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MACROINVERTEBRATE COMMUNITIES AND THEIR RESPONSES TO REGIONAL SEDIMENT LOADS IN TWO HABITAT TYPES OF OAK LAKE, A PRAIRIE POTHOLE IN EASTERN SOUTH DAKOTA

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ABSTRACT

The Clean Water Act aims to maintain the chemical, physical, and biological integrity of the nation's waters. Sedimentation is a major pollutant to South Dakota lakes and sources of sedimentation will likely increase as more rangeland is converted toward production of corn and soybeans in South Dakota. This study examined the influence of experimental sediment loads on aquatic macroinvertebrate communities in a prairie pothole lake. Ten emergent macrophyte beds and ten rocky shoreline plots were treated with soil to simulate an annual sediment load of 25 kg/m^2. Plots were treated and sampled during the summers of 2005 and 2006. Invertebrates were subsampled, identified, and classified into habitat and feeding guilds. A total of 129 genera were identified throughout the experiment. Macrophyte beds contained an average of 23 genera and rocky shores contained an average of 18 genera. Sedimentation significantly decreased the percentages of collector-gatherers and sprawlers. Percentages of gliders, swimmers, and scrapers increased with the addition of sediment. Macrophyte beds had an increase in Ephemeroptera, Trichoptera, and Odonata richness following sedimentation. The percentage of sprawlers in rocky shorelines was significantly decreased due to sedimentation. We recommend that further studies should examine possible threshold levels of increased sediment that could affect macroinvertebrate communities.

Keywords:

Sedimentation, prairie pothole, macroinvertebrate, metrics

INTRODUCTION

Globally, sediment contributes the greatest quantity of unwanted materials to surface waters. Loads of sediment to the world's oceans are estimated to total 13.5 x 10^9 tons per year (Milliman and Meade 1983) while 1 billion tons has been estimated to enter oceans from North America each year (Gleick 1993). Sources and loadings of sediment vary widely among geographic settings due to differences in geology, soil type, topography, climate and land-use. However, within any given region, those activities resulting in soil disturbance and loss of vegetation are known to enhance sediment loadings to surface waters (Chesters and Schierow 1985). Within the United States, 48% of impaired river miles and 33% of impaired lake acres are impaired due to siltation or suspended solids (Gleick 1993). South Dakota ranks 12th among 50 states (US EPA 2000) in sediment loads. Approximately 2,100 miles of South Dakota streams are impaired due to high loads of total solids. Sedimentation and total solids also impair approximately 9600 acres of lakes in South Dakota (SD DENR 2008). The Clean Water Act of 1972 directs states to restore and maintain the chemical, physical, and biological integrity of the nation's waters. All waterbodies of the state that do not meet their assigned beneficial uses must develop a Total Maximum Daily Load (TMDL) to specify targets and actions to reduce pollution (SD DENR 2008). The TMDL process includes implementation of best management practices designed to improve water quality, habitat and biological integrity of impaired waters. However, the relationship between load reductions for a particular contaminant (like sediment) and biological integrity are not well known.

Many studies have examined the detrimental effects of sedimentation on macroinvertebrate communities. Macroinvertebrate abundance and richness were reduced by increased sedimentation (Lenat et al. 1981; Martin and Neely 2001; Shaw and Richardson 2001; Donohue and Irvine 2004). Lemly (1982) found that species richness, diversity and total biomass were reduced in streams of the Appalachian region by increased sedimentation. Zweig and Rabeni (2001) found that taxa richness, density, Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness, EPT densities and EPT/Chironomidae richness were all negatively correlated with increases in sedimentation. Kaller and Hartman (2004) found similar results for EPT richness in streams of West Virginia.

Although there have been many studies on the affects of sedimentation to macroinvertebrates, few have examined the affects of sedimentation on aquatic macroinvertebrate communities in the Prairie Pothole region. Foley (1997) studied macroinvertebrate communities in littoral regions of Oak Lake prone to non-point source disturbance. He found that Oligochaeta and Chironomidae dominated sites prone to disturbance. He also found that Ephemeroptera, Trichoptera, Tanytarsini, and Chironomini were found more frequently in sites not prone to disturbance. Braskamp (2002) found that Ephemeroptera, Trichoptera, and Odonata (ETO) and Ephemeroptera richness were reduced by addition of sediment. He also found that the percent sprawler guild was reduced by sedimentation.

Emergent macrophyte beds and rocky shoreline habitats are the two predominant habitats in the littoral of Oak Lake and other regional lakes. Vegetated and nonvegetated areas of lakes have been shown to have different invertebrate communities (Rennie and Jackson 2005). Areas with macrophytic vegetation, both emergent and submergent, have been shown to support more invertebrates than open water habitats (Beckett et al. 1992; Weatherhead and James 2001; Phillips 2003; Heatherly et al. 2005; Beaty et al. 2006). Weatherhead and James (2001) found that the most important factor for macroinvertebrate abundance and distribution were macrophyte biomass, substrate, and detritus. Beaty et al. (2006) found that rock and macrophyte patches had higher densities of macroinvertebrates than soft bottom sediments in an arctic lake. There have been few studies in prairie wetlands looking at the differences of invertebrate communities in different habitats (Euliss et al. 1999; Rennie and Jackson 2005). The macroinvertebrate communities in these habitats may respond differently to the increase of sedimentation.

The objectives of this experiment were to (1) describe the macroinvertebrate communities for emergent macrophyte bed and rocky shoreline habitats and (2) evaluate the effects of high regional sediment loads to the macroinvertebate community structure of emergent macrophyte bed and rocky shoreline habitats.

STUDY AREA

Experimental plots were constructed within the littoral zone of Oak Lake, Brookings County, South Dakota located at approximately 44° 31’ N latitude and 96° 32’ W longitude (Figure 1).

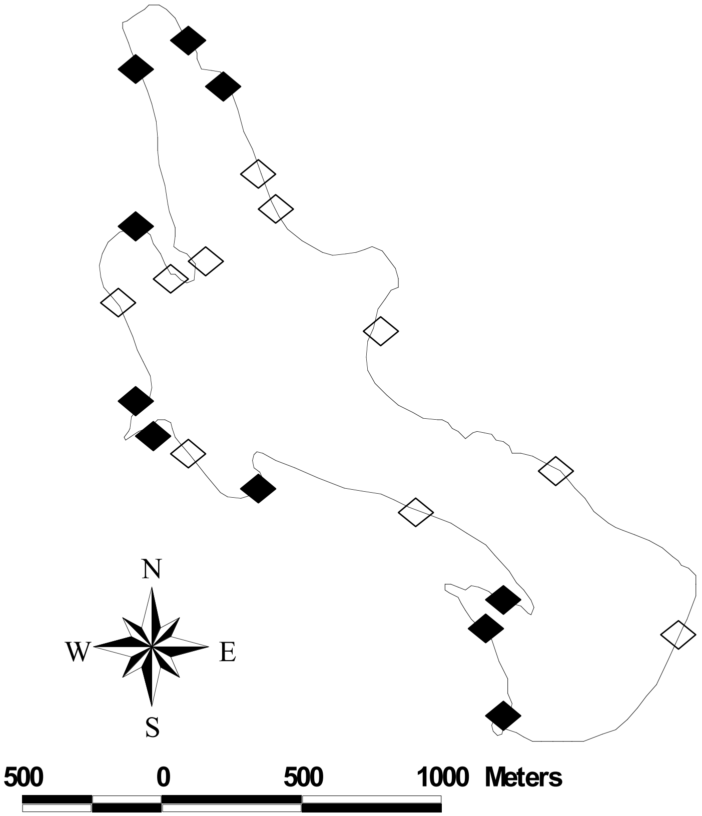

Figure 1. Location of experimental plots around the perimeter of Oak Lake, Brookings County, SD. Solid diamonds represent macrophyte bed plot and open diamonds represent rocky shore plots.

Oak Lake is a 163 ha hypereutrophic basin with an average depth of 1.2 m and watershed area of 1600 ha. Approximately half of the basin perimeter falls within the Oak Lake Field Station. The other half is privately owned and managed primarily as grazed pasture. No cultivated croplands are located adjacent to the lake shoreline. The littoral zone of Oak Lake is comprised primarily of boulder shorelines and emergent macrophyte beds. Thus, sedimentation experiments were designed within these two primary shoreline habitats.

METHODS

Experimental plots were constructed at 20 locations around the perimeter of Oak Lake. Ten experimental sites were randomly located in emergent cattail beds and 10 were located along rocky shorelines. At each of these twenty locations, experimental plots (1 meter by 4 meter) were constructed using silt fence and rebar fence posts to a water depth of 0.5m. The rebar fence posts were located at four corners of a rectangular plot with the silt fence being attached to the fence posts with plastic ties to make enclosures. A buffer of 2 m was retained between plots. The plots were oriented so the long plane (4 meter) of the plot was parallel with the shoreline. Each location contained one control plot (0 $kg/m^2/yr$) and a high treatment plot (25 $kg/m^2/yr$). High treatment levels were established slightly above the highest level reported for drainages of 100 square miles or less within the upper Missouri River watershed (Dunne and Leopold 1978). Soil for sediment treatments was applied in one application and consisted of a clay loam (40% sand, 36% clay, 24% silt) obtained from an upland area within the Oak Lake watershed. Pretreatment sampling occurred prior to addition of sediment during the last week of June 2006 and 2007. Two post treatment samples were taken one and two weeks following treatment with sediment.

Invertebrate samples were collected with a 500 µm petite net. After the substrate was hand-disturbed, we swept the net for 30 seconds in each corner of control and treatment plots for a combined two-minute sampling effort per plot. All samples were preserved in 70% ethanol. A random 300-count invertebrate subsample was drawn, sorted and identified from each whole plot sample. Invertebrates were identified to the lowest possible taxonomic group (Ross 1944; Wiggins 1977; Wiederholm 1983; Provonsha 1990; Thorp and Covich 2001; Merritt et al. 2008). Stem density (macrophyte beds only) and visual determinations of substrate particle size were obtained from each plot. In addition, water temperature, conductance, pH, and dissolved oxygen were measured from each plot using a YSI multiparameter sonde; turbidity was measured with a Hach nephelometer.

Invertebrate counts were used separately to evaluate shifts in community structure, functional feeding guilds, habit use guilds and tolerance to organic pollution (Braskamp 2002). Treatment differences were evaluated using a Split-split-plot ANOVA (Statistix 2003) with habitat type as the main blocking variable. Date served as the sub-plot factor and treatment served as the sub-sub-plot factor. Site was used as the replication variable. Sediment and control plots constituted the treatment groups (n=10 each).

RESULTS

Macroinvertebrate Communities for the two habitats

A total of 129 invertebrate taxa were found from emergent macrophyte and rocky shoreline habitats. Insecta and Oligochaeta contributed approximately 90% of total macroinvertebrate abundance in macrophyte beds and 75% of total macroinvertebrate abundance along rocky shores. Average total richness was higher from macrophyte beds (23) than rocky shore habitats (18). The collector-gatherer feeding guild was most abundant in both habitats, 77% (macrophyte beds) and 71% (rocky shoreline) and over half of all invertebrates collected from both habitats were burrowers (58% from macrophyte beds and 66% from rocky shoreline).

Dominant taxa in macrophyte beds included Oligochaeta, *Caenis latipennis* (Ephemeroptera), Coenagrionidae (Odonata), *Endochironomus* sp. (Diptera) and *Glyptotendipes* sp. (Diptera). Rocky shoreline dominant taxa included Oligochaeta, *Caenis latipennis,* Hydrachnida, *Hydra* sp. (Cnidaria), *Pisidium* sp. (Mollusca), and *Hyalella azteca* (Amphipoda). Macrophyte beds had higher densities of most chironomid genera including *Endochironomus* and *Glyptotendipes*. Macrophyte beds also had higher densities of damselflies (Coenagrionidae) and *Ferrissia* snails. Rocky shore habitats had a lower density of Chironomidae. However, *Nanocladius* and *Pseudochironomus* were found frequently on rocky shores but were found rarely in macrophyte beds. Rocky shore habitats had high densities of Hydrachnida, *Hydra* sp., *Pisidium* sp. and *Physa* sp. The caddisfly *Oecetis* sp. was found in higher densities from rocky shore habitats.

Macrophyte beds had significantly higher percentages of the shredder functional feeding guild (Table 1). The climber and clinger habit guilds were also significantly higher in the macrophyte beds. Rocky shorelines had significantly higher percentages of predator and collector-filterer functional feeding guilds.

Sediment treatment effects

Control plots had significantly higher percentages of collector-gatherers and sprawlers. Treatment plots had significantly higher percentages of scrapers, gliders, and swimmers (Table 1). The collector-gatherers were reduced from 77% (control plots) to 74% (treatment plots) by sedimentation. Sprawlers were reduced from 14% (control plots) to 10% (treatment plots). Scrapers, gliders, and swimmers all increased in abundance about one percent with the addition of sedimentation but each of these guilds comprised only a small percentage (2% to 4%) of the overall community.

Sedimentation in macrophyte beds

Macroinvertebrate composition for macrophyte control plots contained an average of 42% Insecta and 48% Oligochaeta. Collector-gatherers and burrowing taxa dominated the macrophyte control plots, representing 80% of feeders and 60% of habits. Tolerance to organic pollution was moderate with 72% of taxa falling in the tolerance range of 5-7 (0-10 scale).

Table 1. Community metric p-values generated from split-split-plot ANOVA. Asterisks denote significant differences (p >0.05).

Metric	Habitat	Date	Treatment	Habitat*Date	Habitat*Treatment	Treatment*Date
Total Richness	<0.01*	0.07	0.82	0.29	0.44	0.51
ETO Richness	0.80	<0.01*	0.67	0.08	0.04*	0.18
% CF	<0.01*	0.11	0.43	0.53	0.16	0.28
% CG	0.20	0.09	0.03*	0.23	0.98	0.69
% Predator	<0.01*	0.08	0.29	0.02*	0.81	0.84
% Scraper	0.97	<0.01*	0.05	0.75	0.67	0.84
% Shredder	<0.01*	0.15	0.70	0.23	0.79	0.92
% Burrower	0.36	<0.01*	0.54	0.51	0.10	0.97
% Climber	<0.01*	0.02*	0.85	0.11	0.74	0.99
% Clinger	<0.01*	0.83	0.19	0.23	0.37	0.44
% Glider	0.98	0.07	0.03*	0.98	0.51	0.61
% Sprawler	0.06	<0.01*	<0.01*	0.11	0.01*	0.93
% Swimmer	0.96	<0.01*	0.01*	0.90	0.26	0.70

Macroinvertebrate composition for macrophyte treatment plots contained an average of 41% Insecta and 48% Oligochaeta. Collector-gatherers and burrowers dominated the plots with 77% and 58% of the total macroinvertebrate community. Again, most taxa (73%) fell within the organic pollution tolerance range of 5-7.

Oligochaeta, *Caenis latipennis, Endochironomus,* and Coenagrionidae abundances were reduced 18%, 15%, 13%, and 6%, respectively in treatment plots. The sum of Ephemeroptera, Trichoptera and Odonata richness was significantly higher from treatment plots versus control plots within macrophyte beds (Table 1).

Sedimentation in rocky shoreline

Macroinvertebrate composition for rocky shore control plots contained 58% Oligochaeta and 17% Insecta. Collector-gatherers and burrowers dominated this habitat. Collector-gatherers represented 73% of taxa, and burrowers represented 62% of taxa. Most taxa (71%) had tolerance values that ranged from 5 to 7.

Macroinvertebrate composition for rocky shore treatment plots contained 60% Oligochaeta and 14% Insecta. Collector-gatherers and burrowers represented 71% and 66% of the community. Most taxa (70%) had tolerance values between 5 and 7.

Oligochaeta, Hydrachnida, and *Hyalella azteca* abundances increased by 14%, 16%, and 96%, due to treatment, respectively. The abundances of *Caenis latipennis* and *Hydra* decreased by 53% and 54% due to treatment. Percent sprawlers decreased significantly from 11% to 6% after sediment was added.

DISCUSSION

Emergent macrophyte beds and rocky shore habitats of this prairie pothole contained similar overall communities but with different dominant taxa. Macrophyte beds contained higher densities of Insecta than rocky shorelines (Beckett et al. 1992; Weatherhead and James 2001; Phillips 2003; Heatherly et al. 2005; Rennie and Jackson 2005; Beaty et al. 2006). However, we observed fewer predators and greater numbers of generalist collector-gatherers than were previously reported (Heatherly et al. 2005).

We found few community richness metrics and functional feeding guilds that were affected in both habitats by high sediment loads. Tangen et al. (2003) also found a weak correlation between land use and macroinvertebrate assemblages. They attributed their results to natural variability, harsh climatic situations and fish predation. Carroll (2005) found no significant differences in community assemblages among treatment and control plots with increased levels of sedimentation from a single emergent macrophyte bed in Oak Lake. Like Martin and Neely (2001), we found that predators and collector-gatherers were negatively affected by sedimentation. In addition, we found that scrapers, gliders, and swimmers, but not predators, were also negatively affected by sedimentation.

Ephemeroptera, Trichoptera and Odonata (ETO) richness increased after addition of sediment, but this only occurred in macrophyte beds. These organisms are generally thought to be pollution sensitive (Gerritsen et al. 1998, Voshell 2002), yet when sediment was added to Oak Lake macrophyte plots, richness increased. The presence of *Oecetis* (Trichoptera) increased in five of ten plots and Baetidae (Ephemeroptera) increased in three plots following treatment. *Caenis latipennis,* the dominant Ephemeroptera, and Coenagrionidae, the dominant Odonata, are considered to be somewhat tolerant to pollution (Voshell 2002), so their presence was not affected by sedimentation in any of the macrophyte bed plots.

Rabeni et al. (2005) found that clingers and sprawlers were reduced by sedimentation in streams of Missouri. We also had a reduction in the density of clingers, while scrapers, gliders, and swimmers displayed slightly increased densities following sedimentation. Rabeni et al. (2005) also found that burrowers were the most tolerant habit group, similar to our results. Significant shifts in habit guilds suggest altered habitat utilization by aquatic macroinvertebrates following sedimentation (Chutter 1969; Crowe and Hay 2001). We observed significantly higher amounts of silt and clay after treatment was applied which led to an altered habitat.

Overall, we observed no real change in dominant taxa, total richness or functional feeding groups (except collector-gatherers) due to sedimentation, regardless of habitat type. With exception to shifts in habitat utilization, our results suggest that Oak Lake shoreline invertebrates are well adapted to the upper reported range of annual sediment loads observed from the upper Missouri River watershed (Dunne and Leopold 1978). These results are unusual as many studies have documented reduced diversity and altered guild structure associated with increased sediment load (Lenat et al. 1981; Lemly 1982; Angradi 1999; James et al. 2000; Martin and Neely 2001; Shaw and Richardson 2001; Wood et al. 2001; Zweig and Rabeni 2001; Crowe and Hay 2004; Donohue and Irvine 2004; Kaller and Hartman 2004). Euliss et al. (1999) suggest that Prairie Pothole macroinvertebrate assemblages are comprised of ecological generalists and our results appear to support that generalization. Anthropogenic sources of sediment may be expected to increase if Conservation Reserve Program acres are converted back to cultivated croplands. Additional research is needed to define sediment thresholds beyond which significant changes in community composition and guild structure are likely to occur. Our results suggest that this threshold may be beyond the high end of the range reported by Dunne and Leopold (1978) for small drainages of the upper Missouri River.

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LITERATURE CITED

Angradi, T.R. 1999. Fine sediment and macroinvertebrate assemblages in Appalachian streams: a field experiment with biomonitoring applications. Journal of the North American Benthological Society 18:49-66.

Beaty, S.R., K. Fortino, and A.E. Hershey. 2006. Distribution and growth of benthic macroinvertebrates among different patch types of the littoral zones of two arctic lakes. Freshwater Biology 51:2347-2361.

Beckett, D.C., T.P. Aartila, and A.C. Miller. 1992. Contrasts in density of benthic invertebrates between macrophyte beds and open littoral patches in Eau Galle Lake, Wisconsin. American Midland Naturalist 127:77-90.

Braskamp, C.W. 2002. Biogeographic patterns of littoral invertebrate communities and responses to disturbance in prairie lakes. M.S. Thesis. South Dakota State University. Brookings, SD, USA.

Carroll, D. 2005. The effects of sedimentation on the invertebrate assemblage within a lacustrine littoral zone. M.S. Thesis. Manchester Metropolitan University. Manchester, England.

Chesters, G. and L.J. Schierow. 1985. A primer on non point pollution. Journal of soil and water conservation 40:9-13.

Chutter, F.M. 1969. The effects of silt and sand on the invertebrate fauna of stream and rivers. Hydrobiologia 34:57-76.

Crowe, A. and J. Hay. 2004. Effects of fine sediment on river biota. Prepared for Motueka Integrated Catchment Management Programme.

Donohue, I. and K. Irvine. 2004. Seasonal patterns of sediment loading and benthic invertebrate community dynamics in Lake Tanganyida, Africa. Freshwater Biology 49:320-331.

Dunne, T. and L.B. Leupold. 1978. Water in Environmental Planning. W.H. Freeman and Company, San Francisco, CA, USA.

Euliss, N.H., Jr., D.A. Wrubleski, and D.M. Mushet. 1999. Wetlands of the Prairie Pothole Region: invertebrate species composition, ecology, and management. p. 471-514. *In* D.P. Batzer, R.B. Rader, and S.A. Wissinger (eds.) Invertebrates in Freshwater Wetlands on North America: Ecology and Management. John Wiley & Sons. Inc., New York, NY, USA

Foley, J.L. 1997. A biological assessment of landscape disturbance potential on a northern prairie pothole lake. M.S. Thesis. South Dakota State University. Brookings, SD, USA.

Gerritsen, J., R.E. Carlson, D.L. Dycus, C. Faulkner, G.R. Gibson, J. Harcum, and S.A. Markowitz. 1998. Lake and Reservoir Bioassessment and Biocriteria. Technical Guidance Document. United States Environmental Protection Agency. Washington D.C. USA.

Gleick, P.H. 1993. Water in Crisis. Oxford University Press, Oxford, New York, USA.

Heatherly, T., M.R. Whiles, D. Knuth, and J.E. Garvey. 2005. Diversity and community structure of littoral zone macroinvertebrates in Southern Illinois reclaimed surface mine lakes. American Midland Naturalist 154:67-77.

James, M.R., I. Hawes, and M. Weatherhead. 2000. Removal of settled sediments and periphyton from macrophytes by grazing invertebrates in the littoral zone of a large oligotrophic lake. Freshwater Biology 44:311-326.

Kaller, M.D. and K.J. Hartman. 2004. Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. Hydrobiologia 518:95-104.

Lemly, A.D. 1982. Modification of benthic insect communities in polluted streams: combined effects of sedimentation and nutrient enrichment. Hydrobiologia 87:229-245.

Lenat, D.R., D.L. Penrose, and K.W. Eagleson. 1981. Variable effects of sediment addition on stream benthos. Hydrobiologia 79:187-194.

Martin, D.C. and R.K. Neely. 2001. Benthic macroinvertebrate response to sedimentation in a *Typha angustifolia* L. wetland. Wetlands Ecology and Management 9:441-454.

Merritt, R.W., K.W. Cummins, and M.B. Berg (ed.). 2008. An Introduction to the Aquatic Insects of North America. 4th Edition. Kendall/Hunt Publishing Company, Dubuque, IA, USA. 1158 pp.

Milliman, J.D. and R.H. Meade. 1983. World-wide delivery of river sediment to the oceans. Journal of Geology 91:1-21.

Phillips, E.C. 2003. Habitat preference of aquatic macroinvertebrates in an East Texas sandy stream. Journal of Freshwater Ecology 18:1-11.

Provonsha, A.V. 1990. A revision of the genus *Caenis* in North America (Ephemeroptera: Caenidae). Transactions of the American Entomological Society 116:801-884.

Rabeni, C.F., K.E. Doisy, and L.E. Zweig. 2005. Stream invertebrate community functional responses to deposited sediment. Aquatic Sciences 67:395-402.

Rennie, M.D. and L.J. Jackson. 2005. The influence of habitat complexity on littoral invertebrate distributions: patterns differ in shallow prairie lakes with and without fish. Canadian Journal of Fisheries and Aquatic Sciences 62:2088-2099.

Ross, H.H. 1944. The caddisflies, or Trichoptera, of Illinois. Bulletin of Illinois Natural History Survey 23:1-326.

Shaw, E.A. and J.S. Richardson. 2001. Direct and indirect effects of sediment pulse duration on stream invertebrate assemblages and rainbow trout *(Oncorhynchus mykiss)* growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58:2213-2221.

SD DENR (South Dakota Department of Environment and Natural Resources). 2008. The 2008 South Dakota Integrated Report for Surface Water Quality Assessment. Pierre, SD, USA.

Statistix for Windows 8. 2003. Analytical Software. Tallahassee, FL, USA.

Tangen, B.A., M.G. Butler, and M.J. Ell. 2003. Weak correspondence between macroinvertebrate assemblages and land use in Prairie Pothole region wetlands, USA. Wetlands 23:104-115.

Thorp, J.H. and A.P. Covich (ed.). 2001. Ecology and classification of North American freshwater invertebrates. 2nd Edition. Academic Press, Inc., New York, NY, USA. 1056 pp.

US EPA (United States Environmental Protection Agency). 2000. National Water Quality Inventory 2000. EPA 841-R-02-001. U.S. Environmental Protection Agency, Washington, D.C., USA.

Voshell, J.R. 2002. A guide to common freshwater invertebrates of North America. The McDonald & Woodward Publishing Company, Blacksburg, VA, USA. 442 pp.

Weatherhead, M.A. and M.R. James. 2001. Distribution of macroinvertebrates in relation to physical and biological variables in the littoral zone of nine New Zealand lakes. Hydrobiologia 462:115-129.

Wiederholm, T. (ed.). 1983. Chironomidae of the Holarctic region. Keys and diagnoses. Part 1. Larvae. Entomologica Scandinavica Supplement 19:1-457.

Wiggins, G.B. 1977. Larvae of the North American caddisfly genera. University of Toronto Press, Toronto, Canada. 401 pp.

Zweig, L.D. and C.F. Rabeni. 2001. Biomonitoring for deposited sediment using benthic invertebrates: a test on 4 Missouri streams. Journal of the North American Benthological Society 20:643-657.