Effects of Urbanization on Stream Ecosystems in the Milwaukee and Green Bay areas, Wisconsin

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ABSTRACT

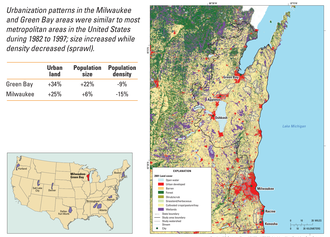
In 2003 and 2004, 30 streams near Milwaukee and Green Bay, Wisconsin were part of a national study by the USGS National Water-Quality Assessment program to assess urbanization effects on stream ecosystems. An urban intensity index was developed using GIS-based data to quantify the gradient of urbanization within relatively homogeneous environmental settings. Stream physical habitat, hydrology, stream temperature, water chemistry, benthic algae, benthic invertebrates, and fish were examined. Physical habitat measurements reflective of channel enlargement increased with urbanization but river engineering features in some of the watersheds may have confounded other potential habitat responses to urbanization. Streamflow flashiness, duration of low flow, and stream temperature were positively correlated with urbanization. Spring and summer chloride concentrations were greater with increasing road infrastructure characteristics, urban land, and other landscape variables related to urbanization as a result of road salt deicer usage. Spring sulfate, prometon, and diazinon increased with road indices, percent impervious surface, and percent urban land. Potential aquatic toxicity and organic contaminants, as measured from semi-permeable membrane devices, were higher with increasing road density, percent impervious surface, and urban land. The quality of algae, invertebrate and fish assemblages was negatively related to increasing percentages of urban land and associated characteristics of increasing impervious surface, streamflow flashiness, chloride, and decreases in watershed wetland area and streambank vegetative cover.

INTRODUCTION

Urbanization has been linked to environmental problems related to loss of aquatic habitat; degradation in water quality; and changes in aquatic algal, invertebrate, and fish assemblages. Urban development affects stream hydraulics and sediment input, transport, and deposition; thereby altering aquatic habitat and the aquatic biotic community. Abundance and diversity of aquatic biota generally decrease with increasing urbanization of stream areas. Altered flow regimes can result in dying aquatic biota associated with lower oxygen levels; burying of biota under fine sediment; flushing of biota downstream; and disrupting of normal feeding, resting, and swimming patterns. In addition, increasing chemical concentrations cause aquatic biota shifts to pollution-tolerant species. Ultimately, urban impacts on streams can lead to increased vulnerability of aquatic biological communities to non-native/exotic species.

Urbanization patterns in the Milwaukee and Green Bay areas were similar to most metropolitan areas in the United States during 1982 to 1997; size increased while density decreased (sprawl).

	Urban land	Population size	Population density
Green Bay	+34%	+22%	-9%
Milwaukee	+25%	+6%	-15%



The Milwaukee-Green Bay study was one of 9 areas across the U.S. studied for effects of urbanization on stream ecosystems. Study area and land cover shown above.

METHODS

Urban intensity index (UII)

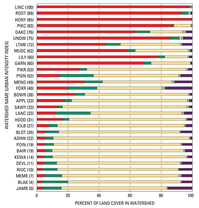
An urban intensity index (UII) for the study area was computed using 35 GIS-derived variables that included: road infrastructure (road area, road traffic density), 100-meter-buffer riparian land cover, watershed land cover* and 26 socioeconomic variables (2000 Census). The approach used a substitution of space for time.

* 2001 National Land Cover Data (NLCD)

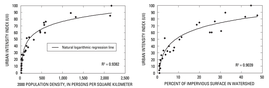
Site selection

30 sites were selected based on environmental setting and urban gradient:

- Urban intensity index (UII) – gradient (0–100), weighted towards lower intensities where changes are likely to occur
- Surficial deposits – clay
- Ecoregion – Southeast Wisconsin Till Plains



Urban intensity index values and land cover for the 30 study sites.



The urban intensity index (UII), percent impervious surface and percent urban developed land in the watershed and 100-m riparian zone, household density, and road density were all highly related (rho > 0.90). It was difficult to separate out effects of watershed impervious surface compared to riparian zone impervious surface.

Data collection

Data were collected during the 2004 water year (Oct. 2003–Sept. 2004). Data collection for habitat, water quality, and biological characteristics followed standardized USGS procedures. In addition, potential toxicity was measured with SPMD's (semipermeable-membrane devices) and streamflow was measured using pressure transducers at 22 sites and standard USGS streamflow-gaging station site equipment at the remaining 8 sites.

Physical characteristics:
Habitat
Hydrology/flow
Temperature

Water-quality characteristics:
Chloride, sulfate, nutrients
DOC, POC
Suspended sediment
Pesticides
Semipermeable membrane devices

Biological characteristics:
Algae (attached/periphyton)
Invertebrates
Fish

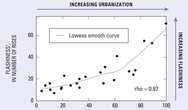
RESULTS

PHYSICAL EFFECTS

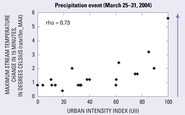
Habitat

- Bankfull channel area (normalized by drainage area) and length of unvegetated bank increased with increasing percent impervious surface in watershed.
- Percentage of riffles, streambed-substrate size, silt coverage, and embeddedness correlated with reach slope and not with urbanization.
- Local geologic setting (alluvial vs. bedrock channels) and historical channel modifications (bank stabilization or grade control) can confound habitat relations to urbanization.

Hydrology/temperature

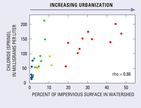


[1] When total rise of cross-sectional area is greater than or equal to 5 times the median total rise over the post-rice period of record.

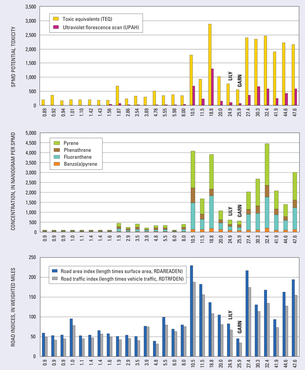


- Streamflow flashiness, duration of low flow, and weekly mean stream temperature increased with urbanization, while the duration of high flow decreased with urbanization.

WATER-QUALITY EFFECTS



- Spring concentrations of chloride, prometon, and diazinon increased with the urban intensity index. Chloride and prometon had the most, and strongest, positive correlations to landscape variables related to urbanization—percent urban developed land in the watershed; size, location and distance of urban patches; and percent impervious surface in the watershed.
- Chloride had a strong, positive correlation to the urban intensity index in both spring and summer.

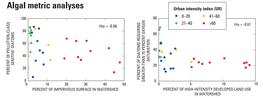


Semipermeable-membrane device (SPMD) results showed a strong relationship with synthetic organics and urbanization. Two measures of potential toxicity and concentrations of four polycyclic aromatic hydrocarbons (PAHs) increased with the urban intensity index; concentrations and potential toxicity increased significantly when the percentage of impervious surface in the watershed was greater than 8 percent.

BIOLOGICAL EFFECTS

Algae

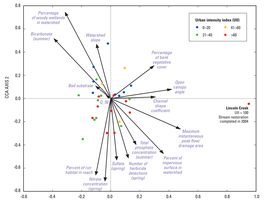
Algal metric analyses



- Pollution-sensitive diatoms decreased as the percentage of impervious surface in the watershed increased.
- The percentage of diatoms requiring high oxygen saturation decreased with increasing amounts of urban developed land.

Algal assemblage analyses

Canonical correspondence analysis (CCA) biplot of the relations of representative environmental characteristics to algal assemblages.

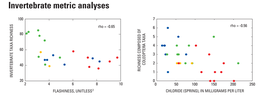


Arrows indicate the importance and direction of the influence of environmental characteristics; characteristics shown were significantly related to one or more CCA axes.

Differences in algal assemblages between sites related most to:
- percent of woody wetlands in the watershed
- nitrate (depositional-substrate algae only)
- total phosphorus (riffle-rock-substrate algae only)
- percent of run habitat in the reach
- bicarbonate
- percent of impervious surface in the watershed
- sulfate
- maximum instantaneous peak flow (normalized by drainage area)
- number of herbicide detections
- slope
- open canopy angle
- stream bank vegetative cover

Invertebrates

Invertebrate metric analyses

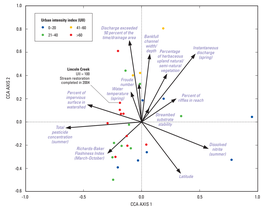


[1] Sum of the absolute values of the relative change in cross-sectional area.

- Invertebrate taxa richness decreased with increasing streamflow flashiness.
- Chloride, found to increase with the urban intensity index and impervious surface in our study, was related to adverse changes in benthic invertebrates. Coleoptera taxa richness decreased with increasing spring chloride; EPT and overall invertebrate abundance decreased with increasing summer chloride.

Invertebrate assemblage analyses

Canonical correspondence analysis (CCA) biplot of the relations of representative environmental characteristics to benthic macroinvertebrate assemblages.

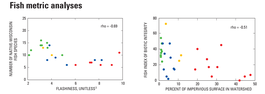


Arrows indicate the importance and direction of the influence of environmental characteristics; those characteristics shown were significantly related to one or more of the CCA axes.

Differences in invertebrate assemblages between sites related most to:
- instantaneous discharge, measured in spring
- discharge exceeded 50% of the time (normalized by drainage area)
- percentage of impervious surface in the watershed
- streamflow flashiness
- total pesticide concentration
- nitrite
- average bankfull channel width-to-depth ratio
- riffles in the reach
- herbaceous upland natural/semi-natural vegetation in the 100-m riparian zone

Fish

Fish metric analyses

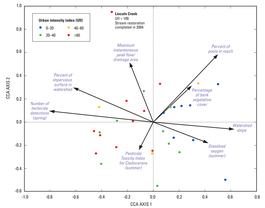


[1] Sum of the absolute values of the relative change in cross-sectional area.

- Increasing values of the urban intensity index were related to decreases in fish Index of Biotic Integrity (IBI) scores, total number of fish taxa, and number of native fish taxa.
- The highest correlations between fish and water chemistry were for chemical characteristics measured in spring, especially for chloride, sulfate, alkalinity/bicarbonate, and pesticides.

Fish assemblage analyses

Canonical correspondence analysis (CCA) biplot of the relations of representative environmental characteristics to fish assemblages.



Arrows indicate the importance and direction of the influence of environmental characteristics; those characteristics shown were significantly related to one or more of the CCA axes.

Differences in fish assemblages between sites related most to:
- percent of impervious surface in the watershed
- spring herbicide detections
- percentage of pools in the reach
- watershed slope
- maximum instantaneous peak flow (summer; normalized by drainage area)
- dissolved oxygen
- percentage of stream bank vegetative cover in the reach

SUMMARY AND CONCLUSIONS

Effects of Urbanization

PHYSICAL EFFECTS

- Habitat characteristics, reflective of hydrologic changes such as channel enlargement and bank erosion, increased with increasing urbanization.
- Potential changes in channel substrate conditions and geomorphic units were masked by variations in local geology and artificial channel modifications.
- Hydrologic-condition metrics representing stream flashiness, daily stream temperature, and duration of low flow increased with increases in the urban intensity index.

WATER-QUALITY EFFECTS

- Strong positive relations between chloride and PAHs and impervious surfaces, road area and traffic indices, high-density urban land cover, and land cover fragmentation indicate that road infrastructure is a significant source of chloride and PAHs.

BIOLOGICAL EFFECTS

- Our results suggest that even relatively low percentages of impervious surface and increasing streamflow flashiness degrade quality communities of stream biota.
- Differences in algae, invertebrates, and fish among sites were related to environmental characteristics in the watershed and 100-m riparian zone; these groups did not always respond similarly to the same environmental characteristics.
- Algae, invertebrates, and fish showed significant relations to increasing percentages of urban land and associated characteristics of increasing impervious surface, streamflow flashiness, chloride, and decreases in wetland area and woody vegetation.
- Some relations between biota and selected urban-associated characteristics (such as percent impervious surface and streamflow flashiness) were stronger than relations between biota and the urban intensity index.
- Correlations between percent impervious surface in the watershed and riparian zone made it difficult to separate effects of each on biologic integrity; however, significant relations between increasing impervious surface and adverse changes in biotic communities were found for algae, invertebrates, and fish.

ACKNOWLEDGEMENTS:
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FOR MORE INFORMATION:

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http://wi.water.usgs.gov/nawqa/urban/index.htm