Human Stress Gradient of Coastal Zones

All terrestrial and aquatic systems are stressed by human-associated sources at various levels of intensity. The levels of stress can vary depending on such influences as weather, climate, and land use. Geographic information systems have been used to gather data on where and when these stresses occur. However, we still do not have methods for using stressor data to estimate the relative types and influence of human stress and apply those estimates to identify ecological risks in any given area.

Scientists collaborating on the Great Lakes Environmental Indicators (GLEI) project have developed a methodology to estimate the degree of anthropogenic stress for the coastal region of the US Great Lakes coast. The project was funded by EPA's Science to Achieve Results (STAR) program to develop environmental indicators of condition, integrity, and change within this coastal region.

The first phase divided the Great Lakes basin into segments based on the location and size of the streams that enter the lakes. The researchers identified publicly available GIS data layers of stress variables and compiled them for each segment. These data layers fell into broad categories of stress: 1) land use and cover, 2) agriculture and agricultural-chemicals, 3) point and non-point sources, 4) atmospheric deposition, and 5) human population density and development.

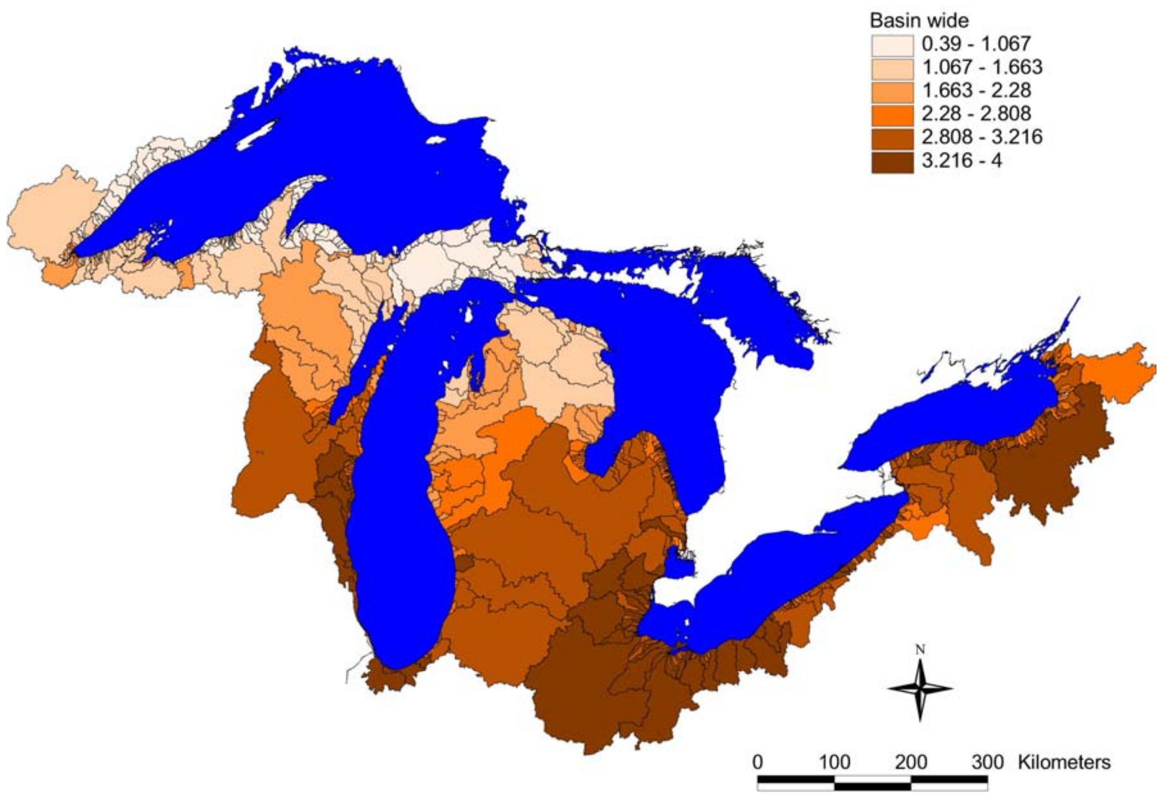
The second phase sampled communities of birds, amphibians, diatoms, fish, macroinvertebrates, and wetland vegetation at sites across the Great Lakes basin. Water quality and contaminant levels were sampled in many of the sites. Multivariate cluster analyses (i.e., statistical analysis of multiple variables at a time) identified segment sheds with similar anthropogenic stress profiles which could be summarized across a gradient of stress.

The stress gradient is illustrated by the shaded map, which represents an index created from the compiled human disturbance datasets: agriculture, atmospheric deposition, land use, human population density, and point source pollution. For each disturbance dataset, principal components analysis (PCA) was used to remove redundancy in the input variables. The first PC from each PCA analysis was then normalized so that each ranged between 0 and 1. These PCs were interpreted to represent overall gradients of stress for each type of disturbance. The overall index of vulnerability was created by summing the scores for the five PCs for each watershed within the Great Lakes basin, giving the index a range from 0-5. Generally, areas in the southern Great Lakes have higher amounts of stressors than do areas in the northern Great Lakes, following trends in amounts of agriculture and human population density.

Due to the large number of variables representing various disturbances and the clear interpretations of the first principal components, we believe the disturbance gradients summarize the major threats to coastal ecosystems in the U.S. Great Lakes.

Environmental responses such as water quality, fish community metrics, and bird abundances summarized by GLEI researchers have been shown to be strongly correlated with the disturbance gradients.

Being able to quantify the degree of human stress is important for identifying the degree of ecological risk found within specific regions of land or water. These gradient analyses are useful to environmental managers for prioritizing problems for relatively small areas and placing these areas into a larger regional or national context. The analyses also hold promise for EPA's Region V, Great Lakes National Program, and other regional water programs to establish a design framework for monitoring biological resources and diagnosing causes of anthropogenic impairment across the Great Lakes coastal zone.



Caption: Index of vulnerability for coastal watersheds in the US Great Lakes basin. Darker shading indicates greater vulnerability.

Agriculture

Agriculture is a primary stress to coastal ecosystems in terms of increasing nutrients (which results in eutrophication and concomitant changes in food web structure), chemical contaminants from pesticides, and sedimentation resulting from erosion. We used 21 variables representative of these types of agricultural activities from the USGS and USDA. Variables related to agricultural land cover were included in the land cover category described below.

Table 1. The five variables with the highest Pearson correlations (r) with agriculture PC1.

Variable	*r*
Nitrogen fertilizer export into streams	0.95
Phosphorus fertilizer applications	0.95
Agricultural herbicide applications	0.95
Potash applications	0.95
Total nitrogen fertilizer applications	0.94

There was a high degree of redundancy among the 21 input variables. The first principal component explained 73% of the variance and over half of the variables had loadings > 0.85. Among the variables with high loadings were those representing nutrients, erosion, and pesticides, indicating that Ag PC1 can be interpreted as an overall gradient in agriculture (Table 1).

The most heavily agricultural regions in the basin received high scores on agriculture PC1 (Figure 1), with the western Lake Erie and Saginaw Bay, MI (Lake Huron) regions having extremely high values. The north shore of Lake Superior (MN) and the Upper Peninsula of Michigan, which are largely forested regions today, received the lowest scores along PC1.

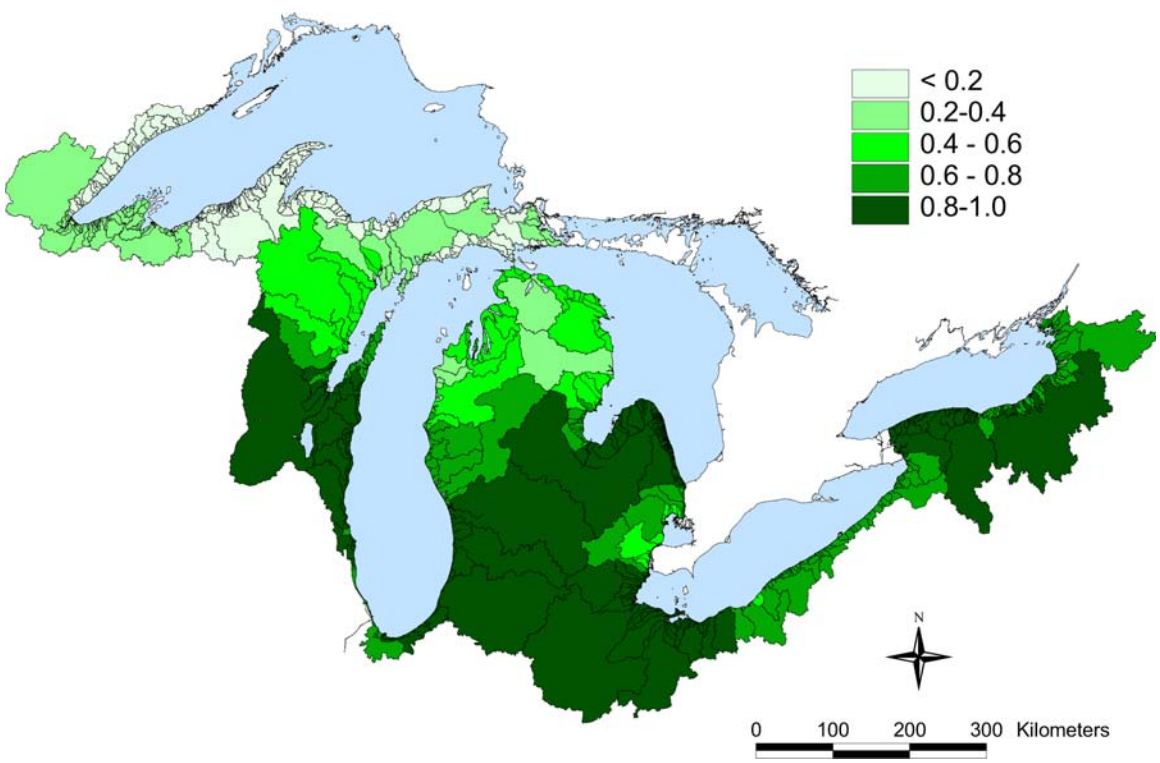


Figure 1. The first principal component of the agriculture variables for the US Great Lakes basin. Darker shading indicates greater amounts of agricultural activity.

Atmospheric Deposition

Atmospheric deposition has been an important stress to the upper Midwestern United States, primarily by acidification of surface waters and lakes and deposition of mercury. We used 11 variables summarizing precipitation chemistry from the National Atmospheric Deposition Program. Sulfate, nitrate, ammonium, chloride, base cations, and pH are among the chemicals reported on.

The first principal component explained 75% of the variance in the atmospheric deposition variables. All eleven variables had positive loadings > 0.55 on Atm. Dep. PC1, indicating that this component represented an overall gradient in deposition.

Table 2. The five variables with the highest Pearson correlations (r) with the atmospheric deposition PC1.

Variable	*r*
Inorganic Nitrogen (N)	0.97
Chloride (Cl)	0.96
Nitrate (NO_3)	0.95
Sulfate (SO_4)	0.95
Sodium (Na)	0.95

Figure 2 displays the strong east/west gradient in atmospheric deposition across the basin, likely due in part to the prevailing wind direction and to greater industrial activities in the lower lakes, particularly around Lake Erie, southern Lake Michigan, and eastern Lake Ontario.

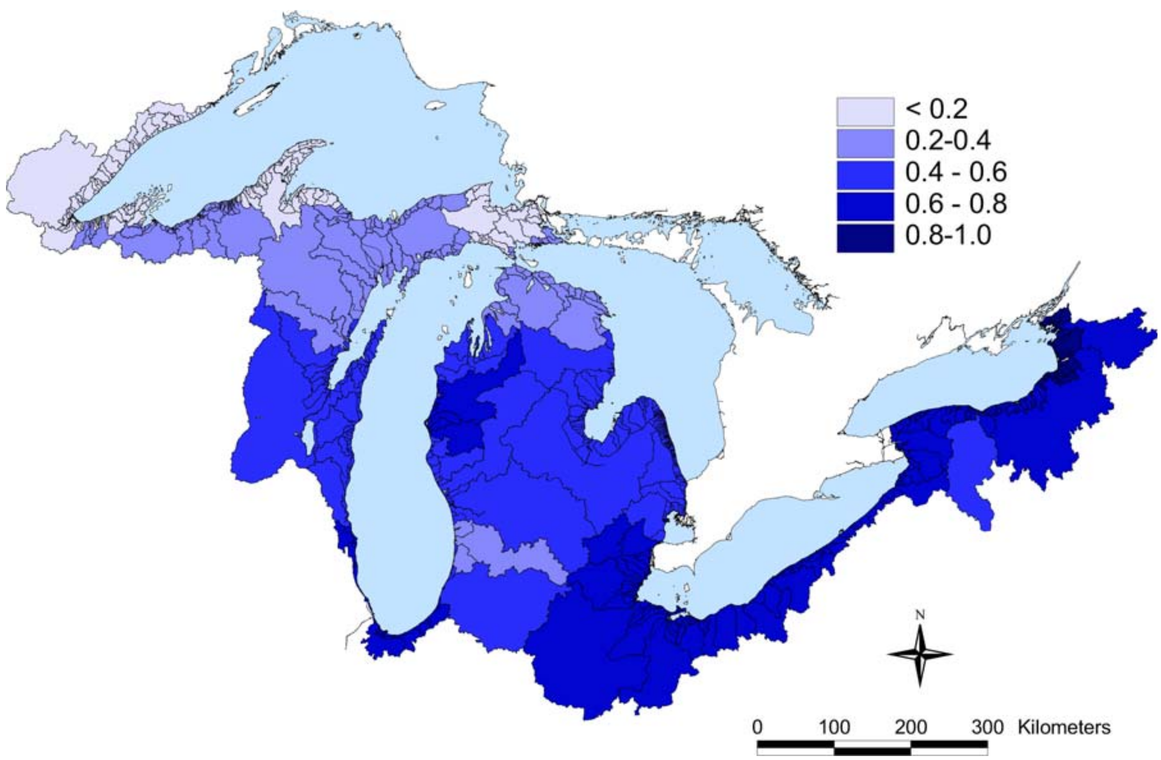


Figure 2. The first principal component of the atmospheric deposition variables for the US Great Lakes basin. Darker shading indicates greater amounts of deposition.

Land Cover

Forest lands throughout the Great Lakes basin were generally cleared of timber in the 19th-20th centuries, and while some watersheds have been allowed to return to forest, other watersheds have been permanently converted to agricultural lands or human settlements. The land cover category represents the degree to which humans have permanently modified the land since presettlement. We included 23 land cover and land use variables primarily from the National Land Cover Dataset (NLCD). Variables represented the proportion of segment-sheds in a particular cover class.

The first principal component explained 23% of the variance in the input variables. Croplands received the highest negative scores on Land Cover PC1, while forested lands received the highest positive scores; thus this PC1 represents a gradient from agricultural to forested lands.

Table 3. The five variables with the highest Pearson correlations (r) with the land cover PC1.

Variable	*r*
Cultivated cropland	-0.86
Row crops	-0.76
Coniferous forest	0.73
Hay	-0.72
Mixed forest	0.64

Agricultural lands are most common in the southern lakes, in particular in near the western coast of Lake Michigan, the western Lake Erie region, western Lake Ontario, and the Saginaw Bay, MI region (Lake Huron). Forested lands are abundant around Lake Superior and northern Lake Michigan.

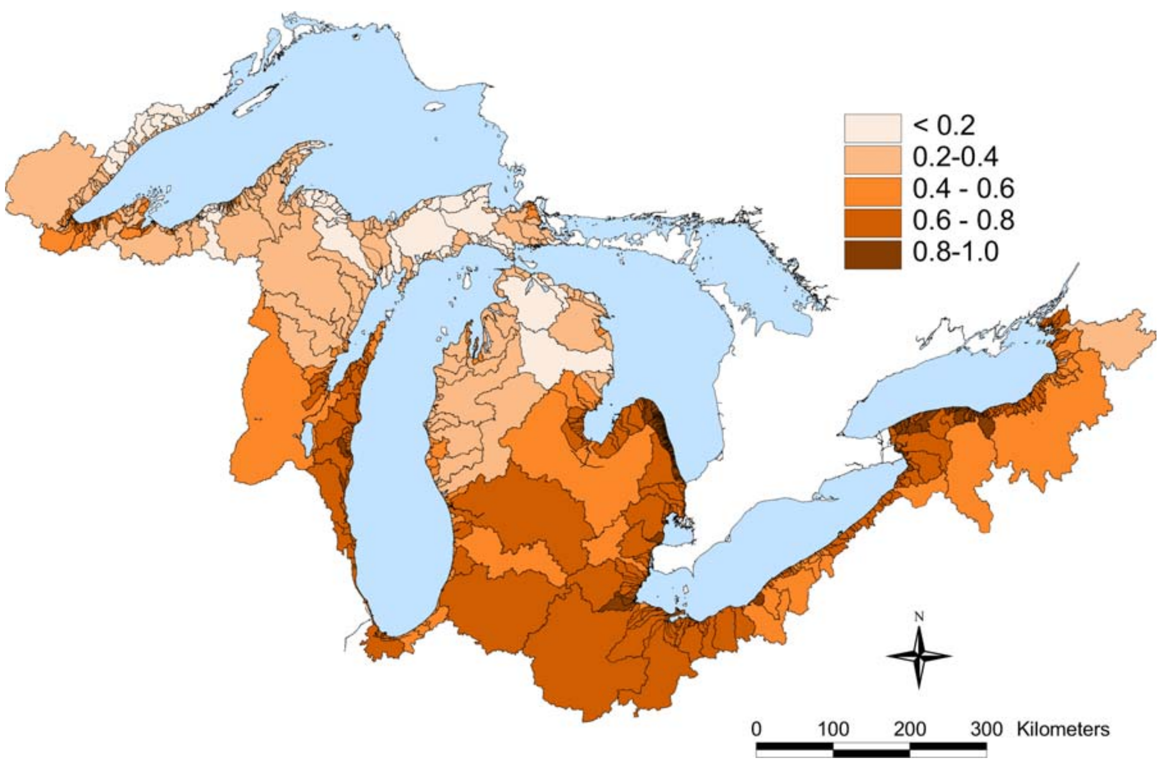


Figure 3. The first principal component of the land cover variables for the US Great Lakes basin. Lighter shading indicates forested lands, darker shading indicates agricultural lands.

Population Density

We focus this category of human disturbance on the effects of human populations in coastal watersheds. Because human populations are often concentrated in coastal regions for economic and recreational resources, the direct effects of population density can be dramatic, including altering runoff patterns, decreasing the amount of habitat, and the introduction of exotic species. We used fourteen variables related to human population density, road density, and wetlands lost to development.

The Population Density PC1 explained 33% of the variance in the input variables, with variables related to roads and population density being prominent. Wetland loss variables were related to second and subsequent PCs. In general, population centers including Green Bay, Milwaukee, Chicago, Detroit, Toledo, Cleveland, Buffalo, and Rochester received high scores on this PC1, while most of the Lake Superior coastline and the northern lower peninsula of Michigan received lower scores. This gradient is sensitive enough to portray differences on a fine scale as well. For example, the largest urban centers within the least populated lake were clearly identified: Duluth, MN; Ashland, WI, and Marquette, MI had the highest scores on this gradient in Lake Superior.

Table 4. The five variables with the highest Pearson correlations (r) with human population density PC1.

Variable	*r*
Human population density	0.90
Total road density	0.85
Developed land	0.81
Local road density	0.74
Highway density	0.64

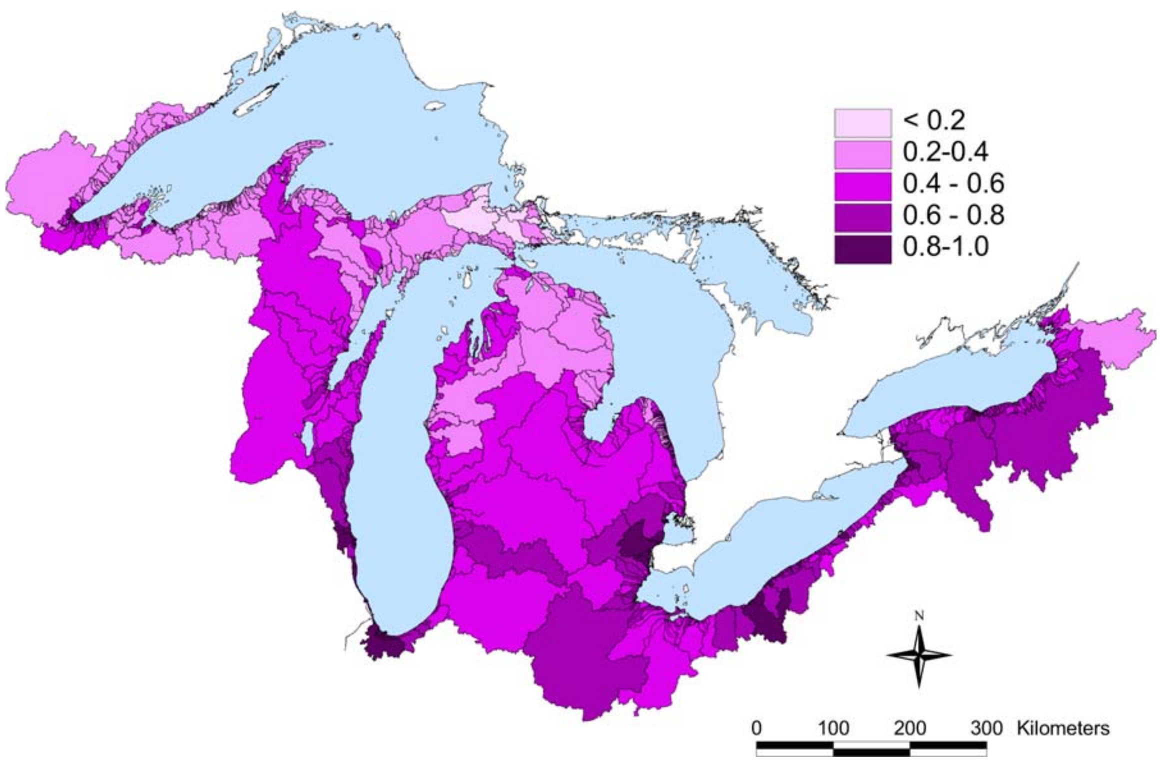


Figure 4. The first principal component of the human population variables for the US Great Lakes basin. Darker shading indicates greater human population density.

For more information about the GLEI project, visit our website (http://glei.nrri.umn.edu) or contact Dr. Gerald Niemi (gniemi@nrri.umn.edu).

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