan et al. (1984) (see (a) above). The subchronic standard and the protection it provides are not present under the current law. This alone provides a great deal of justification for modification of the current law. The 50th percentile pH will ensure that the CCC is met on average, also consistent with the intent of the CCC as described by Stephan et al. (1984) (see (b) above).

Also, the overall approach used in the 1999 Ammonia Update for chronic ammonia criteria development is superior to that of 1985 Ammonia Guidance. In the 1985 Ammonia Guidance, chronic water quality criteria were derived from estimates of chronic effects threshold concentrations, or the geometric mean of the lower and upper chronic limits; i.e., the highest concentration in a test that did not cause an unacceptable adverse effect and the lowest concentration that caused an unacceptable adverse effect, respectively. There is a high degree of statistical and scientific uncertainty in estimates of chronic effects threshold concentrations using this method. In the 1999 Ammonia Update, chronic criteria are set by interpolating a single value (the EC20) from a concentration-toxicity relationship developed from an entire data set. Thus, in the 1985 Ammonia Guidance chronic criteria are determined using only two data points taken from the portion of the concentration-toxicity relationship where statistical error and scientific uncertainty are high. In the 1999 Ammonia Update, an entire data set (that includes values with lower statistical error rates and higher scientific certainty) is used to develop chronic criteria.

V. Mussels

USEPA Region V has provided a document with a list of studies examining ammonia toxicity in mussels, due to concerns that the 1999 Ammonia Update did not adequately address this taxonomic group. The vast majority of the referenced studies are not published in the peer-reviewed literature, and most certainly had not been subjected to USEPA procedures or public comment regarding their suitability for inclusion in data bases for water quality criteria development. By my count, 13 works were referenced and only two of those were published in the peer-reviewed scientific literature. I am a coauthor (Goudreau et al. 1993) of one of the two published papers. Because of my familiarity with that work, I was somewhat surprised that the LC50 value we obtained was included in the proposed mussel database without any comment regarding its appropriateness. Our study was cutting edge research at the time, the first study to examine ammonia toxicity in larval (glochidia) mussels. However, the toxic response we measured, closure of the valves, occurred in up to 50% of the control glochidia, a problem we described in the paper. According to generally accepted guidelines for toxicity tests (USEPA 1991), no more than 10% of control group animals should show the toxic response, if a toxicity test is to be considered valid. Some mention of the problem we encountered with control animals should at least have been method. I was also surprised to read in the document provided by Region V USEPA that, "There were no applicable acute:chronic ratios for sublethal ammonia impacts to freshwater mussels", because we reported both an EC50 value and an LC50 value from which an acute-chronic ratio for mussels could have been obtained. It should be mentioned that our Goudreau et al. (1993) paper was considered in the 1999 Ammonia Update, but it did not affect the outcome of chronic criteria that were developed.

Given the lack of both USEPA and public review, as well as a lack of peer review by the scientific community for most of the mussel studies provided in the document from Region V, I do not believe there is compelling evidence regarding the tolerance of mussels to ammonia to justify modification of criteria based on 1999 Ammonia Update at this time.

VI. Summary Conclusions

1. The theoretical framework used to formulate Illinois' ammonia water quality criteria was based on USEPA guidelines; USEPA now questions the theoretical basis of that framework.

2. USEPA now proposes that models developed using empirical methods be used to determine water quality criteria; these models are the best available for this

purpose at this time, and I believe Illinois' regulations should be revised according to the new models proposed by USEPA.

3. The method for calculating chronic criteria that is described in USEPA's latest guidance is superior to the previous method and should be adopted in the state's regulations.

4. I urge that Illinois establish another water quality criterion, the subchronic criterion described in the latest USEPA guidance, to more fully protect the organisms in the state's waters.

5. The early life history states present period, used to establish chronic criteria, should be considered as March through October in most of the state.

6. In waters where the harlequin darter is found, the early life history stages present period should be considered as February through October, unless this species proves to be relatively insensitive to ammonia.

7. Lastly, using the 50th percentile pH for calculating effluent limits to meet chronic ammonia criteria is consistent with current USEPA guidance.

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Table 1. Spawning periods for fishes in Illinois.

SPECIES	COMMON NAME	ILLINOIS SPAWNING PERIOD
Ichthyomyzon bdellium	Ohio lamprey	Early spring
I. castaneus	Chestnut lamprey	Late May to June
I. fossor	Northern brook lamprey	Early May
I. unicuspis	Silver lamprey	May and June
Lampetra aepyptera	Least brook lamprey	Late March
L. appendix	American brook lamprey	April or May
Petromyzon marinus*	Sea lamprey	April to July (introduced into Illinois waters)
Acipenser fulvescens	Lake sturgeon	May and June
Schaphyrhynchus albus	Pallid sturgeon	May and June
S. platorynchus	Shovelnose pallid sturgeon	April to June
Polyodon spathula	Paddlefish	April and May
Lepisosteus oculatus	Spotted gar	Late April and May
L. osseus	Longnose gar	Late April and May
L. platostomus	Shortnose gar	Mid May to July
L. spatula	Alligator gar	May
Amia calva	Bowfin	April to June
Anguilla rostrata	American eel	Spawns in the ocean
Alosa alabamae	Alabama shad	May to June
A. chrysochloris	Skipjack herring	Late April to late June
A. psedoharengus*	Alewife	June into August
Dorosoma cepedianum	Gizzard shad	April to June
D. petenense	Threadfin shad	Throughout the summer
Hiodon alosoides	Goldeye	May
H. tergisus	Mooneye	Late March to April
Coregonus artedii*	Cisco	November (only introduced populations in Illinois outside of Lake Michigan)
C. clupeiformis*	Lake whitefish	October and November
C. hoyi*	Bloater	January into March
C. nigripinnis*	Blackfin cisco	Winter (extirpated in Illinois)
Prosopeum cylindraceum*	Round whitefish	Fall (maybe extirpated in Illinois waters)
Salvelinus fontinalis*	Brook trout	Fall and winter
S. namaycush*	Lake trout	October
Oncorhynchus mykiss*	Rainbow trout	Fall and spring spawning stocks (introduced into Illinois)
Salmo trutta*	Brown trout	November to December (introduced into Illinois waters)
Oncorhynchus kisutch*	Coho salmon	Winter, but can be variable (introduced into Illinois waters)
O. tshawytscha*	Chinook salmon	Winter, but can be variable
Osmerus mordax*	Rainbow smelt	Spring spawner (introduced into the great lakes and other Illinois waters)
Umbra limi	Mudminnow	April and later; probably dependent on floodplain inundations for spawning
Esox americanus	Grass pickeral	March and April

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Table 1. Spawning periods for fishes in Illinois (cont.)

SPECIES	COMMON NAME	ILLINOIS SPAWNING PERIOD
E. lucius	Northern pike	March
E. masquinongy	Muskellunge	March and April (widely stocked, but natural populations in Illinois, if any, probably extirpated)
Carassius auratus	Goldfish	Late March through June
Cyprinella lutrensis	Red shiner	Late May to August
C. spiloptera	Spotfin shiner	Early June to mid-August
C. venusta	Blacktail shiner	June into August
C. whipplei	Steelcolor shiner	June to mid-August
Ctenopharyngodon idella	Grass carp	May to July (introduced into Illinois waters)
Hypophthalmichthys molotrix	Silver carp	Spring through summer (introduced into Illinois waters)
H. nobilis	Bighead carp	Summer; increases in river stage (introduced into Illinois waters)
Notemigonus crysoleucas	Golden shiner	April to early June
Semotilus atromaculatus	Creek chub	April and May
Couesius plumbeus*	Lake chub	April and May
Nocomis biguttatus	Hornyhead chub	Late April through June
N. micropogon	River chub	April through June
Macrhybopsis aestivalis	Speckled chub	Late May to August
M. gelida	Sturgeon chub	May to late August
M. gracilus	Flathead chub	July to August
M. meeki	Sicklefin chub	Unknown (large river species)
Hybopsis amblops	Bigeye chub	May through June
H. storeriana	Silver chub	Unknown
Erimystax x-punctatus	Gravel chub	April
Osopoeodus emiliae	Pugnose minnow	Late June
Rhinichthys atratulus	Blacknose dace	Late April through July
R. cataractae	Longnose dace	April through June
Luxilus chrysocephalus	Striped shiner	Late April into June
L. cornutus	Common shiner	Late April into June
Lythrurus ardens	Rosefin shiner	Late April through June
L. fumeus	Ribbon shiner	June
L. umbratilis	Redfin shiner	Mid May to early August
Phenacobius mirabilis	Suckermouth minnow	Late April into August
Notropis amnis	Pallid shiner	April
N. anogenus	Pugnose shiner	May to June
N. atherinoides	Emerald shiner	June into July
N. blennius	River shiner	Late June into August
N. boops	Bigeye shiner	Early June to Late August
N. buchanani	Ghost shiner	Late April to early July
N. chalybaeus	Ironcolor shiner	Late June to July
N. dorsalis	Bigmouth shiner	June and July
N. heterodon	Blackchin shiner	Unknown

Table 1. Spawning periods for fishes in Illinois (cont.)

SPECIES	COMMON NAME	ILLINOIS SPAWNING PERIOD
N. heterolepis	Blacknose shiner	June though July
N. hubbsi	Bluehead shiner	May
N. hudsonius	Spottail shiner	May, and June, August possible
N. rubellus	Rosyface shiner	May to early June
N. shumardi	Silverband shiner	Late summer
N. ludibundus	Sand shiner	Late April through September
N. texanus	Weed shiner	August
N. volucellus	Mimic shiner	June into August
N. wickliffi	Channel shiner	June and July
Ericymba buccata	Silverjaw minnow	March to July
Phoxinus erythrogaster	Southern redbelly dace	Late April through June
Dionda nubile	Ozark minnow	May and June
Hybognathus argyritis	Western silvery minnow	June to July
H. hankinsoni	Brassy minnow	Late May in Wisconsin
H. hayi	Cypress minnow	April or later
H. nuchalis	Silvery minnow (Mississippi silvery minnow)	June
H. placitus	Plains minnow	June to July
Pimephales notatus	Bluntnose minnow	May through August
P. promelas	Fathead minnow	May through August
P. vigilax	Bullhead minnow	Late May into July
Campostoma anomalum	Common stoneroller	April through May
C. olegolepis	Largescale stoneroller	April through May (assumed to be similar to common stoneroller)
Cycleptus elongates	Blue sucker	Unknown (found in medium to large rivers)
Ictiobus bubalus	Smallmouth buffalo	May and June
I. cyprinellis	Bigmouth buffalo	May and June (assumed to be similar to the smallmouth buffalo)
I. niger	Black buffalo	May and June (assumed to be similar to other buffalo spp.)
Cyprinus carpio	Common carp	Late March through June (introduced into Illinois waters)
Carpiodes carpio	River carpsucker	May through July
C. cyprinus	Quillback (carpsucker)	Mid April into June
C. velifer	Highfin carpsucker	Unknown; probably late spring through mid summer
Moxostoma anisurum	Silver redhorse	March into May
M. carinatum	River redhorse	April and May
M. duquesnei	Black redhorse	April and May
M. erythrurum	Golden redhorse	April into June
M. macrolepidotum	Shorthead redhorse	April into July
M. valenciennesi	Greater redhorse	Extirpated in Illinois
Hypentelium nigricans	Northern hog sucker	April and May
Catostomus catostomus*	Longnose sucker	Unknown (early spring probable)

Table 1. Spawning periods for fishes in Illinois (cont.)

SPECIES	COMMON NAME	ILLINOIS SPAWNING PERIOD
Ameiurus catus	White catfish	June and July
A. melas	Black bullhead	May and June
A. natalis	Yellow bullhead	May and June
A. nubulosus	Brown bullhead	May and June
Ictalurus furcatus	Blue catfish	June
I. punctatus	Channel catfish	June
Pylodictis olivaris	Flathead catfish	Late June and July
Noturus eleutherus	Mountain madtom	June and July
N. exilis	Slender madtom	June and July
N. flavus	Stonecat	June and July
N. gyrinus	Tadpole madtom	June and July
N. miurus	Brindled madtom	June
N. nocturnus	Freckled madtom	Late June into July
N. stigmosus	Northern madtom	June
Chologaster agassizi	Spring cavefish	January through March
Aphredoderus sayanus	Pirate perch	April and May
Percopsis omiscomaycus	Trout-perch	April to August
Lota lota*	Burbot	January to March
Fundulus catenatus	Northern studfish	May into July
F. diaphanous	Banded killifish	April to September
F. dispar	Starhead topminnow	May and June
F. notatus	Blackstripe topminnow	Late spring and summer
F. olivaceus	Blackspotted topminnow	May and into summer
Gambusia affinis	Mosquitofish	Mid April to September
Labidesthes sicculus	Brook silverside	May into August
Culaea inconstans	Brook stickleback	Late spring and early summer
Pungitius pungitius*	Ninespine stickleback	Summer in Canada
Myoxocephalus quadricornis*	Fourhorn sculpin	June
Cottus bairdi	Mottled sculpin	March through June
C. carolinae	Banded sculpin	March through April
C. cognatus*	Slimy sculpin	Unknown (assumed to be similar to other Cottus spp.)
C. ricei*	Spoonhead sculpin	Fall (not known with certainty)
Morone chrysops	White bass	April or May
M. mississippiensis	Yellow bass	April or May
M. saxatilis	Striped bass	Does not reproduce in IL
Micropterus dolomieui	Smallmouth bass	May and June
M. punctulatus	Spotted bass	May and June
M. salmoides	Largemouth bass	May and June
Lepomis cyanellus	Green sunfish	May and into summer
L. gibbosus	Pumpkinseed	May and into summer

Table 1. Spawning periods for fishes in Illinois (cont.)

SPECIES	COMMON NAME	ILLINOIS SPAWNING PERIOD
L. gulosus	Warmouth	May and into summer
L. humilus	Orangespotted sunfish	May and into summer
L. macrochirus	Bluegill	May and into summer
L. megalotis	Longear sunfish	May to August
L. microlophus	Redear sunfish	May and into summer
L. punctatus	Spotted sunfish	May into August
L. symmetricus	Bantam sunfish	Late May
Ambloplites rupestris	Rock bass	May
Pomoxis annularis	White crappie	April through June
P. nigromaculatus	Black crappie	April through June
Centrarchus macropterus	Flier	March into May
Elassoma zonatum	Banded pygmy sunfish	April and May
Stizostedion canadense	Sauger	March into June
S. vitreum	Walleye	March and April
Perca flavescens	Yellow perch	March through June
Percina caprodes	Logperch	Mid March to mid July
P. evides	Gilt darter	Extirpated in Illinois; would spawn during the summer
P. maculata	Blackside darter	April to June
P. phoxocephala	Slenderhead darter	Early June
P. sciera	Dusky darter	Late May to early July
P. shumardi	River darter	April and May
P. uranidea	Stargazing darter	Unknown (probably should not be considered endemic to Illinois waters)
Crystallaria asprella	Crystal darter	March
Ammocrypta clara	Western sand darter	Thought to be a summer spawner
A. pellucida	Eastern sand darter	Unknown, but later than most of the darters, if consistent with A. clara
Etheostoma asprigene	Mud darter	March into May
E. blenniodes	Greenside darter	March and April
E. caeruleum	Rainbow darter	March into June
E. camurum	Bluebreast darter	May and June
E. chlorosomum	Bluntnose darter	Early May
E. exile	Iowa darter	April
E. flabellare	Fantail darter	April into June
E. gracile	Slough darter	Late May
E. histrio	Harlequin darter	February and March
E. kennicotti	Stripetail darter	Late April
E. microperca	Least darter	April through June
E. nigrum	Johnny darter	March into June
E. proeliare	Cypress darter	Mid March to June
E. spectabile	Orangethroat darter	Mid March through May
E. squamiceps	Spottail darter	Late March to June

Table 1. Spawning periods for fishes in Illinois (cont.)

SPECIES	COMMON NAME	ILLINOIS SPAWNING PERIOD
E. zonale	Banded darter	April into July
Aplodinotus grunniens	Freshwater drum	Late April through July or later
Aplodinotus grunniens	Freshwater drum	Late April through July or later

* No naturally reproducing populations in waters receiving NPDES permit discharges.

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Influences of Hypoxia and Hyperthermia on Fish Species Composition in Headwater Streams

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Abstract.—Indices of hypoxia and hyperthermia tolerance for Missouri fish assemblages were based on laboratory measurements of lethal dissolved oxygen concentrations and temperatures, combined with field measures of the relative abundances of tolerant and sensitive species. Fish assemblages and extreme physicochemical conditions were monitored over 3–4 years at 18 sites on headwater streams in the Prairie, Ozark Border, and Ozark regions of Missouri. Oxygen minima ranged from 0.8 to 6.0 mg/L, and temperature maxima ranged from 19.6 to 30.7°C; oxygen minima at study sites were not correlated with temperature maxima. Hypoxia tolerances of fish assemblages were strongly correlated with minimum stream oxygen concentrations and varied concordantly with regional, longitudinal, and temporal gradients in stream oxygen minima. Hyperthermia tolerances of fish assemblages were not correlated with maximum stream temperatures, nor were regional, longitudinal, or temporal differences in hyperthermia tolerances concordant with variation in temperature maxima. Axis scores from a detrended correspondence analysis of species frequencies were strongly correlated with dissolved oxygen minima for all 18 sites, but axis scores correlated with temperature maxima only at the four well-oxygenated sites. Low dissolved oxygen levels had a substantial effect on the composition of fish assemblages at most sites, but maximum temperatures influenced assemblages only at the few sites without severe levels of hypoxia.

Measurements of the tolerances of fish species to low dissolved oxygen concentrations and high temperatures are a potentially valuable tool for testing hypotheses about the effects of extreme physicochemical conditions on fish assemblages and for evaluating the effects of organic and thermal pollution (Warren et al. 1973; Magnuson et al. 1979; Armour 1991). In the field, species-specific differences in mortality, abundance, and distribution in relation to hypoxia (Thomson 1925; Katz and Gaufin 1952; Larimore et al. 1959; Gammon and Reidy 1981; Coble 1982) or hyperthermia (Bailey 1955; McFarlane 1976; Tramer 1977; Matthews and Maness 1979; Brandt et al. 1980; Matthews et al. 1982) have been observed. But relatively few field studies have supported field observations with laboratory tolerance measurements (Lowe et al. 1967; Matthews 1987; Cech et al. 1990). The complexity of environmental challenges faced by fish in natural situations does not inspire confidence in the applicability of apparently simplistic and reductionist laboratory tolerance data. Lethal conditions of hypoxia and hyperthermia vary with a number of secondary environmental factors, as well as with the physiological condition of the fish (Fry 1967, 1971; Hutchison 1976), and tolerances under natural conditions can differ markedly from those in the laboratory (Moore 1942). Furthermore, sublethal inhibiting effects of hypoxia and hyperthermia on growth (Stewart et al. 1967; Bejda et al. 1992), reproduction and recruitment (Hubbs 1964; Gerking et al. 1979; Henderson and Brown 1985), and habitat selection (Ultsch et al. 1978; Baltz et al. 1987) may be more ecologically influential than direct mortality. However, even laboratory measurements that are too simplistic to precisely predict absolute values of temperatures or dissolved oxygen levels that are limiting to fish in natural environments may still be used in a relative manner to distinguish tolerant from sensitive species. If we assume that rankings of species by their tolerance to lethal physicochemical conditions remain the same under both laboratory and field conditions, and if we further assume that sublethal levels of hypoxia and hyperthermia affect sensitive species more strongly than tolerant species under equivalent conditions, then tolerance measurements for a group of species should predict those species which will be most successful in the field under various physicochemical conditions.

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In a concurrent laboratory study (Smale and Rabeni 1995, this issue), we measured hypoxia and hyperthermia tolerances for 35 fish species commonly found in headwater streams in the midwestern United States. In this field study, our primary objective was to determine whether such tolerance measurements predicted the success of different species, relative to each of the other species tested, under natural conditions which encompassed strong gradients of both hypoxia and hyperthermia. Rather than examine the response of individual species to physicochemical gradients, we developed two assemblage-level indices that expressed the composite hypoxia or hyperthermia tolerances of all fish species in the assemblages we investigated. These two indices of hypoxia tolerance and hyperthermia tolerance were then analyzed in relation to geographical and temporal differences in stream dissolved oxygen minima and temperature maxima.

We restricted the study to headwater reaches, where extreme physicochemical conditions are most likely to occur (Winger 1981; Matthews 1987). To ensure an adequate range of stream conditions, we selected sites in three of Missouri's most extensive physiographic regions: the Prairie region of northern Missouri, the Ozark region of southern Missouri, and a geographically intermediate Ozark Border region (Thom and Wilson 1980). Within each region, we also contrasted conditions and assemblages at upstream sites with those observed at downstream sites to test for longitudinal effects. Additionally, severe drought in northern and central Missouri (NOAA 1990) during the middle of our study period enabled us to examine temporal changes in the frequencies of tolerant and intolerant fishes under unusually harsh physicochemical conditions.

We developed the study design so that we could pursue two secondary objectives. First, we selected sites that were typical of headwater streams throughout the state; therefore, this study was a survey of the influence of hypoxia and hyperthermia on fish assemblages in small nonurban streams in Missouri. Secondly, we investigated whether physicochemical conditions and their ecological consequences were randomly distributed throughout the state or were patterned according to regional and longitudinal differences in stream conditions.

Methods

Study site locations.—We monitored physicochemical conditions and fish species composition at 18 sites in the Salt, Cuivre, Lamine, and Gasconade river drainages of Missouri (Figure 1). Sites were chosen to be representative of streams in the Prairie, Ozark Border, and Ozark physiographic regions (Pflieger 1975; Thom and Wilson 1980). In contrast to Prairie region streams, the steeper terrain, more permeable soils, and reduced agricultural usage that typify Ozark region watersheds result in streams with more stable flow, relatively low turbidity, greater mean substrate particle size, and increased riffle–pool development (Horwitz 1978; MDNR 1986). The Ozark Border region represents an ecotonal transition between Prairie and Ozark conditions. Physiographic, land use, and stream characteristics in Ozark Border watersheds were typically intermediate between those in Ozark and Prairie watersheds.

Sites were assigned to regional groups (Table 1) on the basis of similarities in a number of physical, chemical, and hydrological characteristics (Rabeni and Smale 1991). The Lamine and Cuivre river drainages included both Prairie and Ozark Border sites; the Salt River (Prairie) and Gasconade River (Ozark) sites were all within a single region. The four Ozark sites were added to the study in the spring of 1988; all other sites were monitored from the spring of 1987 through the fall of 1990.

Sites were also selected and grouped by their longitudinal (upstream versus downstream) positions in the drainage. On three short streams, only one study site was established. On all other streams, an upstream site was located near the point farthest upstream at which we expected to find permanent standing water inhabited by fish, and a downstream site was established where the drainage area of the stream was from two to four times larger. This longitudinal comparison was initially intended to contrast characteristics of stream reaches with a permanent flow with reaches with intermittent flows, but severe droughts during much of the study resulted in no-flow conditions that persisted for considerable periods at all but the four Ozark region sites.

Sites were located in intermittent or first-order reaches and their drainage areas (Table 1), as measured from 1:24,000 scale U.S. Geological Survey topographic maps, ranged from 600 to 11,000 ha. Study sites consisted of a 200–250-m-long section of stream that we judged to be morphologically typical of streams in the vicinity. The same locations were monitored at all sites for the duration of the study.

Monitoring of physicochemical conditions.—Monitoring of stream dissolved oxygen concentrations and temperatures was scheduled specifically for the purpose of measuring the most extreme conditions that occurred at each site in each year. During 1987 and 1988, oxygen concentrations and temperatures were measured frequently (usually at least once per month between May and October) at selected sites and under meteorological and hydrological conditions which were as varied as possible. Also, several locations were monitored at each site in order to determine the degree of within-site variation. This initial phase of intensive and frequent sampling at some sites clearly established that extremes of low dissolved oxygen concentrations and high temperatures consistently occurred in midsummer (late June through early September) on warm, mostly sunny days (air temperatures above 29°C) following extended periods of minimum or no flow in the streams.

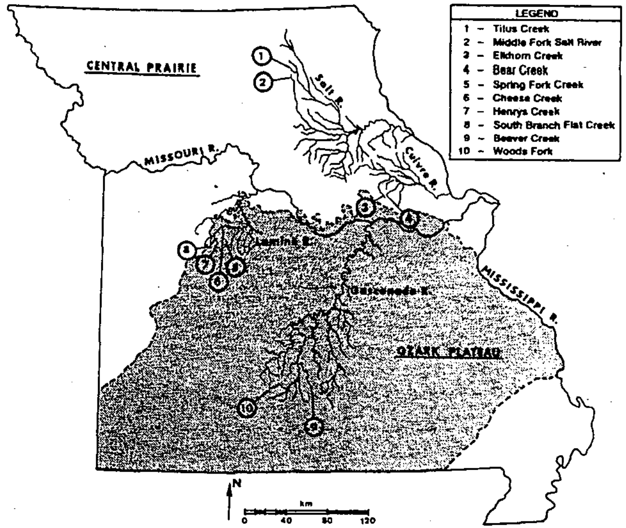

FIGURE 1.—Locations of the study streams and their drainage basins in Missouri. The boundary for the Ozark region (shaded area) is taken from MDNR (1986), and sites in both the Ozark and Ozark Border groups in this study are encompassed by this boundary.

At the remaining sites, and at all sites in 1988 and 1989, physicochemical monitoring was conducted when these extreme meteorological and hydrological conditions occurred. Although dissolved oxygen and temperature measurements were often made at other times, only data from the one or two dates per year per site when extreme conditions prevailed were used in this analysis. All the sites in the same drainage basin were monitored on the same day, but different drainages were monitored on different days. Sites were visited frequently throughout the spring, summer, and fall, which enabled us to observe when streamflow either ceased or was exceptionally low. Once streamflows subsided to what we expected to be their lowest levels of the summer, we monitored conditions in each of the drainages over the following 2 weeks. At most sites in most years, measurements were repeated later in the summer if low-flow or no-flow conditions persisted. Monitoring was scheduled only when weather conditions were mostly sunny and maximum air temperatures were between 29 and 33°C.

Dissolved oxygen concentrations and temperatures were measured with a polarographic oxygen meter calibrated at the beginning of each day by

TABLE 1.—Dissolved oxygen minima, temperature maxima, and tolerance index values for study sites grouped by region and by longitudinal position in streams. Physicochemical values and tolerance index values given are averages for the 3–4-year study period; minimum and maximum values occurring in this period are also given for tolerance index values.

Stream (site abbreviation)[a] or statistic	Drainage area (ha)	Mean oxygen minimum (mg/L)	Mean temperature maximum (°C)	Hypoxia tolerance index		Hyperthermia tolerance index	
				Mean	Range	Mean	Range
Prairie upstream group							
Middle Fork Salt River (MF 1)	900	0.83	24.6	0.69	0.64–0.73	37.0	36.5–37.6
Titus Creek (TI 1)	1,800	2.98	27.5	0.84	0.69–0.99	36.8	36.5–37.0
Elkhorn Creek (EL 1)	1,200	2.05	23.9	0.74	0.67–0.83	37.0	36.6–37.4
Bear Creek (BR 1)	600	1.89	24.5	0.79	0.64–0.89	36.8	36.0–37.7
South Branch Flat Creek (FC 1)	1,200	1.65	24.3	0.69	0.63–0.71	37.1	36.9–37.4
Group average		1.88	25.0	0.75		36.9	
Prairie downstream group							
Middle Fork Salt River (MF 2)	4,800	3.40	26.8	0.90	0.78–1.00	36.8	36.4–37.2
Middle Fork Salt River (MF 3)	4,800	2.25	25.4	0.84	0.73–0.90	36.8	36.4–37.2
Elkhorn Creek (EL 2)	3,900	2.10	25.6	0.88	0.68–1.08	36.9	36.2–37.5
Group average		2.58	25.9	0.87		36.8	
Ozark Border upstream group							
Spring Fork Creek (SF 1)	2,200	3.80	26.8	0.90	0.81–0.99	36.6	36.4–36.9
Cheese Creek (CH 1)	1,900	2.41	26.1	0.83	0.81–0.85	36.6	36.2–36.8
Henrys Creek (HE 1)	2,100	3.46	30.7	0.94	0.82–1.04	36.6	36.4–37.0
Group average		3.23	27.9	0.89		36.6	
Ozark Border downstream group							
Bear Creek (BR 2)	3,800	4.06	27.0	0.98	0.92–1.06	36.6	36.2–36.9
Spring Fork Creek (SF 2)	7,700	5.11	30.1	0.96	0.85–1.09	36.5	36.4–36.8
South Branch Flat Creek (FC 2)	6,400	4.34	28.1	0.96	0.85–1.00	36.5	36.2–36.6
Group average		4.50	28.4	0.97		36.5	
Ozark upstream group							
Woods Fork (WF 1)	3,200	4.90	24.3	1.10	1.06–1.17	36.0	35.7–36.2
Beaver Creek (BV 1)	3,400	4.47	19.6	0.83	0.78–0.86	36.3	36.0–36.5
Group average		4.68	22.0	0.96		36.1	
Ozark downstream group							
Woods Fork (WF 2)	7,500	5.97	26.5	1.20	1.13–1.26	36.1	35.8–36.5
Beaver Creek (BV 2)	11,200	4.37	26.6	1.18	1.15–1.21	36.0	36.0–36.1
Group average		5.17	26.6	1.19		36.0	

[a] Sites on streams with more than one site are numbered consecutively from upstream to downstream locations.

the air saturation method. Monitoring started at dawn and continued until streams were mostly shaded in late afternoon, and measurements were made at approximately 90-min intervals. During no-flow periods, conditions often varied from location to location within a site, and pools were often stratified. Thus two or three locations with typical conditions were monitored per site, and separate readings were taken within 10 cm of the stream surface and 10 cm from the bottom whenever stratified conditions were found.

Only the lowest dissolved oxygen concentration and highest temperature recorded at each of the several locations and strata monitored at each site during each day were used in this analysis. These minimum or maximum values from all locations were averaged and used as an index of extreme conditions at the site on the day they were monitored. When extremes were monitored more than once per year, these average daily extremes were averaged to give an index for the site in a given year. The yearly averages for each site were further averaged to give index values of the typical minimum dissolved oxygen concentration (DO_{min}) and maximum temperature (T_{max}) for each of the 18 sites.

Fish collection.—We sampled fish in the spring (April–May) and fall (September–October) of each year. Sites were subdivided into segments approximately 25 m long, and block nets were used to isolate each segment. Segments were seined with a variety of minnow seines, depending on the

width and shape of the segment. Stretched mesh sizes were less than 1 cm. Riffles were sampled by kick-seining fish into nets anchored across the bottom of the riffle. We made three seine sweeps per segment, and the fish captured in each sweep were recorded separately. Fish were identified to species (Pflieger 1975), measured for length, and released.

Fish metrics.—To compensate for species-selective gear bias, we corrected the number caught for each species at each site by efficiency-of-capture coefficients estimated from depletion rates over the three successive seine sweeps. Depletion rates were first estimated for each species in each segment sampled (DeLury 1947; Zippin 1958) then averaged for all the segments and samples from sites of similar size and morphology. Depletion rates were converted to efficiency coefficients, and the number of fish captured for each species at each site was multiplied by the inverse of this coefficient. For example, we found that in upstream Prairie sites, three seine sweeps captured, on average, 37% of the johnny darters and 87% of the golden shiners (scientific names are given in the appendix). Numbers caught for each species were divided by 0.37 and 0.87, respectively, to compensate for differences in capture efficiency. These corrected numbers were then converted to relative abundance (species frequency) estimates for all species captured at the site. These frequencies are listed in the appendix.

Relative frequencies of tolerant and intolerant species in each community were expressed by the hypoxia index and the hyperthermia index. An index value for a site was calculated by assigning a tolerance value to each species—the mean critical dissolved oxygen concentration or temperature from our laboratory tests (listed in the appendix)—and multiplying it by the frequency of occurrence (as a decimal fraction) for that species. These products were then summed for all species present at the site. In effect, the index value represented an estimate of the critical dissolved oxygen concentration or temperature for the average fish in each sample.

We made laboratory tolerance measurements for only 35 of the 51 species captured during this field study. In calculating the indices, we assumed that these untested species were average in their tolerance to hypoxia and hyperthermia, and we substituted means of all measured species tolerance values for these unknown values. In most cases, these untested species constituted such a small portion of the community that this substitution had no meaningful effect on results. Untested species made up less than 8% of the assemblages at 17 of the 18 sites. By substituting different species tolerance values, we found that untested species had no effect on the rankings of tolerance index values when they constituted less than 10% of the sampled assemblages. However, at one site (upstream Beaver Creek), tolerance index values may be unreliable because of exceptionally high frequencies of one untested species, the Ozark sculpin.

Sites were classed into six stream groups: upstream and downstream sites in each of the three regions. Site and group means were calculated for minimum dissolved oxygen (DO_{min}) values, maximum temperature (T_{max}) values, and for hypoxia and hyperthermia tolerance indices. Correlation coefficients (Steel and Torrie 1980) were used to test relationships among these four physicochemical and biotic index values. Mean values for groups were compared without statistical tests of significance because of the limited sample size per group and unbalanced design. Temporal changes were assessed by comparing site means and group means for drought years (1988 and 1989) and nondrought years (1987 and 1990).

Ordination analysis.—In the second step in the analysis, we used detrended correspondence analysis (DCA) to ordinate species frequency lists from the 18 sites. Mean frequencies from the 3–4 years of sampling were used in the ordination, and results were calculated by the computer program CANOCO (terBraak 1988). Ordination generated a set of x- and y-coordinates, or axis scores, for each site such that assemblages with very similar compositions plotted closely together and dissimilar assemblages plotted farther apart (Gauch 1982; Austin 1985). Ordination reduces a large matrix of frequency-by-sample measurements to a much more manageable set of coordinates, which can then be analyzed in relation to environmental gradients of interest (terBraak 1987).

We calculated linear regression equations for relationships between ordination axis scores and stream DO_{min} and T_{max} values. Nonsignificant correlations were discarded, and significant relationships were used to build a descriptive model that predicted ordination coordinates, an expression of community composition, from DO_{min} and T_{max} values.

Results

Stream Oxygen Minima and Temperature Maxima

Site means for DO_{min} values ranged from 0.8 to 6.0 mg/L, and means for T_{max} values ranged

TABLE 2.—Correlation coefficients (r) for relationships between site drainage areas, physicochemical variables, and tolerance index values; site means were used for each variable. Significant correlations are marked with an asterisk (df = 16, $P \leq 0.01$).

Variable	Site drainage area	Mean dissolved oxygen minima (DO_{min})	Mean temperature maxima (T_{max})	Hypoxia tolerance index values
Mean dissolved oxygen minima (DO_{min})	0.77*			
Mean temperature maxima (T_{max})	0.31	0.25		
Hypoxia tolerance index values	0.77*	0.85*	0.35	
Hyperthermia tolerance index values	0.63*	0.85*	0.02	0.87*
Ordination x-axis scores		0.87*	0.20	
Ordination y-axis scores		0.09	0.58	

from 19.6 to 30.7°C. Dissolved oxygen as low as 0.0 mg/L and temperatures as high as 40°C were found at some locations. Site means for DO_{min} were poorly correlated ($r = 0.25$, $P > 0.05$) with mean T_{max} values (Table 2). This near-independence indicated that the warmest sites were not necessarily the most hypoxic sites, nor were cooler sites better oxygenated.

There were large differences in DO_{min} values between regions and between upstream and downstream sites. Oxygen minima were lowest in Prairie sites, intermediate in Ozark Border sites, and highest in Ozark sites (Table 1), regional means differing by 1.3–2.8 mg/L. Values for DO_{min} were also 0.5–1.3 mg/L higher at downstream sites in all three regions. Site mean DO_{min} values were positively correlated ($r = 0.77$, $P \leq 0.01$) with the drainage areas of the sites (Table 2), which indicated a general trend of increasing oxygen levels with increasing stream size across all three regions.

Regional and longitudinal differences in site mean T_{max} values were not as consistent as for DO_{min} values. Temperatures were warmest in Ozark Border sites, which averaged 2.9–5.6°C warmer than Prairie and Ozark upstream sites and 2.4–1.8°C warmer than Prairie and Ozark downstream sites. One upstream Ozark site was spring fed and remained atypically cool, but T_{max} values for the three other Ozark sites were actually slightly warmer than for most Prairie sites. Maximum temperatures also were 0.5–4.6°C higher at downstream than at upstream sites in all three regions. Site mean T_{max} values were mildly correlated ($r = 0.31$, $P > 0.05$) with site drainage areas. Generally, T_{max} values tended to vary more with individual site characteristics, particularly the degree of riparian shading, and were not as strongly patterned with regional or longitudinal differences.

Drought in the summers of 1988 and 1989 resulted in increased hypoxia and hyperthermia levels in Prairie and Ozark Border sites. Because droughts were not as intense or prolonged in the Ozark Region (NOAA 1990) and Ozark streamflow persisted throughout the study, we ignored temporal changes at the four Ozark sites. Streamflow ceased for extensive periods during 1988 and 1989 at all non-Ozark sites; in the more normal years of 1987 and 1990, extended no-flow periods were limited to the upstream Prairie and some upstream Ozark Border sites. Stagnant conditions from low flows resulted in decreases in DO_{min} values during 1988–1989, which averaged from 0.3 to 1.4 mg/L lower than averages for 1987 and 1990 (Figure 2). Temperatures were also higher during 1988–1989, with T_{max} values averaging 1.1–2.1°C higher than in nondrought years (Figure 2). Generally, temporal changes in DO_{min} values were smaller in magnitude than either regional or longitudinal differences, but temporal changes in T_{max} values were of comparable magnitude to geographical differences.

Indices of Hypoxia and Hyperthermia

Mean hypoxia index values (Table 1) ranged from 0.69 to 1.20, a difference of 0.51, and hyperthermia index values ranged from 35.98 to 37.13, a difference of 1.15. Across the 18 sites as a whole, there was a strong relationship between hypoxia index values and stream DO_{min} values (Figure 3). Site means were significantly correlated ($r = 0.85$, $P \leq 0.01$), which indicated that a much higher proportion of hypoxia-tolerant species occurred at sites with the lowest DO_{min} values and that higher proportions of sensitive species occurred at the well-oxygenated sites. Even within each of the three regional groups, where there was much less contrast in DO_{min} conditions, hypoxia index values were positively correlated with DO_{min} levels.

Hyperthermia index values varied independently of T_{max} values ($r = 0.02$, $P > 0.05$; Figure 3). The highest frequencies of hyperthermia-tolerant species did not occur at the warmest sites, nor were sensitive species relatively more abundant at cooler sites. When sites were grouped by region, hyperthermia index values were negatively correlat-

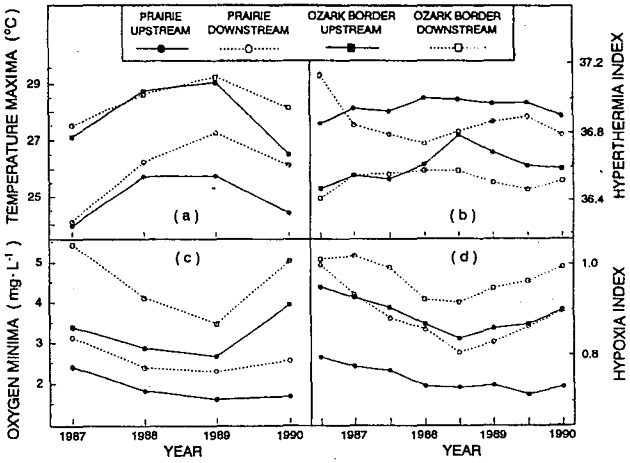

FIGURE 2.—Temporal trends in physicochemical conditions and tolerance index scores for upstream and downstream groups at Prairie and Ozark Border sites. Values for (a) stream temperature maxima and (c) dissolved oxygen minima are averages of the extreme values measured during the year at all locations and dates from all sites in the group. Scores for (b) the hyperthermia index and (d) the hypoxia index are running means from two consecutive samples, averaged for all sites in the group.

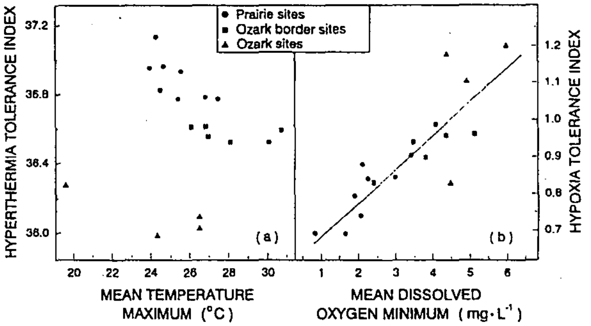

FIGURE 3.—Scores for (a) the hyperthermia index and (b) the hypoxia index averaged over the duration of the study for each site in relation to site mean temperature maxima and dissolved oxygen minima.

ed with T_{max} values within all three groups, which indicated a trend of increased frequencies of hyperthermia-sensitive species at warmer sites. This trend was contrary to expectations.

There were strong and consistent differences in hypoxia index values between regions and between upstream and downstream sites in all regions. At upstream sites, hypoxia values were lower in the Prairie region (indicating more tolerant species) than in the Ozark Border and Ozark regions by magnitudes of 0.14 and 0.22, respectively. At downstream sites, tolerances in the Prairie region averaged 0.10 and 0.32 lower than in the Ozark Border and Ozark regions. Increased frequencies of hypoxia-tolerant species were found at upstream than at downstream sites; average differences in hypoxia values between upstream and downstream groups were 0.07–0.22. Site mean hypoxia index values were also positively correlated (r = 0.77, $P \leq 0.01$) with site drainage areas, which indicated a general increase in the frequencies of sensitive species with larger stream sizes across the three regions. These regional and longitudinal differences in hypoxia index values were concordant with differences in DO_{min} values.

There were also distinct regional and longitudinal differences in hyperthermia index values, but these differences were discordant with the pattern of differences in stream T_{max} values. Much higher frequencies of hyperthermia-tolerant species occurred at Prairie than at Ozark sites, even though T_{max} values differed little between these regions. Hyperthermia index values were intermediate at the warmest Ozark Border region sites. At upstream sites, hyperthermia values in the Prairie region averaged 0.33 and 0.80 higher than values in the Ozark Border and Ozark regions, and at downstream sites, tolerances in the Prairie region averaged 0.30 and 0.78 higher than values in the Ozark Border and Ozark regions. Higher hyperthermia values were also found at upstream sites than at downstream sites in all three regions, the difference ranging from 0.07 to 0.10. Site mean hyperthermia index values were negatively correlated (r = −0.63, $P \leq 0.05$) with drainage areas. Even though temperatures tended to increase with stream size, downstream assemblages were actually more sensitive to hyperthermia.

Although hyperthermia index values were independent of maximum temperatures, they were strongly correlated with site mean DO_{min} values (r = 0.85, $P \leq 0.05$) and with site mean hypoxia index values (r = 0.87, $P \leq 0.05$). Additionally, the highest hyperthermia index values occurred in stream groups with the lowest DO_{min} values rather than in stream groups with highest T_{max} values. On the whole, the highest frequencies of both hypoxia- and hyperthermia-tolerant species were found at the most hypoxic sites, and species sensitive to either factor were most frequent at well-oxygenated rather than at cool sites. Hypoxia values were poorly correlated with site T_{max} values (r = -0.35, $P > 0.05$), which indicated that there was no complementary relationship whereby hypoxia values were influenced by temperatures.

In the non-Ozark sites, consistent increases occurred in hypoxia index values, but not in hyperthermia values, in response to the harsher physicochemical conditions brought about by drought (Figure 2). Hypoxia indices in drought years averaged from 0.02 (upstream Prairie) to 0.07 (downstream Ozark Border) lower in 1988–1989 samples than in 1987 and 1990 samples. Although temporal changes were smaller in magnitude than geographical differences, they were consistent. Decreased hypoxia index values occurred in all four groups (Figure 2) and at all 14 of the non-Ozark sites, which differed significantly (chi-square test, $P \leq 0.05$) from the 50:50 ratio expected by chance. On the other hand, there was little average difference in hyperthermia values between drought-year and nondrought-year samples. Although hyperthermia index values fluctuated somewhat from year to year, there was no steady trend of increase (Figure 2) in any group, and drought-year values were higher than nondrought-year values at only 9 of the 14 sites (chi-square, $P > 0.10$). In general, the overall abundance of fishes at all sites declined during the droughts. Hypoxia-tolerant species were less affected than sensitive species, and hyperthermia-tolerant species were neither selectively favored nor disfavored.

Ordination Analysis

The DCA ordination coordinates for the 18 species composition lists (Figure 4) showed a strong segregation along the x-axis with Prairie sites to the left, Ozark Border sites near the middle, and Ozark sites to the right of the diagram. A secondary segregation along the y-axis occurred only among the four Ozark sites; y-axis scores for the other two regions were virtually uniform. Assemblages from some sites that were a considerable geographic distance apart ordinated closely together, and some geographically neighboring sites ordinated far apart, which indicated that similarity in species composition was not a simple function of distance between sites.

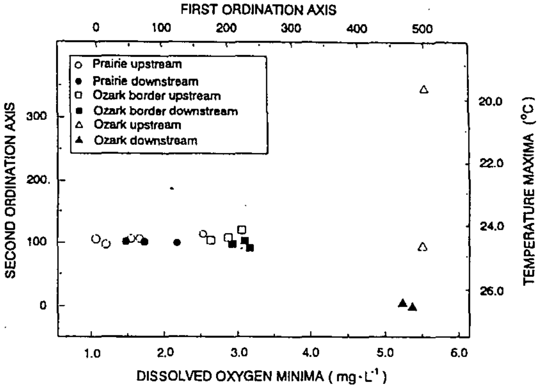

FIGURE 4.—Detrended correspondence analysis scores for species-frequency data averaged over the duration of the study from the 18 sites. The top and left axis scales are the original ordination scores. The bottom and right axis scales are stream dissolved oxygen minima and temperature maxima, calculated from the regression equations relating axis scores to each physicochemical variable.

Fish assemblages from hypoxic sites ordinated to the far left in Figure 4, and assemblages from more oxygenated sites ordinated to the right. The x-axis scores were strongly correlated (r = 0.85, $P \leq 0.05$) with site DO_{min} values (Table 2), which indicated a strong shift in species composition along the gradient from low to high minimum oxygen levels. The x-axis scores were therefore described by the regression equation

$$x\text{-axis} = -108 + 94.4(DO_{min}).$$

The effect of this regression equation is shown in Figure 4 as a simple substitution of a DO_{min} gradient for the original ordination x-axis values.

For the 18 sites as a whole, y-axis scores were moderately correlated (r = 0.58, $P > 0.05$) with site T_{max} values but not with DO_{min} values. But when we considered the 14 non-Ozark sites separately from the Ozark sites, there was almost no variation in y-axis scores. Thus, for these 14 sites, y-axis scores could be described by the mean value: y-axis = 101. At the non-Ozark sites, relatively cool and warm sites ordinated closely together; therefore, there was no relationship between T_{max} values and ordination scores on either axis.

Considered separately, the four Ozark sites segregated strongly along the y-axis in relation to temperature maxima. These sites segregated into a coolwater site at the top of the diagram and warmwater sites toward the bottom. For the four Ozark sites, y-axis scores were strongly correlated with T_{max} values (r = 0.99, $P \leq 0.01$); thus, scores could be described by the regression equation

$$y\text{-axis} = 1{,}306 - 49.4(T_{max}).$$

The effect of this equation is shown in Figure 4 as a substitution of a maximum temperature gradient for the original y-axis scale, but this particular substitution applied only to Ozark assemblages.

These relationships between site ordination axis scores and site DO_{min} and T_{max} values resulted in a simple two-step model for predicting both x-axis and y-axis coordinates from the two environmental variables.

Step 1: $x\text{-axis} = -108 + 94.4(DO_{min})$.

Step 2: $y\text{-axis} = 101$

if $DO_{min} < 4$ mg/L; or

$y\text{-axis} = 1{,}306 - 49.4(T_{max})$

if $DO_{min} > 5$ mg/L.

The simplest interpretation of this model is that sites segregated primarily in relation to the degree of hypoxia. At severe to moderate levels of hypoxia, when DO_{min} values were less than 4–5 mg/L, communities varied in relation to oxygen minima but not to T_{max} values or any other variable. Variation in composition of the fish assemblages, as expressed by the ordination coordinates, occurred independently of DO_{min} values only in those few Ozark sites where severe to moderate hypoxia was absent. In these few sites, assemblages appeared to vary in relation to maximum temperatures.

Discussion

Several lines of evidence suggest that hypoxia exerted a major effect on fish assemblages in small headwater streams. The strong correlation between hypoxia index values and stream oxygen minima clearly indicated that the relative frequency of hypoxia-tolerant species increased as stream DO_{min} values decreased. Frequencies of hypoxia-tolerant species also increased at all non-Ozark sites when drought induced more extensive hypoxia. We also found clear and concordant geographical patterns in oxygen minima and hypoxia tolerance index values such that the most severe hypoxia and the most tolerant assemblages were found at upstream and at Prairie region sites. Geographical variation in physicochemical conditions is considered a probable influence on both the longitudinal zonation of stream fishes and their long-term zoogeographic distributions (Schlosser 1987; Matthews 1987), and results from our study support this assertion. Most of the exceptionally hypoxia-tolerant species in this study are common in Prairie region streams; the most sensitive species are restricted to Ozark and Ozark Border streams (Pflieger 1975). This regional distribution of tolerant and sensitive species also suggests that relatively severe hypoxia has been a persistent and endemic characteristic of Prairie region streams.

The DCA ordination analysis provided additional evidence that species composition was strongly influenced by oxygen minima under the range of conditions encompassed by this study. Sites with similar DO_{min} values supported assemblages with similar species compositions, as expressed by ordination coordinates, regardless of their geographical location or temperature maxima. Sites with different DO_{min} values supported dissimilar assemblages even when sites were in close geographical proximity or differed markedly in temperature maxima. By itself, this association between species composition and oxygen minima could be spurious. But the ordination model was supported by concurrent shifts in hypoxia index scores that showed that the frequencies of tolerant and sensitive species responded to oxygen minima. It seems very unlikely that such strong shifts in both the compositions of assemblages and the tolerances of their members would be caused by any factor other than hypoxia.

We did not investigate the specific mechanisms by which hypoxia influenced these assemblages. In the laboratory, hypoxia was not lethal to any species when dissolved oxygen was above 1.6 mg/L. But in the field, DO_{min} values influenced species compositions up to approximately 4–5 mg/L, which is similar to recommended standards for oxygen minima in warmwater streams (Welch and Lindell 1992). Dissolved oxygen requirements for long-term persistence of stream fishes are typically much higher than those determined in laboratory survival tests (Moore 1942; Warren et al. 1973; Davis 1975), and there is a need to understand why this discrepancy occurs. Previous studies (Bailey 1955; Tramer 1977) showed that fish trapped in pools with severe conditions often die in masses during brief time periods. However, during this study, we never observed extensive fish kills, even at the most hypoxic sites. None of our observations suggested that direct species-selective mortality was the most common means by which hypoxia influenced the compositions of these assemblages. We expect that additional investigation into the effects of hypoxia on selective emigration, habitat selection, and suppression of growth and reproduction might bring understanding of why species are often less abundant at hypoxia levels well above their apparent lethal thresholds.

In contrast to our field test of hypoxia tolerances, the field test of the hyperthermia index was negative. Hyperthermia index scores were not related to site T_{max} values, nor were there any concordant regional, longitudinal, or temporal patterns to these two variables. These negative results may have occurred simply because the initial assumption of constant relative species tolerances under both laboratory and field conditions was false. However, other results, particularly the ordination model, indicated that other factors were important. For the 14 non-Ozark sites, species composition, as expressed by ordination coordinates, was not related to temperature maxima. Sites with dissimilar T_{max} values sometimes supported similar assemblages, and dissimilar assemblages were found at sites with similar T_{max} values. Additionally, hyperthermia-sensitive species such as white suckers were common even at the warmest sites, which implied that the absence of these species from most sites cannot be explained on the basis of temperature maxima. Thus, the best explanation for the negative test of the hyperthermia index is that assemblage compositions were not, in most cases, affected by temperature maxima.

The only evidence we found that fish compositions responded to hyperthermia was segregation of the Ozark region sites into coolwater versus warmwater assemblages. One unusually cool Ozark site may have supported a relatively unique assemblage for reasons other than temperature. The hyperthermia index value for this coolwater assemblage was similar to those from the warmer Ozark sites, but we believe this apparent discrepancy is an error caused by the high percentage of untested species in this particular assemblage. Ozark sculpins, which were very abundant at this site, are probably very sensitive to warm temperatures (Pflieger 1975). But, regardless of whether temperature differences were the actual cause, the well-oxygenated Ozark sites were the only cases where sites with similar oxygen minima supported varying assemblages.

Hyperthermia index values were neither uniform nor random in their variation among the study sites; instead, they were strongly correlated with both DO_{min} and hypoxia index values. This false-positive result occurred because several tested species were either dually sensitive (e.g., bleeding shiners) or dually tolerant (e.g., green sunfish) of both hypoxia and hyperthermia. High frequencies of either dually sensitive or dually tolerant species in assemblages resulted in corresponding changes to both the hypoxia and hyperthermia index values. Thus, both indices were affected by oxygen minima, which resulted in a spurious relationship between DO_{min} and hyperthermia index values. This effect is a potential problem in applying these indices because the effects of hyperthermia on assemblages cannot necessarily be distinguished from the effects of hypoxia without additional data.

The ordination model suggested that species compositions could be predicted from two simple physicochemical variables and that these variables could be predicted for other sites from species frequency measurements. The ordination model supported the tolerance index results by establishing that both assemblage compositions and assemblage tolerances were influenced by the same variables. The model also indicated that at sites with severe to moderate levels of hypoxia, the effect of hypoxia on species composition was dominant over the effects of hyperthermia and that effects of temperature maxima were expressed only when oxygen minima exceeded 4–5 mg/L. Below this range, assemblages differed only when oxygen minima differed, which indicated that other potential influences were overwhelmed by the stronger effects of hypoxia. Above this range, sites with similar oxygen minima but dissimilar temperature maxima supported varied assemblages. A follow-up study is needed that compares assemblages at a larger number of well-oxygenated sites with varying temperature maxima to confirm that assemblages do respond to hyperthermia in the absence of severe to moderate hypoxia.

Hypoxia was severe enough to influence species composition at all but a few of the 18 study sites, which implied that this effect is common in small streams of Missouri. The extent to which stream hypoxia is influenced by agriculture and is in need of management attention is not known. Although organic material from both natural and agricultural sources can deplete stream oxygen, hypoxia in some cases may be a natural feature of this type and size of stream to which fish have become adapted. The frequently low oxygen minima at many sites were largely an effect of stagnant conditions which prevailed during periods of little or no streamflow. Severe hypoxia did not occur in streams with persistent flow.

Stream hydrological characteristics are influenced mostly by watershed factors such as drainage area, slope, soil permeability, and vegetative cover. The strong longitudinal and regional patterning of oxygen minima and hypoxia index values was probably an effect of these factors. Management of stream oxygen levels because of their potential to affect fish assemblages requires consideration of such watershed factors.

Riparian shading, the primary influence on temperature maxima, was much more dependent on local factors, particularly the condition of riparian vegetation at each site. The warmest sites were those with the least shade, and individual pools without shade were warmer than adjacent shaded pools. Thus, temperature maxima were not as strongly geographically patterned as oxygen minima. Oxygen minima and temperature maxima were controlled by different factors, and this was reflected in the poor correlation between them. Although temperature maxima may be relatively manageable through efforts to improve local riparian vegetation. results of this study indicated that such management is likely to result in a response of the fish assemblage only in streams without severe hypoxia.

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Appendix follows

Appendix: Collection Data

TABLE A.1.—Species collected at each study site, with the critical dissolved oxygen concentrations and temperatures for each species (Smale and Rabeni 1995) and the frequencies of occurrence (percent by number of fish) of species at each site. The frequencies given are averages over the 3–4-year study period. Site abbreviations are listed in Table 1. Dashes are sight guides only.

Common name	Scientific name	Species mean critical oxygen concentration (mg/L)	Species mean critical temperature (°C)	Species frequency at Prairie sites:					
				MF 1	TI 1	EL 1	BR 1	FC 1	MF 2
Gizzard shad	*Dorosoma cepedianum*	[a]	[b]	–	–	–	–	–	–
Common carp	*Cyprinus carpio*	[a]	[b]	–	–	–	–	–	–
Golden shiner	*Notemigonus crysoleucas*	0.70	36.8	12.2	0.3	21.6	12.7	40.2	4.8
Creek chub	*Semotilus atromaculatus*	0.84	35.7	0.7	3.8	9.4	2.5	9.5	8.8
Hornyhead chub	*Nocomis biguttatus*	1.06	35.6	–	–	–	–	–	–
Suckermouth minnow	*Phenacobius mirabilis*	1.04	[b]	–	–	–	–	–	0.3
Southern redbelly dace	*Phoxinus erythrogaster*	0.74	35.9	–	–	–	–	–	–
Rosyface shiner	*Notropis rubellus*	1.49	35.3	–	–	–	–	–	–
Bigmouth shiner	*Notropis dorsalis*	1.02	36.6	[c]	32.2	–	–	–	36.4
Bigeye shiner	*Notropis boops*	[a]	[b]	–	–	–	–	–	–
Sand shiner	*Notropis stramineus*	0.93	37.0	–	–	–	–	–	–
Blacknose shiner	*Notropis heterolepis*	[a]	[b]	–	–	–	–	–	–
Ozark minnow	*Notropis nubilus*	1.45	36.2	–	–	–	–	–	–
Redfin shiner	*Lythrurus umbratilis*	1.17	36.2	0.4	6.5	5.7	4.0	5.1	6.9
Common shiner	*Luxilus cornutus*	0.97	35.7	–	–	–	0.3	0.1	–
Striped shiner	*Luxilus chrysocephalus*	1.03	36.2	–	–	–	–	–	–
Bleeding shiner	*Luxilus zonatus*	1.35	35.3	–	–	–	–	–	–
Red shiner	*Cyprinella lutrensis*	0.91	38.1	0.8	5.7	2.4	[c]	[c]	8.7
Bluntnose minnow	*Pimephales notatus*	1.04	36.6	–	4.2	0.1	0.6	–	2.8
Fathead minnow	*Pimephales promelas*	0.73	36.5	41.5	26.8	20.8	0.1	–	6.4
Central stoneroller	*Campostoma anomalum*	0.95	37.2	0.1	0.5	1.1	2.6	0.1	4.1
Largescale stoneroller	*Campostoma oligolepis*	[a]	[b]	–	–	–	–	–	–
White sucker	*Catostomus commersoni*	0.98	34.9	0.1	–	1.0	4.9	0.4	1.5
Northern hogsucker	*Hypentelium nigricans*	[a]	[b]	–	–	–	–	–	–
Golden redhorse	*Moxostoma erythrurum*	[a]	[b]	–	–	–	–	–	–
Yellow bullhead	*Ameiurus natalis*	0.49	37.9	5.2	0.7	8.1	0.2	16.1	0.9
Black bullhead	*Ameiurus melas*	1.13	38.1	0.1	–	0.3	–	1.2	[c]
Slender madtom	*Noturus exilis*	0.60	36.5	–	–	–	–	–	–
Mosquitofish	*Gambusia affinis*	[a]	[b]	–	–	–	–	–	–
Blackstripe topminnow	*Fundulus notatus*	0.88	38.3	–	–	0.1	–	–	–
Blackspotted topminnow	*Fundulus olivaceus*	0.88	38.8	–	–	–	–	–	–
Northern studfish	*Fundulus catenatus*	[a]	[b]	–	–	–	–	–	–
Plains topminnow	*Fundulus sciadicus*	0.92	37.0	–	–	–	–	–	–
Brook silversides	*Labidesthes sicculus*	1.59	36.0	–	–	–	–	–	–
Ozark sculpin	*Cottus hypselurus*	[a]	[b]	–	–	–	–	–	–
Rock bass	*Ambloplites rupestris*	[a]	[b]	–	–	–	–	–	–
Largemouth bass	*Micropterus salmoides*	0.70	36.3	–	0.1	[c]	0.7	0.8	–
Smallmouth bass	*Micropterus dolomieu*	1.19	36.9	–	–	–	–	–	–
Green sunfish	*Lepomis cyanellus*	0.63	37.9	34.2	12.4	22.3	22.7	24.8	8.2
Orangespotted sunfish	*Lepomis humilis*	0.62	36.4	4.4	–	0.3	–	–	1.0
Longear sunfish	*Lepomis megalotis*	0.68	37.8	–	–	–	–	–	–
Bluegill	*Lepomis macrochirus*	0.66	37.9	–	1.7	0.1	2.0	0.9	0.1
White crappie	*Pomoxis annularis*	[a]	[b]	–	–	–	–	0.1	[c]
Logperch	*Percina caprodes*	[a]	[b]	–	–	–	–	–	–
Johnny darter	*Etheostoma nigrum*	0.70	36.5	0.1	5.1	4.2	9.5	0.5	8.7
Orangethroat darter	*Etheostoma spectabile*	0.86	36.4	–	–	2.4	37.2	0.3	0.1
Fantail darter	*Etheostoma flabellare*	0.98	36.0	0.1	–	0.1	[c]	–	0.2
Banded darter	*Etheostoma zonale*	[a]	[b]	–	–	–	–	–	–
Rainbow darter	*Etheostoma caeruleum*	1.10	35.6	–	–	–	–	–	–
Greenside darter	*Etheostoma blennioides*	[a]	[b]	–	–	–	–	–	–
Stippled darter	*Etheostoma punctulatum*	[a]	[b]	–	–	–	–	–	–
All untested species				0.0	0.0	0.0	0.0	0.1	0.0

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[a] Species hypoxia tolerance was not tested; therefore, the average value for all tested species (0.93 mg/L) was used in calculating index values.

[b] Species hyperthermia tolerance was not tested; therefore, the average value for all tested species (36.6°C) was used in calculating index values.

[c] Species was present at this site, but at an average frequency of less than 0.05%.

TABLE A.1.—Extended.

Common name	Species frequency at Prairie sites:		Species frequency at Ozark Border sites:						Species frequency at Ozark sites:			
	MF 3	EL 2	SF 1	CH 1	HE 1	BR 2	SF 2	FC 2	WF 1	BV 1	WF 2	BV 2
Gizzard shad	–	[c]	–	–	–	–	–	–	–	–	–	–
Common carp	[c]	–	–	–	–	–	–	–	–	–	–	–
Golden shiner	7.7	24.8	24.4	12.4	3.6	1.3	0.7	0.6	–	–	[c]	–
Creek chub	13.2	1.1	2.5	9.6	2.4	1.8	2.0	4.4	–	–	–	–
Hornyhead chub	–	–	–	–	–	–	–	–	0.1	–	0.5	1.7
Suckermouth minnow	0.1	–	–	–	–	–	–	–	–	–	–	–
Southern redbelly dace	–	–	–	–	–	–	–	–	18.3	54.9	0.1	0.3
Rosyface shiner	–	–	–	–	–	–	0.2	2.3	1.2	–	0.8	5.3
Bigmouth shiner	1.4	[c]	–	–	–	–	–	–	–	–	–	–
Bigeye shiner	–	[c]	–	–	–	6.6	–	–	–	–	–	–
Sand shiner	–	0.1	–	–	–	0.1	–	[c]	–	–	–	–
Blacknose shiner	–	–	0.8	–	7.5	–	1.3	[c]	–	–	–	–
Ozark minnow	–	–	–	–	–	–	–	–	4.7	–	19.1	12.9
Redfin shiner	16.4	27.2	22.1	0.1	22.7	26.3	17.1	23.1	–	–	–	–
Common shiner	–	0.3	2.7	–	4.6	9.2	4.5	10.4	–	–	–	–
Striped shiner	–	–	–	–	–	–	–	–	0.4	1.1	6.7	15.6
Bleeding shiner	–	–	–	–	–	–	–	–	40.9	0.2	36.5	31.2
Red shiner	12.4	5.3	0.1	–	1.2	4.3	0.8	10.2	–	–	–	–
Bluntnose minnow	1.0	1.2	0.8	–	16.9	5.3	11.1	5.3	–	–	0.3	[c]
Fathead minnow	18.1	1.1	[c]	–	–	[c]	–	–	–	[c]	–	–
Central stoneroller	2.6	0.2	2.9	6.7	3.7	5.9	2.2	1.7	16.7	14.2	11.1	7.2
Largescale stoneroller	–	–	–	–	–	–	–	–	0.1	–	0.2	0.3
White sucker	2.9	4.2	0.1	0.1	0.1	0.1	0.2	0.3	–	0.1	0.1	–
Northern hogsucker	–	–	–	–	–	–	–	–	–	–	0.2	0.1
Golden redhorse	–	–	–	–	–	[c]	–	–	–	–	–	–
Yellow bullhead	3.5	0.3	[c]	0.4	0.2	0.4	0.2	0.3	–	–	–	–
Black bullhead	0.2	–	0.2	–	[c]	–	–	0.3	–	–	–	–
Slender madtom	–	–	[c]	–	–	0.1	[c]	0.1	[c]	–	0.1	[c]
Mosquitofish	–	[c]	–	–	[c]	–	–	[c]	–	–	–	–
Blackstripe topminnow	–	4.6	–	–	–	4.9	–	–	–	–	–	–
Blackspotted topminnow	–	–	–	–	–	–	–	–	0.2	–	1.8	1.2
Northern studfish	–	–	–	–	–	–	–	–	3.8	–	7.2	3.8
Plains topminnow	–	–	–	–	–	–	–	–	3.4	–	0.7	[c]
Brook silversides	–	–	3.0	–	–	–	8.3	[c]	[c]	–	0.6	0.8
Ozark sculpin	–	–	–	–	–	–	–	–	0.7	18.2	[c]	0.1
Rock bass	–	–	–	–	–	–	–	–	–	–	–	[c]
Largemouth bass	0.1	0.9	0.7	0.2	0.5	0.5	0.3	0.7	–	–	[c]	[c]
Smallmouth bass	–	–	–	–	0.5	–	–	–	–	–	1.1	0.5
Green sunfish	10.8	18.1	9.0	8.4	7.1	3.7	2.3	2.0	0.1	[c]	0.2	0.1
Orangespotted sunfish	3.8	0.3	–	–	–	–	0.4	0.1	–	–	–	–
Longear sunfish	–	–	–	–	0.5	–	1.4	[c]	–	–	0.2	0.6
Bluegill	–	2.4	1.9	0.9	0.5	2.1	5.7	1.5	[c]	[c]	0.3	[c]
White crappie	0.5	1.0	–	0.1	[c]	0.1	[c]	0.1	–	–	–	–
Logperch	–	–	–	–	[c]	–	0.1	0.1	–	–	–	[c]
Johnny darter	5.1	1.6	1.9	–	0.8	1.1	1.1	2.4	–	–	–	–
Orangethroat darter	0.1	4.9	26.6	61.1	27.2	24.8	40.2	34.1	5.2	10.7	9.1	14.2
Fantail darter	–	0.2	–	0.1	–	1.3	–	–	1.4	0.2	0.1	0.3
Banded darter	–	–	–	–	–	–	–	–	–	–	[c]	[c]
Rainbow darter	–	–	–	–	–	–	–	–	2.7	0.3	2.7	3.2
Greenside darter	–	–	–	–	–	–	–	–	[c]	–	0.1	0.1
Stippled darter	–	–	–	–	–	–	–	–	–	[c]	0.2	[c]
All untested species	0.5	1.1	0.8	0.1	7.6	6.7	1.4	0.3	4.5	18.2	7.7	4.4