

Confronting Climate Change in the Great Lakes Region

Technical Appendix

Wetland Ecosystems

*This document is a technical appendix providing further detail on the water resource information in the Report on **Confronting Climate Change in the Great Lakes Region** available at <http://www.ucsusa.org/greatlakes/> (Kling et al. 2003). The principal author contact for this background paper is Lucinda Johnson, and co-authors include (alphabetically) Katharine Hayhoe, George Kling, John Magnuson, and Brian Shuter.*

Introduction

Wetlands play an integral role in the hydrologic cycle, and provide important ecosystem services that may include flood storage, water quality amelioration and enhancement, carbon storage, wildlife habitat, and buffers during periods of high water (NRC 1995). Economic benefits of wetlands include timber production, peat extraction, and recreation. Although littoral zones and wetlands make up only ~12% of the surface area of the Great Lakes, these zones are “hot spots” of primary and secondary production because of watershed inputs of nutrients and sediments (Brazner et al. 2000). Coastal wetlands such as those in Saginaw Bay, and large estuaries such as Green Bay, Sturgeon Bay, and the St. Louis River Estuary support rich communities and unique plants, birds, and fish (Jude and Pappas 1992; Brazner 1997). Bogs and fens cover extensive areas in the northern Great Lakes region and contain a wide variety of acid-loving plants – the pitcher plant being among the most familiar.

Because of the low-lying topography or the presence of impervious soils, the Great Lakes region historically contained extensive expanses of wetlands, particularly in the prairie regions of Minnesota and Illinois, the boreal regions of northern Minnesota and Ontario, and the low-lying fringes of Lake Michigan and Lake Erie (e.g., the Great Black Swamp). The cumulative effects of human activity on wetlands are especially apparent in the southern portion of the region. Wetlands have been extensively modified or drained for urban development and agricultural production, resulting in huge losses in wetland area. In Minnesota, Wisconsin, Ohio, Illinois, and New York a total of 42, 46, 90, 85, and 60% of the wetland area has been drained. About 70% of the total number of wetlands has been lost from the lower Great Lakes and lower St. Lawrence River valley of Canada (Mitsch and Gosselink 2000).

Wetlands near the Great Lakes occur as three distinct types: fringing coastal marshes that are directly impacted by lake levels and wave action; riverine wetlands that are partially influenced by both lake and river; and protected lagoons or barrier beach systems that are hydrologically connected to the lake via groundwater only (Keough et al. 1999). Where they have not disappeared, coastal marshes in the southern part of the Basin, particularly on Lake Erie and southern Lake Ontario, have been extensively diked to protect them from water level fluctuations. Inland wetlands are even more diverse, and span the gradient from entirely precipitation-driven (e.g., bogs) to systems stabilized by both surface and groundwater contributions (e.g., riparian wetlands). Changes in lake water levels in the past thousands of years have had huge impacts on the wetlands by exposing or inundating vast expanses of shoreline (Booth et al. 2001).

Threats to Wetlands

All wetland types are sensitive to alterations in their hydrologic regime (LaBaugh et al. 1996; Mortsch and Quinn 1996; Keough et al. 1999). These threats are superimposed on a myriad of anthropogenic disturbances such as dredging and filling, water diversion, and degraded water quality (Patterson and Whillans 1985; Adamus 1991; Wilcox 1995). With increased demands for irrigation water and public water supplies, groundwater drawdown also poses a great threat to wetlands. Such disturbances directly influence plant (Poiani et al. 1995), invertebrate, and fish communities (Wilcox and Meeker 1992), trophic structure (Mensing et al. 1998), and productivity (Davis and Brinson 1980). Finally, the introduction of invasive species (e.g., *Phragmites*, purple loosestrife, or water milfoil) poses a threat to many wetlands, particularly those experiencing other types of anthropogenic disturbances such as water level alteration or increased nutrient loading (Galatowitsch et al. 1999). The threats to wetlands resulting from climate change are described in detail below and summarized in *Table 5*.

Climate-Driven Changes in Hydrology and Resulting Impacts

The future climate scenario (described in Kling et al. 2003 and the associated technical appendices) is expected to have a negative impact on both inland and coastal Great Lakes wetlands (Mortsch and Quinn 1999; Bridgham et al. 1999), although higher precipitation during winter and spring and intense storm events may at times offset the generally decreased water levels anticipated from increased evaporation (see technical appendix on [lake level changes](#)). Impacts of changing climates on Great Lakes wetlands have been assessed using general circulation models (GCMs), climate spatial transpositions, and historic climate analogs (Mortsch 1998; Chao 1999). Those models predict scenarios leading to earlier spring flows and lower or unchanged lake levels, but anticipated changes vary by lake and by the model used (Chao 1999; Quinn *In press*). The models used in those studies predicted smaller temperature increases than those used in Kling, et al. 2003 (see technical appendix on [climate projections](#)); therefore, evidence points to greater certainty that lake water levels will decline (see technical appendix on [lake level changes](#)).

A general drying in climate will mainly impact precipitation-dominated wetlands, since groundwater-dominated wetlands rely on aquifer discharge to maintain their integrity, and thus are hydrologically more stable and resistant to climate-driven changes in their spatial extent and functions (Brinson 1993). Decreases in summer precipitation in the southern and western portions of the region (*Figure 12* in Kling et al. 2003) will most negatively impact depressional wetlands such as those in the prairie pothole region of the western Great Lakes. As water levels drop the surface area of existing wetlands will decline; however, depending on the shape of the shoreline additional habitat may be exposed and new wetland vegetation could grow in formerly open water habitats (Poiani et al. 1995). In wetlands fringing the Great Lakes, shoreline damage and erosion is likely to decrease under lower water level regimes (Chao 1999; Quinn *In press*).

Biotic communities in both coastal and inland wetlands are continually adapting to changing water levels, and the timing, duration, and amplitude of inundation influences vegetation community structure (Poiani et al. 1996), decomposition rates, primary and secondary production, biogeochemical cycling, and rates of gas exchange in wetlands (Mulholland et al. 1997). The effects of extreme droughts and floods on vegetation and water chemistry in wetlands are not limited to the period of disturbance, but rather, integrate both preceding and antecedent conditions (LaBaugh et al. 1996).

Climate Change Impacts on Ecosystem Structure and Functioning

Wetlands are the main interface for moving nutrients, pollutants, and sediments from land to water. Decreased overland flow as a result of drying or drought will decrease the inputs from uplands to wetlands, but will increase the retention of these substances in the wetlands. Fluctuating water levels combined with higher temperatures should result in an eventual decrease in nutrient and carbon storage (Mulholland et al. 1997). The capacity for wetlands to assimilate nutrients and human and agricultural wastes will be greatly reduced during such periods. Warmer temperatures and elevated CO₂ should result in higher primary production per unit biomass (Morin and Bourassa 1992), but the negative effects of ozone and fluctuating hydrologic regimes may offset these increases in wetland productivity.

Northern peatlands such as those found in Minnesota and Ontario are formed when low temperatures and waterlogged soils limit the rate of decomposition, resulting in large pools of stored carbon (Gorham 1991). A future climate of higher temperatures and *lower* water levels is likely to increase the rate of organic matter decomposition and accelerate CO₂ releases to the atmosphere. Methane releases tend to increase with warmer temperatures and a *rising* water table (Bridgham et al. 1995; Updegraff et al. 2001). The exact responses of peatlands to climate change are difficult to predict because of differences in plant production and community composition (Weltzin et al. 2000), and to decomposition rates as a function of temperature, soil quality, and moisture (Bridgham et al. 1998).

Fluctuations in water levels and soil moisture also influence the release of nutrients and heavy metals (Mastalerz et al. 2001; Grigal 2002). Lower water levels expose more organic wetland soils to oxygen and may reduce mercury exports, but also may reduce the removal of nitrate from the soil. Increased oxygen concentrations in exposed soils, especially when accompanied by acid precipitation, may release metals such as cadmium, copper, lead, and zinc (Perkins et al. 2000; Dollar et al. 2001), and wetlands downstream of industrial effluents could face increased risk of heavy metal contamination during periods of low water.

Lower water levels have also been shown to reduce the export of dissolved organic carbon (DOC) from uplands to wetlands in Ontario (Schindler et al. 1996). Overall, water flow strongly controls DOC export and during droughts or reduced streamflow less DOC will be exported from land to surface waters. In turn, reduced amounts of DOC in surface waters result in higher doses of UV-B radiation penetrating further through the water column (Morris and Hargreaves 1997). Organisms living in shallow waters will be at greatest risk (Kiesecker et al. 2001; Ankley et al. 2002) because UV-B penetration is generally restricted to the top 5 to 20 cm of the surface water (Peterson et al. 2002). In deeper wetlands the organisms can find a refuge from this harmful radiation (Diamond et al. 2002).

Climate warming will likely cause some wetland species to shift their ranges to accommodate their thermal tolerances (see also the technical appendix on [fish responses to climate change](#)). Because of differences in breeding habits, age to maturity, or dispersal rates, some species are more vulnerable than others to natural or anthropogenic stressors affecting these ecosystems (Skelly 1996; Gibbs 1998). Earlier drying of ephemeral wetlands will threaten reproductive success of certain species such as wood frogs and many salamanders in the Great Lakes region (E. Werner, *personal communication*).

As water availability changes, wetlands expand or contract in area. At the end of a drought cycle, deep wetlands serve as refugia, or source populations, for other wetlands that have dried out. Higher water levels, on the other hand, would increase the connections between wetlands, which could serve as conduits for the spread of both native but also exotic invasive species. Loss of refugia during longer or more severe droughts will impact less mobile species (especially amphibians and reptiles) that frequently are the top predators in wetlands without fish. Landscape fragmentation exacerbates the impact of wetland loss because of scarce refugia and isolation of source populations (Gibbs 1993). Studies in the northeastern U.S. have indicated that red-backed salamanders, spotted and blue-spotted salamanders, red-spotted newts, and wood frogs are sensitive to the effects of forest fragmentation (deMaynadier and Hunter 1998; Gibbs 1998).

Great Lakes coastal wetlands can function as reservoirs of biodiversity for offshore habitats, because plant, invertebrate, and fish species richness is higher along the coast than offshore (Brazner et al. 2001; Brown et al. 1996). The complexity of the food web depends on the extent of the connection between the wetland and the open water (Keough et al. 1996; Brazner et al. 2001), and especially in less productive lakes, such as Lake Superior, the open waters depend upon inputs of material and energy from coastal systems (Anesio et al. 1999; Denward et al. 1999; Del Giorgio et al. 1999).

The value of all wetlands for wildlife habitat depends on the size of the wetlands, diversity of vegetation, water quality, soil conditions, and topography. Lower water levels generally lead to poorer conditions for aquatic species. Under these conditions, plant communities shift to emergent taxa and ultimately to shrub communities (e.g., Mortsch 1998; Poiani et al. 1995). Animal diversity is often linked to the vegetation community (e.g., Wilcox and Meeker 1992), thus shifts in vegetation may be expected to accompany shifts in fauna, particularly as systems shift from an aquatic to a terrestrial hydrologic regime.

Finally, most aquatic birds in the region also depend upon seasonal flood pulses and gradual water drawdowns. Changes in the timing and severity of this flood pulse will affect the availability of safe breeding sites for birds and amphibians. Midsummer 'spike' floods, for example, can flood bird nests in small wetlands and attract predators such as raccoons to areas where birds and amphibians breed. Changes in the timing of the spring melt also greatly alter migratory pathways and timing. The availability of seasonal mudflats for migratory shorebirds and endangered, beach-nesting species such as the Piping Plover (Great Lakes population of about 20 pairs) will be affected with the drying or loss of wetlands.

Table 2. Summary and synthesis of the changes in wetland ecosystems driven by climate change. Intensifying or confounding factors are discussed in the text.

| Climate Driven Change | Likely Impacts on Physical Properties | Likely Impacts on Ecosystem Properties | Intensifying or Confounding Variables |
|-----------------------------|---|---|--|
| Earlier ice-out & snow melt | Wet periods are shorter, especially in ephemeral wetlands | Fast-developing insect and amphibian species are favored, as are species with resting stages The timing of amphibian and insect life cycles could be disrupted | Snowmelt occurs earlier and faster in urban areas and where coniferous forest harvest has occurred |

| | | | |
|---|---|--|--|
| Decreased summer water levels | <p>Isolation and fragmentation within wetland complexes increase</p> <p>Reductions in dissolved organic carbon result in less attenuation of UV-B radiation</p> | <p>Habitat and migration corridors are reduced, as are hydrologic connections to riparian zones and groundwater recharge</p> <p>Emergent vegetation and shrubs dominate plant communities</p> <p>Amphibian and fish reproduction fails more often in dry years</p> <p>Organisms with poor dispersal abilities become extinct</p> | Agricultural and urban development exacerbates fragmentation effects |
| Warmer temperatures | <p>Evaporative losses increase</p> <p>Fens and bogs store less carbon</p> | <p>The rate of decomposition and respiration increase. Insects emerge earlier</p> <p>Primary and secondary production per unit biomass increase when nutrients are not limited</p> <p>Species with limited thermal tolerances at the southern extent of the range become extinct</p> | <p>Impervious surfaces increase water temperature</p> <p>More competition from invasive species may accelerate extinctions</p> |
| Increased intensity and frequency of storms | Wetlands increase in extent | <p>Habitat area increases</p> <p>Ground-nesting birds may be lost during floods</p> | Wetland losses from development reduce flood storage capacity |
| Elevated atmospheric CO ₂ | | Possible changes in leaf litter quality could impact aquatic food webs (see River and Stream Ecosystem appendix) | |

Box 1 Fragmentation, Wetland Conversion, And Loss Of The Yellow-Headed Blackbird

The decline to the point of endangerment of the Yellow-headed Blackbird in the Great Lakes region illustrates metapopulation collapse potentially exacerbated by global climate change. This spectacular blackbird is entirely restricted to a small subset of marshes that have suitable vegetation in any given year as a result of hydrological fluctuations. As a result of wetland loss and increasing unsuitability of remaining marshes caused by changing human land uses and resulting changes in water levels, populations appear to be slipping below the threshold needed to maintain the regional metapopulation. Any further changes in water levels caused by increases in spring precipitation or dry-out in summer, for example, may further reduce the suitability of remaining marshes. The regional population may now be so small that it no longer attracts enough dispersing young to maintain itself; normally, dispersing young are less important, but now very few young return to the marshes where they were born. For this species, there is no longer a sufficient migratory corridor from the main population in the Great Plains. The result is the likely extinction of the Yellow-headed Blackbird from the entire Great lakes region, a range loss of ~250,000 square miles. Even highly mobile migratory songbirds therefore can suffer regional metapopulation collapse, in this case probably driven by climate and land use changes.

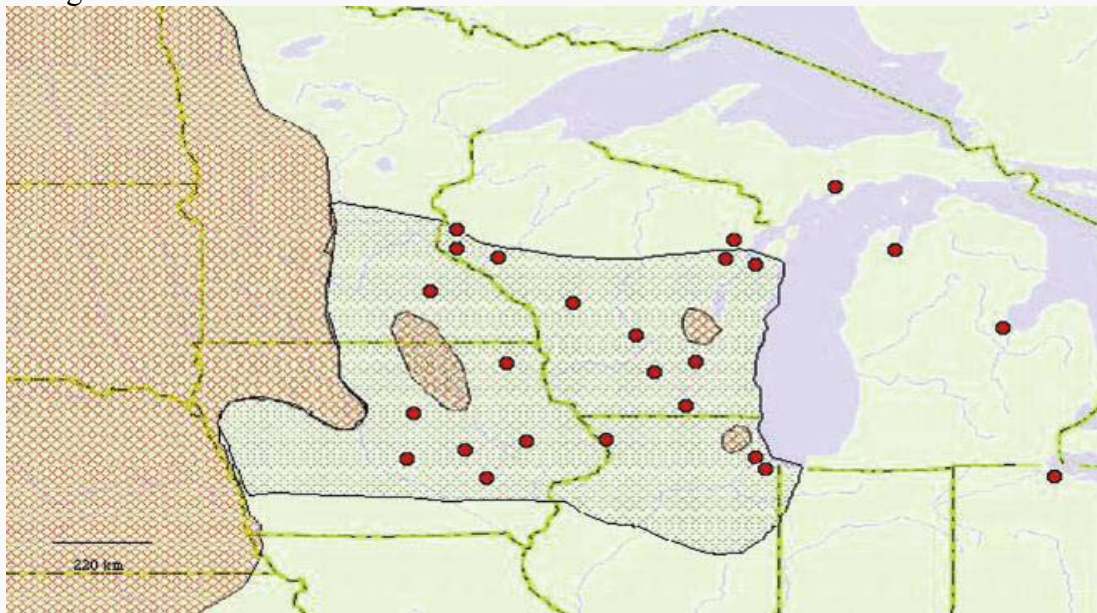


Figure 1. *The present and historical range of yellow-headed blackbirds in the Midwest. The cross-hatched areas (brown) represent current populations of more than 100 individuals, the red dots represent smaller populations of less than 100 individuals, and the stippled area represents the historical range (ca. late 19th century). The yellow-headed blackbird sites in Michigan and Ohio are recent colonizations (ca. 1930's), and it is believed that the combination of drought and wetland drainage led to the species expanding its range further east. These eastern populations are not well established, and the Ohio population may be extirpated (data and figure from Mike Ward).*

References

- Adamus, P.R., L.T. Stockwell, E.J. Clairain, Jr., M.E. Morrow, L.P. Rozas, and R.D. Smith. 1991. Wetland Evaluation Technique (WET) Volume I: Literature Review and Evaluation Rationale. Wetlands Res. Prog. Tech. Rpt. WRP-DE-2. U.S. ACOE, Waterways Experiment Station. 287 pp.
- Anesio, A.M., L.J. Tranvik, and W. Graneli. 1999. Production of inorganic carbon from aquatic macrophytes by solar radiation. *Ecology* 80:1852-1859.
- Ankley, G.T., S.A. Diamond, J.E. Tietge, A.W. Holcombe, K.M. Jensen, D.L. DeFoe and R. Peterson. 2002. Assessment of the risk of solar ultraviolet radiation to amphibians. I. Dose-dependent induction of hindlimb malformations in the northern leopard frog (*Rana pipiens*). *Environ. Sci. Technol.* 36:2853-2858.
- Booth, R.K., S.T. Jackson, and T.A. Thompson. 2002. Paleoecology of a northern Michigan Lake and the relationships among climate, vegetation, and Great Lakes water levels. *Quaternary Research* 57:120-130.
- Brazner, J.C. 1997. Regional, habitat, and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. *J. Great Lakes Res.* 23:36-51.
- Brazner, J.C., M.E. Sierzen, J.R. Keough, and D.K. Tanner. 2001. Assessing the ecological importance of coastal wetlands in a large lake context. *Verh. Int. Ver. Limnol.* 26:1950-1961.
- Bridgham, S.D., J. Pastor, K. Updegraff, T.J. Malterer, J. Johnson, C. Harth, and J. Chen. 1999. Ecosystem control over temperature and energy flux in northern peatlands. *Ecological Applications* 9:1345-1358.
- Bridgham, S.D., K. Updegraff, and J. Pastor. 1998. Carbon, nitrogen, and phosphorus mineralization in northern wetlands. *Ecology* 79:1545 – 1561.
- Bridgham, S.D., C.A. Johnston, J. Pastor, K. Updegraff. 1995. Potential feedbacks of northern wetlands on climate change. *BioScience* 45:262-274.
- Brinson, M. M. 1993. Changes in the functioning of wetlands along environmental gradients. *Wetlands* 13:65-74.
- Brown, R.W., M.P. Ebener, T.J. Sledge, and W.W. Taylor. 1996. Forage fish assemblage structure in the littoral and nearshore areas of St. Martin Bay, Lake Huron. In M. Munawar and J. Leach (eds.) *The Lake Huron Ecosystem: Ecology, Fisheries, and Management*: 207-222. SPB Academic Publishing, Amsterdam/New York.
- Chao, P. 1999. Great Lakes water resources: climate change impact analysis with transient GCM scenarios. *J. Am. Water Res. Assoc.* 35:1499-1507.
- Davis, C.J. and M. Brinson. 1980. Responses of submersed vascular plant communities to environmental change. FWS/OBS-79/330. US Dept. Interior. Fish and Wildlife Service.
- Del Giorgio, P.A., J.J. Cole, N.F. Caraco, and R.H. Peters 1999. Linking planktonic biomass and metabolism to net gas fluxes in northern temperate lakes. *Ecology* 80: 1422-1431.
- Denward, C.M.T., H. Edling, and L.J. Tranvik. 1999. Effects of solar radiation on bacterial and fungal density on aquatic plant detritus. *Freshwater Biology* 41:575-582.
- Diamond, S.A., G.S. Peterson, J.E. Tietge, and G.R. Ankley. 2002. Assessment of the risk of solar ultraviolet radiation to amphibians. III. Prediction of impacts in selected northern Midwestern wetlands. *Environ. Sci. Technol.* 36:2866-2874.
- Dollar, N.L., Souch, C., Filippelli, G.M. and Mastalerz, M. 2001. Chemical fractionation of metals in wetland sediments: Indian Dunes National Lakeshore. *Env. Sci. Technol.* 35:3608-3618.
- Galatowitsch, S.M., N.O. Anderson, and P.D. Ascher. 1999. Invasiveness of wetland plants in temperate North America. *Wetlands* 19:733-755.
- Gibbs, J. P. 1998. Distribution of woodland amphibians along a forest fragmentation gradient. *Landscape Ecology* 13: 263-268.
- Gibbs, J. P. 1993. Importance of small wetlands for the persistence of local populations of

- wetland-associated animals. *Wetlands* 13:25-31.
- Gorham, E. 1991. Northern peatlands: Role in the carbon cycle and probable responses to global warming. *Ecological Applications* 1:182–195.
- Grigal, D.F. 2002. Inputs and outputs of mercury from terrestrial watersheds: A review. *Environmental Review* 10(1):1–39.
- Jude, D.J. and J. Pappas. 1992. Fish utilization of Great Lakes coastal wetlands. *Journal of Great Lakes Research* 18:651-672.
- Keough, J.R., T.A. Thompson, G.R. Guntenspergen, and D.A. Wilcox. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. *Wetlands* 19(4):821-834.
- Keough, J.R., M.E. Sierszen, and C.A. Hagley. 1996. Analysis of a Lake Superior coastal food web with stable isotope techniques. *Limnology and Oceanography* 41:136-146.
- Kiesecker, J.M., A.R. Blaustein, and L.K. Belden. 2001. Complex causes of amphibian population declines. *Nature* 410:681-684.
- LaBaugh, J.W., T.C. Winter, G.A. Swanson, D.O. Rosenberry, R.D. Nelson, and N.H. Euliss, Jr. 1996. Changes in atmospheric circulation patterns affect mid-continent wetlands sensitive to climate. *Limnol. Oceanogr.* 41:864-870.
- Mastarletz, M., Souch, C. Filipelli, G.M., Dollar, N.L. and Perkins, S.M. 2001. Anthropogenic organic matter in the Great Marsh of the Indiana Dunes National Lakeshore and its implications. *Int. J. Coal Geol.* 46:157-177.
- deMaynadier P. G. and M.L. Hunter, Jr. 1998. Effects of silvicultural edges on the distribution and abundance of amphibians in Maine. *Conservation Biology* 12(2):340-352
- Mensing, D.M., S.M. Galatowitsch, and J.R. Tester. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a north temperate landscape. *J. Env. Mgmt* 53:349-377.
- Mitsch, W.J., and Gosselink, J.G. 2000. *Wetlands*. Third Edition. John Wiley & Sons, Inc. 920pp.
- Morin, A. and N. Bourassa. 1992. Modles empiriques de la production annuelle et du rapport P/B d'invert,br, d'eau courante. *Canadian Journal of Fisheries and Aquatic Sciences* 49:532-539.
- Morris, D. P. and B. R. Hargreaves. 1997. The role of photochemical degradation of dissolved organic carbon in regulating the UV transparency of three lakes on the Pocono Plateau. *Limnology and Oceanography* 42:239-249.
- Mortsch, L. D. 1998. Assessing the impact of climate change on the Great Lakes shoreline wetlands. *Climatic Change* 40:391-416.
- Mortsch, L.D. and F.H. Quinn. 1996. Climate change scenarios for the Great Lakes Basin ecosystem studies. *Limnology & Oceanography* 41:903-911.
- Mulholland, P.J., G. R. Best, C. C. Coutant, G.M. Hornberger, J.L. Meyer, P.J. Robinson, J.R. Stenberg, R.E. Turner, F. Vera-Herrera, and R.G. Wetzel. 1997. Effects of climate change on freshwater ecosystems of the south-eastern United States and the Gulf of Mexico. *Hydrological Processes* 11:949-970.
- National Research Council. 1992. *Restoration of Aquatic Ecosystems*. National Academy Press, Washington, D.C. 552 pp.
- Patterson, N.J. and T.H. Whillans. 1985. Human interference with natural water level regimes in the context of other cultural stresses on Great Lakes wetlands. Chapter 14, In: *Coastal Wetlands*. H.H. Prince, F.M. D'Itri (eds). Lewis Publishers, Inc. Chelse Michigan. 286 pp.
- Perkins, Steven M. ; Filippelli, Gabriel M. ; Souch, Catherine J. 2000. Airborne Trace Metal Contamination of Wetland Sediments at Indiana Dunes National Lakeshore. *Water, Air & Soil Pollution* 122,:231-260
- Peterson, G. S., L.B. Johnson, R. P. Axler, and S.A. Diamond. 2002. Assessment of the risk of solar ultraviolet radiation to amphibians. II. In situ characterization of exposure in amphibian habitats. *Environmental Science & Technology* 36: 2859-2865.

- Poiani, K.A., W.C. Johnson, G.A. Swanson, and T.C. Winter. 1996. Climate change and northern prairie wetlands: simulations of long-term dynamics. *Limnol. Oceanogr.* 41:871-881.
- Poiani, K.A., W.C. Johnson, and T.G.F. Kittel 1995. Sensitivity of prairie wetland to increased temperature and seasonal precipitation changes. *Water Resources Bulletin* 31:283-294.
- Quinn, F.H. *In Press*. Lake Erie water level fluctuations. Current perspectives on Lake Erie water level fluctuations. In: Ciborowski, J.J. H., M.N. Charlton, R.G. Kreis, and J.M. Reutter. (eds). Lake Erie at the Millenium- Change;s, Trends and Trajectories. Canadian Scholars Press, Inc. Toronto, ON.
- Schindler, D.W., S.E. Bayley, B.R. Parker, K.G. Beaty, D.R. Cruikshank, E.J. Fee, E.U. Schindler, and M. P. Stainton. 1996. The effects of climatic warming on the properties of boreal lakes and streams at the Experimental Lakes Area, northwestern Ontario. *Limnology & Oceanography* 41:1004-1017.
- Skelly, D. K., 1996. Pond drying, predators, and the distribution of *Pseudacris* tadpoles. *Copeia* 3:599-605.
- Updegraff, K., S.D. Bridgham, J. Pastor, P. Weishampel, C. Harth. 2001. Responses of CO₂ and CH₄ emissions from peatlands to warming and water table manipulations. *Ecological Applications* 11:311-326.
- Weltzin, J.F., J. Pastor, C. Harth, S.D. Bridgham, K. Updegraff, and C.T. Chapin. 2000. Response of bog and fen plant communities to warming and water table manipulations. *Ecology* 81:3464-3478.
- Wilcox, D.A. 1995. Wetland and aquatic macrophytes as indicators of anthropogenic hydrologic disturbance. *Nat. Areas J.* 15(3):240-248
- Wilcox, D.A. and J.E. Meeker. 1992. Implications for faunal habitat regulated to altered macrophyte structure in regulated lakes in northern Minnesota. *Wetlands* 12:192-203.