A spatiotemporal study on urban development in New England watersheds

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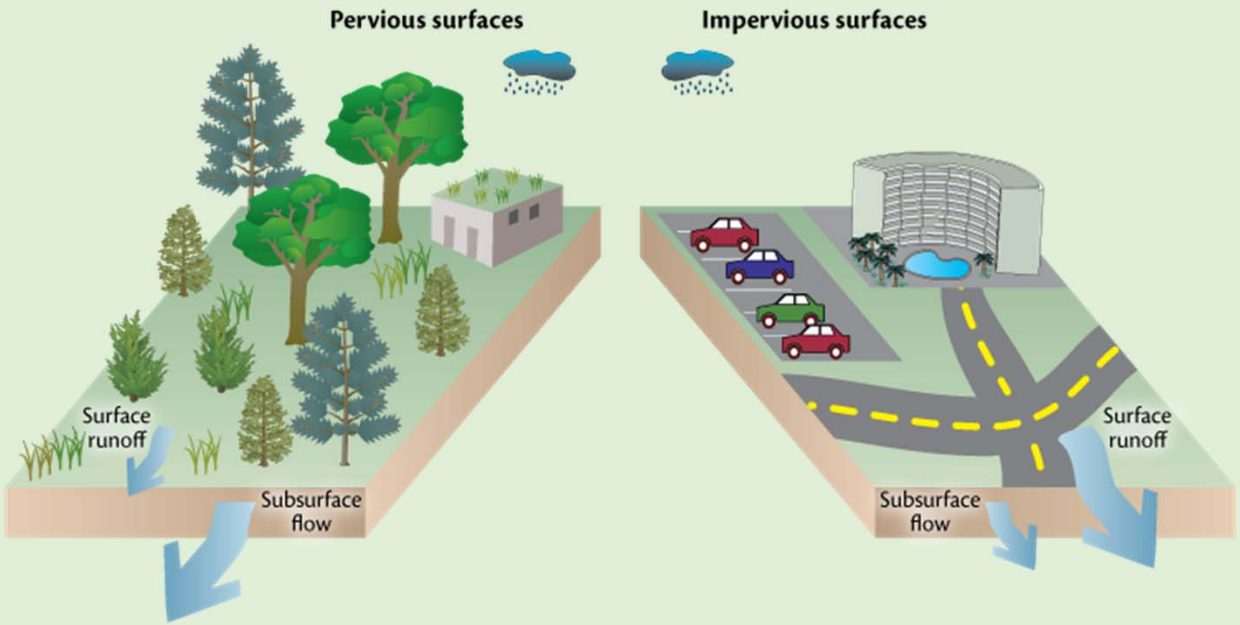
Applied GeoSolutions

Impact on water

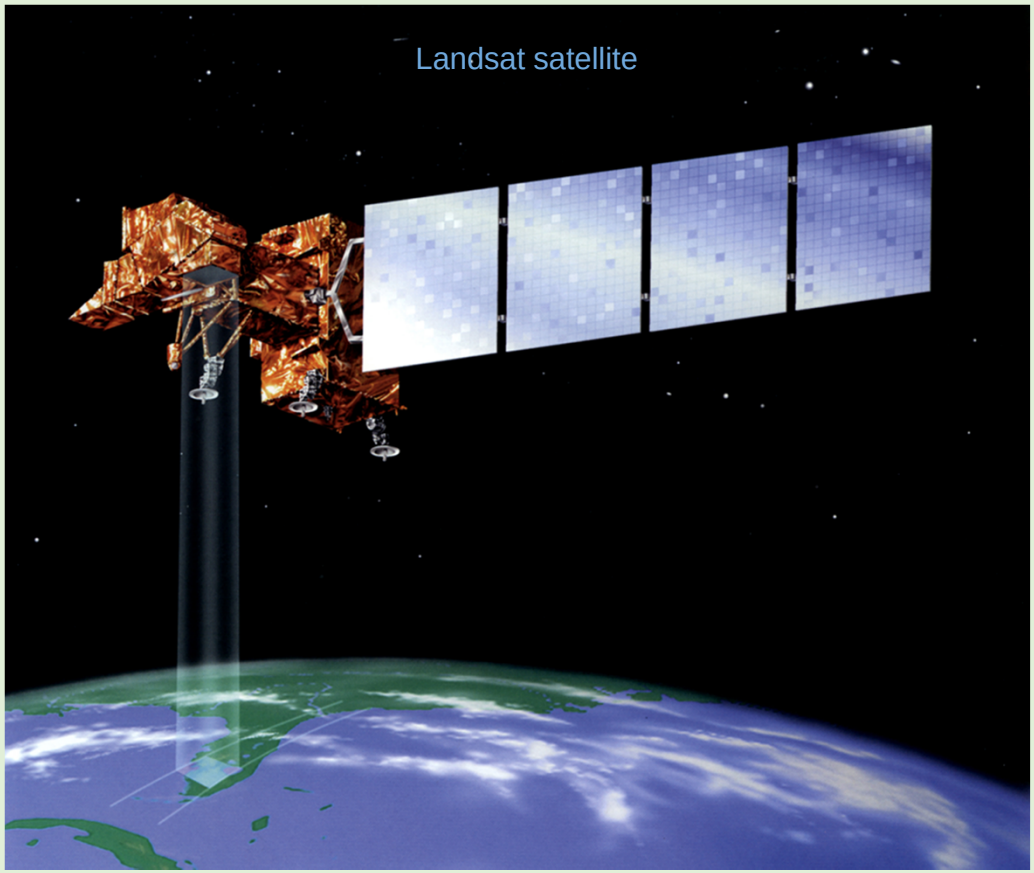
- Impervious Surfaces (IS) impact water quality, volume, and flow rates



http://www.mdcoastalbays.org/bayissues-stormwater-management

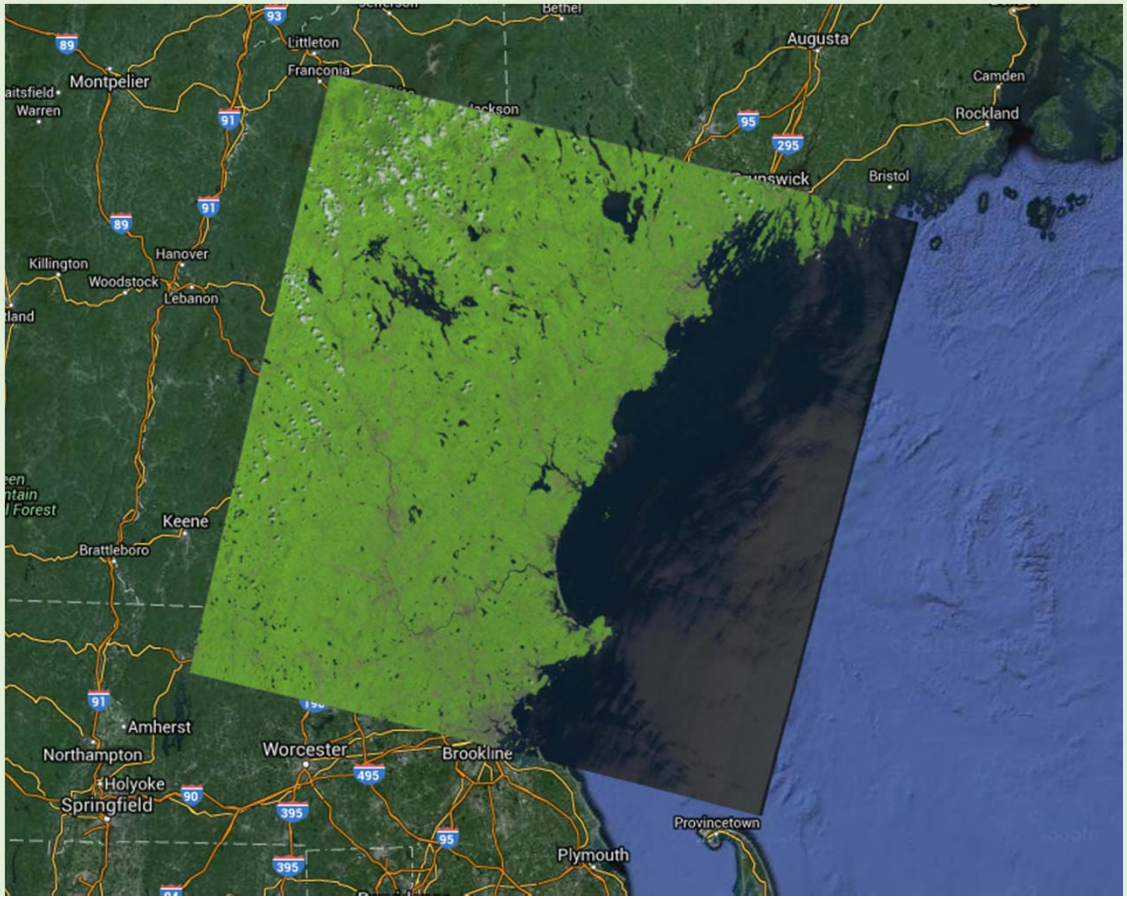
Benefits of Remote Sensing

- Covers a large area
- Can look back in time
- Temporal frequency/consistency
- Cost-effective over large area



Datasets Used

- Landsat
  - Moderate spatial-resolution
  - Managed by NASA and USGS
- National Land Cover Database (NLCD)
  - Decision-tree classification of Landsat data
  - Limited in temporal coverage



NLCD 2011

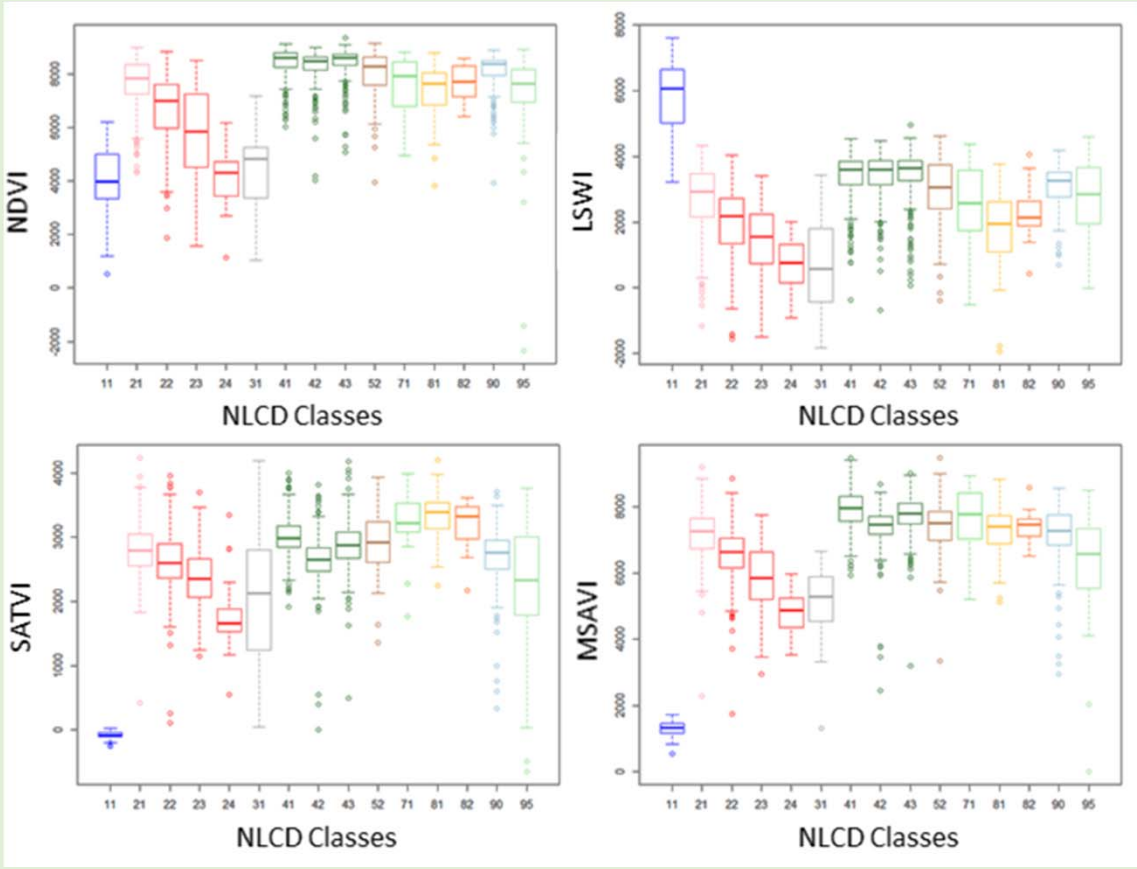
Class\ Value	Classification Description
Water	
11	**Open Water** - areas of open water, generally with less than 25% cover of vegetation or soil.
12	**Perennial Ice/Snow** - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	
21	**Developed, Open Space** - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	**Developed, Low Intensity** - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	**Developed, Medium Intensity** – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	**Developed High Intensity** -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	
31	**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	
41	**Deciduous Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	**Evergreen Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	**Mixed Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	
51	**Dwarf Scrub** - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	**Shrub/Scrub** - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous	
71	**Grassland/Herbaceous** - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
72	**Sedge/Herbaceous** - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
73	**Lichens** - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
74	**Moss** - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	
81	**Pasture/Hay** – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	**Cultivated Crops** – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	
90	**Woody Wetlands** - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	**Emergent Herbaceous Wetlands** - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

How to map from 1975-present

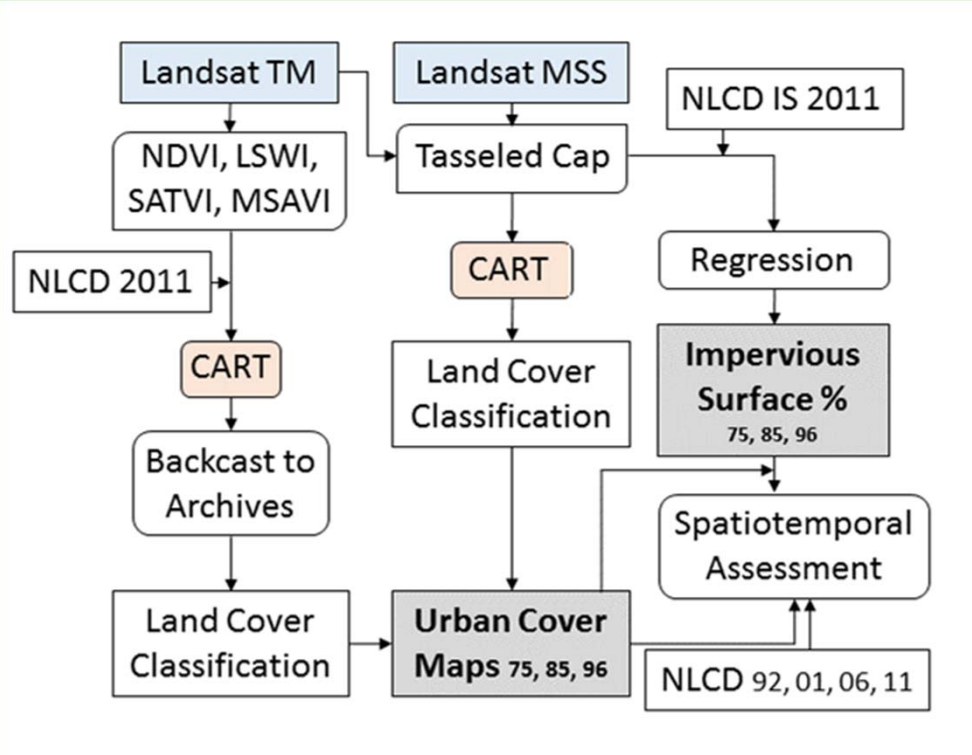
- NLCD products (urban and impervious) + Landsat archives
  - Create our own land-cover maps using Landsat
- Targeted years: 1975, 1985, **1992**, 1996, **2001**, **2006**, **2011**
- 81 Landsat scenes used to fill in the NLCD gaps
- 2011 NLCD landcover/IS classified Landsat indices (NDVI, SATVI, LSWI, MSAVI, Tassled Cap)

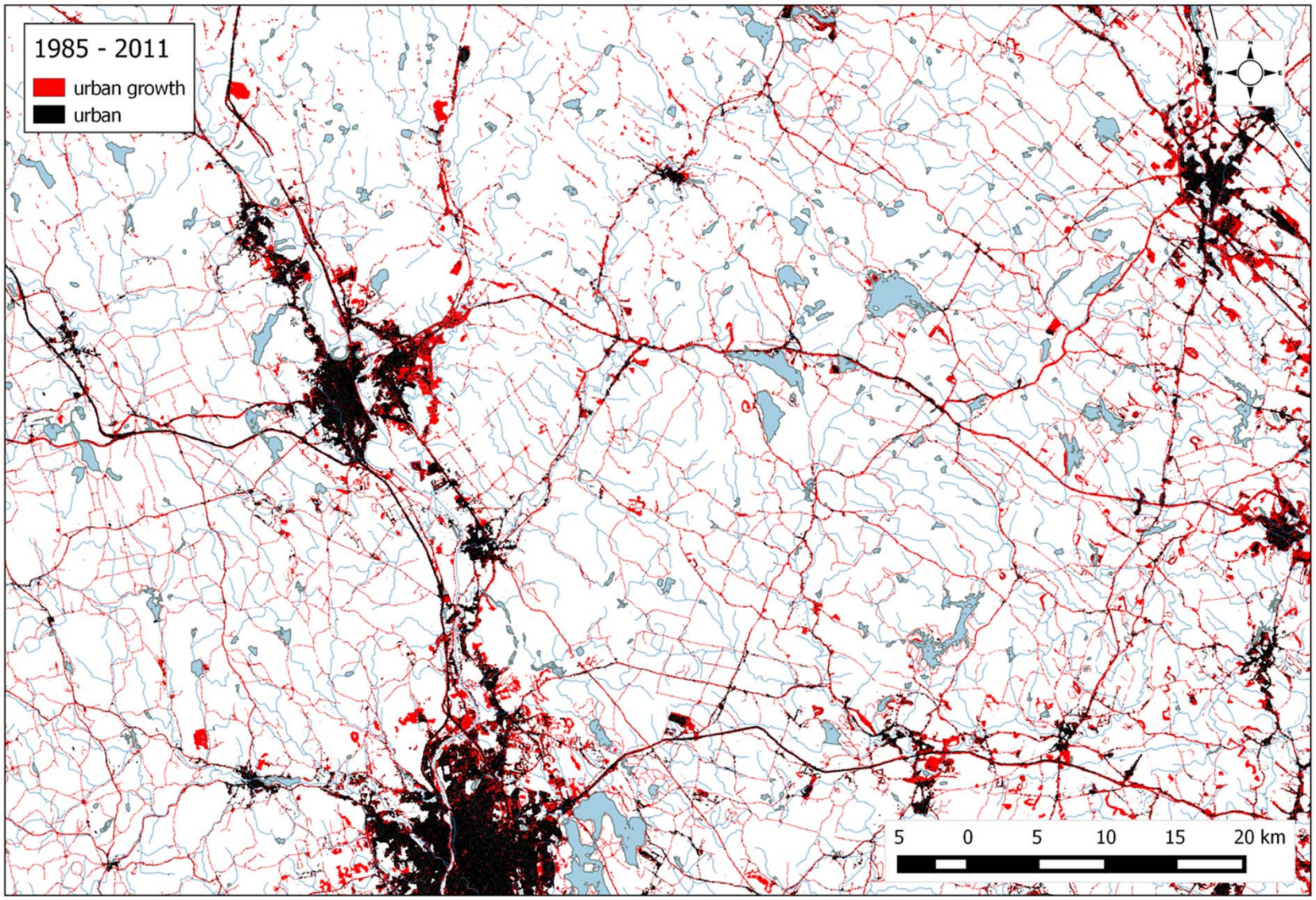
Looking at indices for classifying land

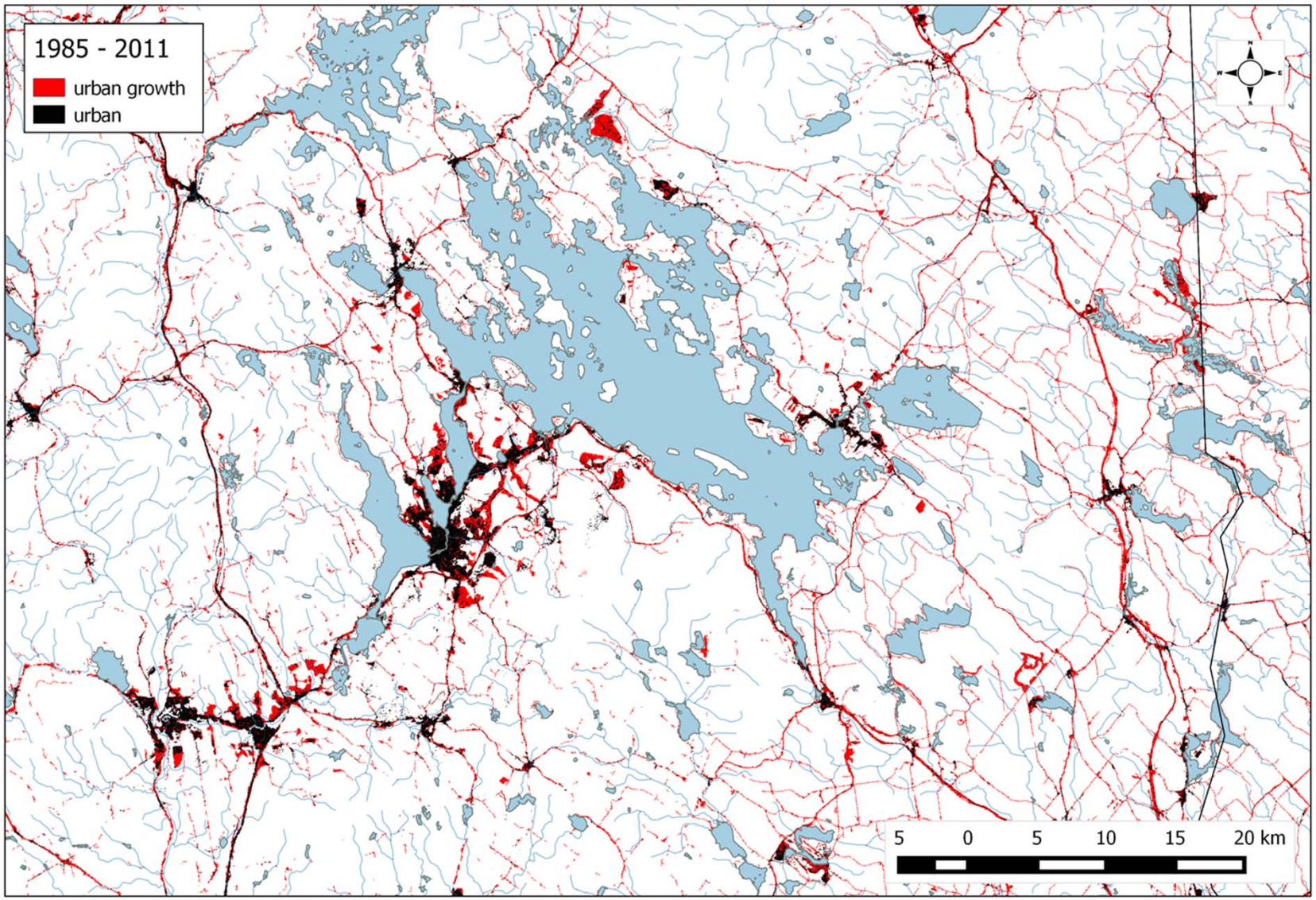
- Boxplots show the ability of each product to separate out land cover classes
- Landcover classification maps were reduced into urban vs non-urban classes.



Work Flow


Landsat TM
Landsat MSS
NLCD IS 2011
NDVI, LSWI, SATVI, MSAVI
Tasseled Cap
NLCD 2011
CART
Regression
CART
Land Cover Classification
Impervious Surface %
75, 85, 96
Backcast to Archives
Spatiotemporal Assessment
Land Cover Classification
Urban Cover Maps 75, 85, 96
NLCD 92, 01, 06, 11

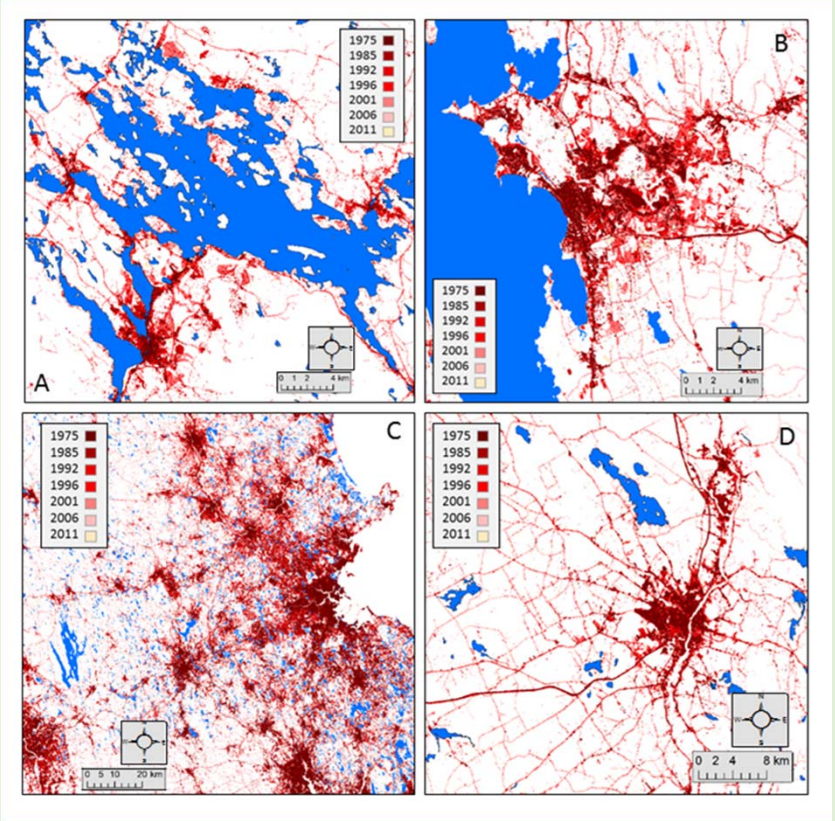

1985 - 2011
urban growth
urban
5 0 5 10 15 20 km

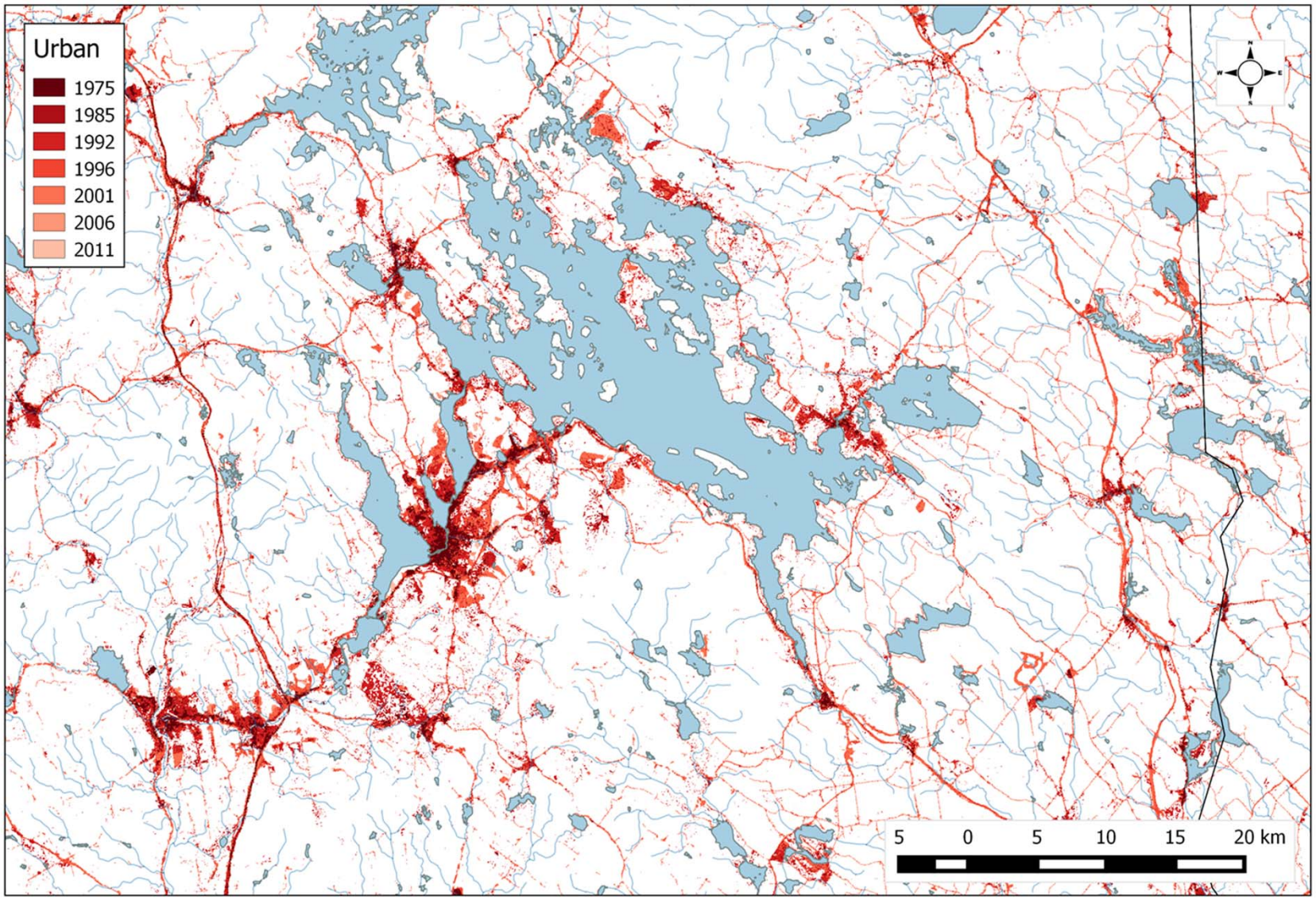

1985 - 2011
urban growth
urban
5 0 5 10 15 20 km

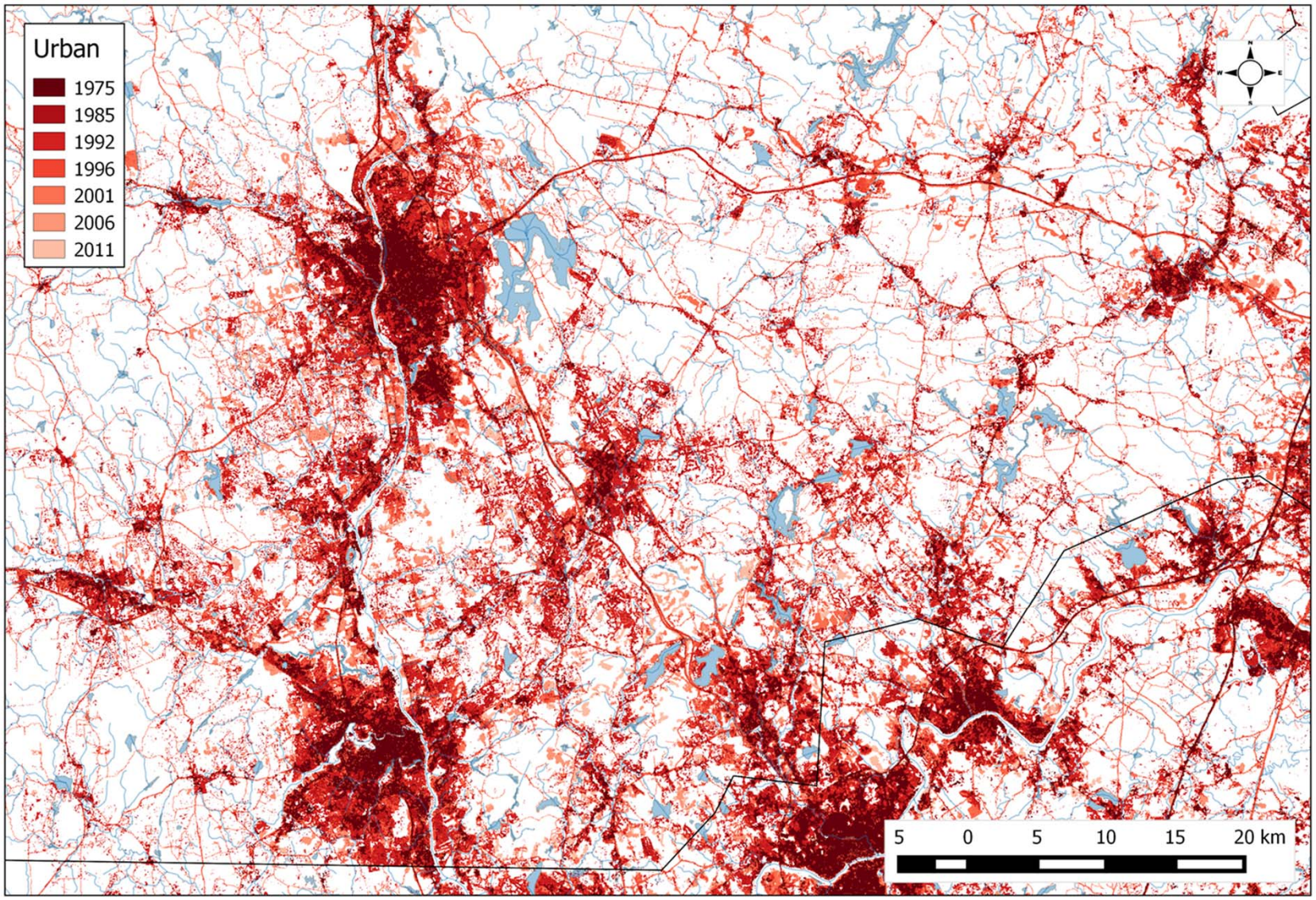
Urban Sprawl

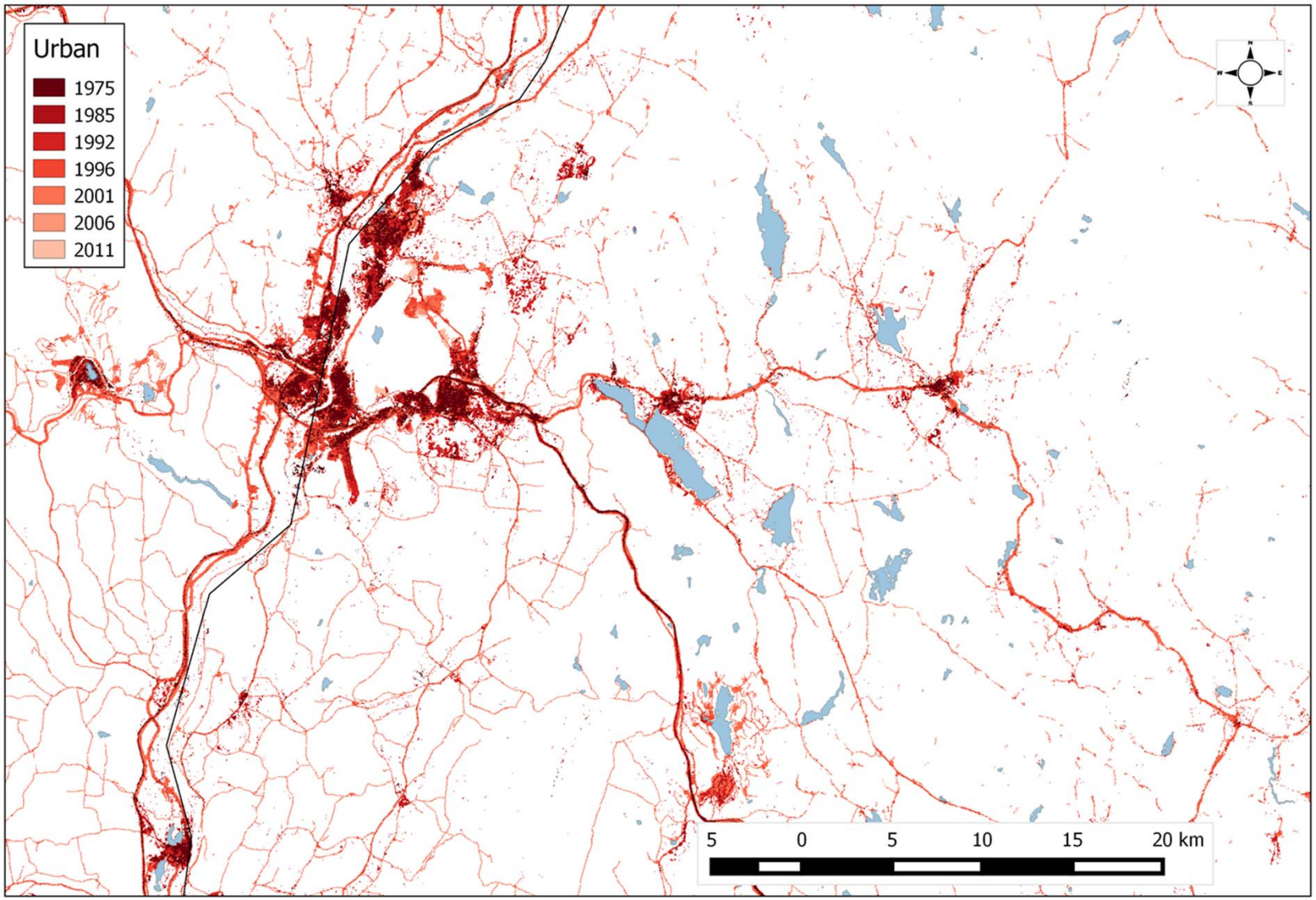
- Example areas of urban sprawl using the time series classification maps stacked chronologically to highlight patterns of sprawl.
- Results show growth corresponding to major travel routes, urbanized centers, and adjacent to waterbodies.

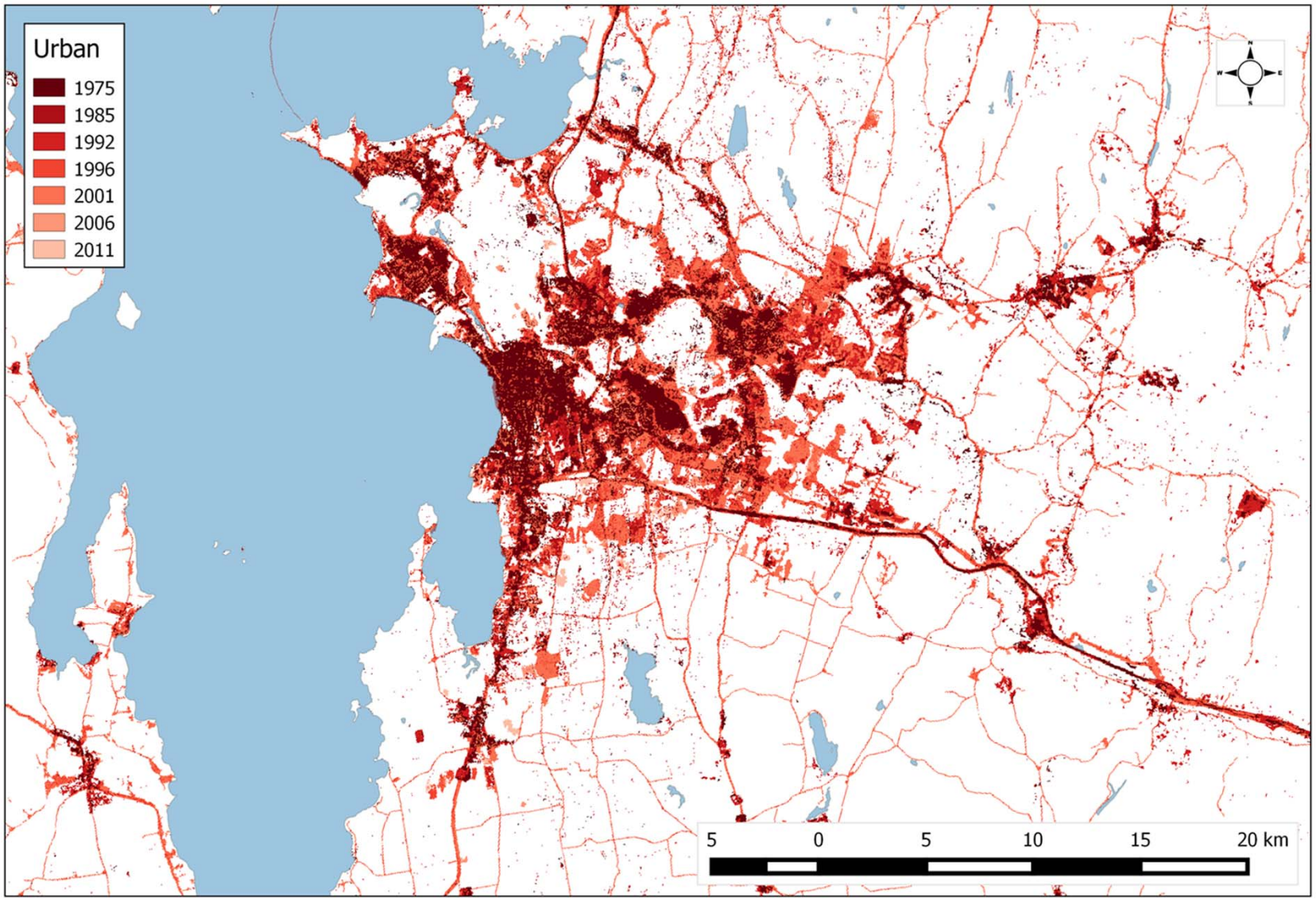
A.) Lake Winnipesaukee, NH
B.) Burlington, VT
C.) greater Boston, MA region
D.) Bangor, ME




Urban
1975
1985
1992
1996
2001
2006
2011
5 0 5 10 15 20 km

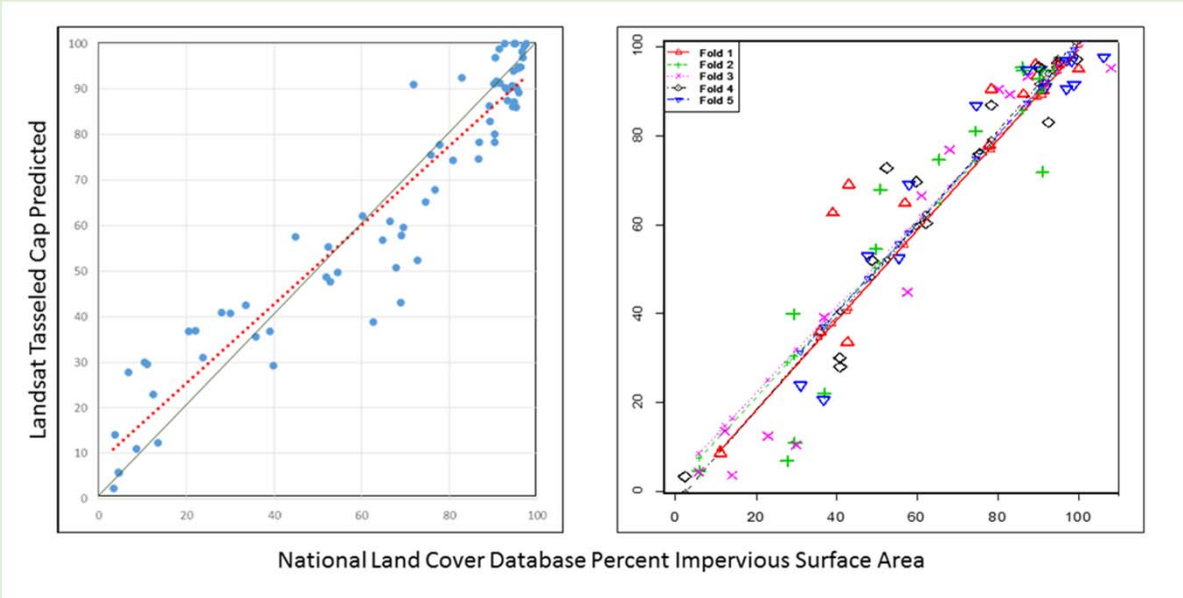

Urban
1975
1985
1992
1996
2001
2006
2011
5 0 5 10 15 20 km


Urban
1975
1985
1992
1996
2001
2006
2011
5 0 5 10 15 20 km

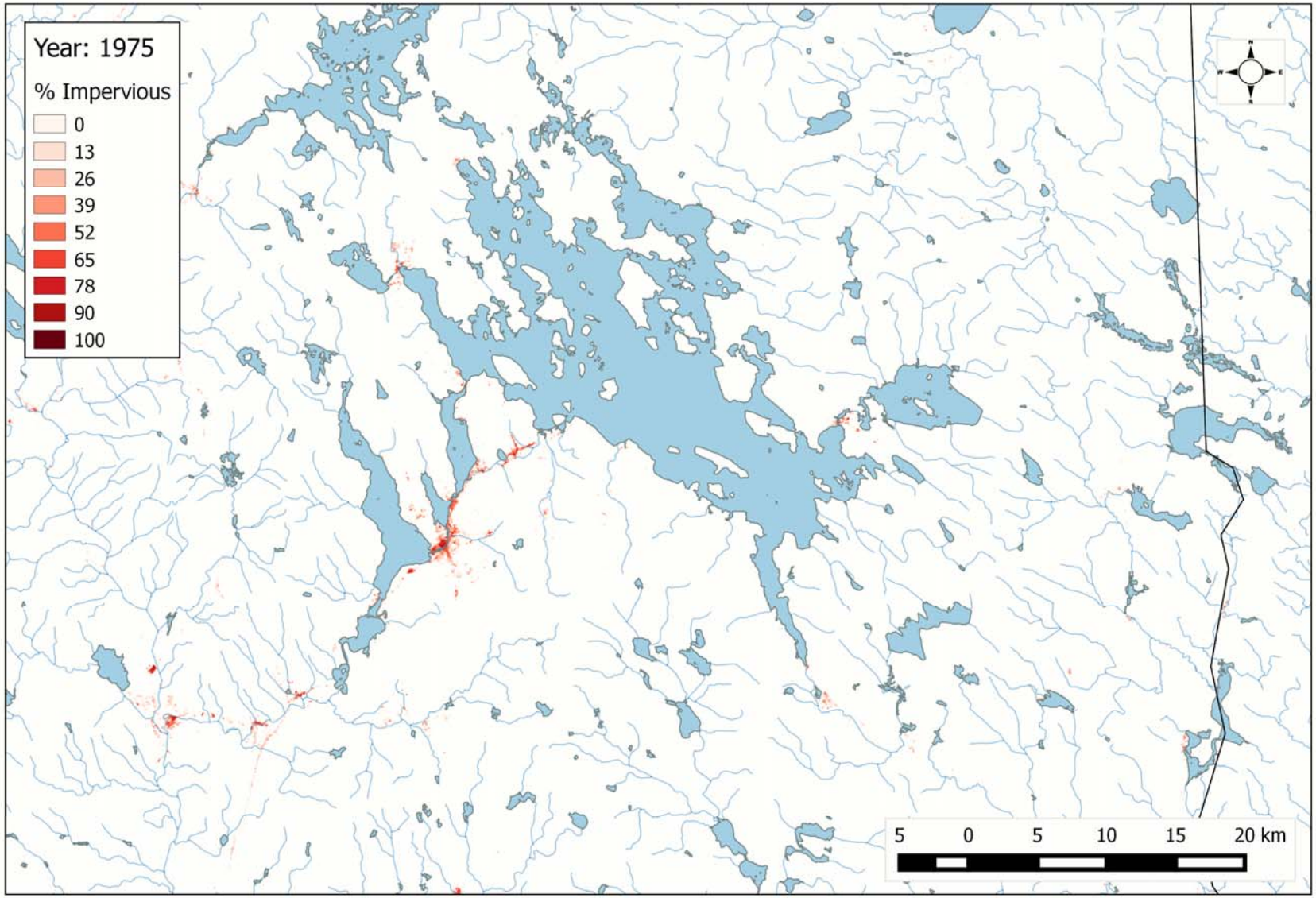

Urban
1975
1985
1992
1996
2001
2006
2011
5 0 5 10 15 20 km

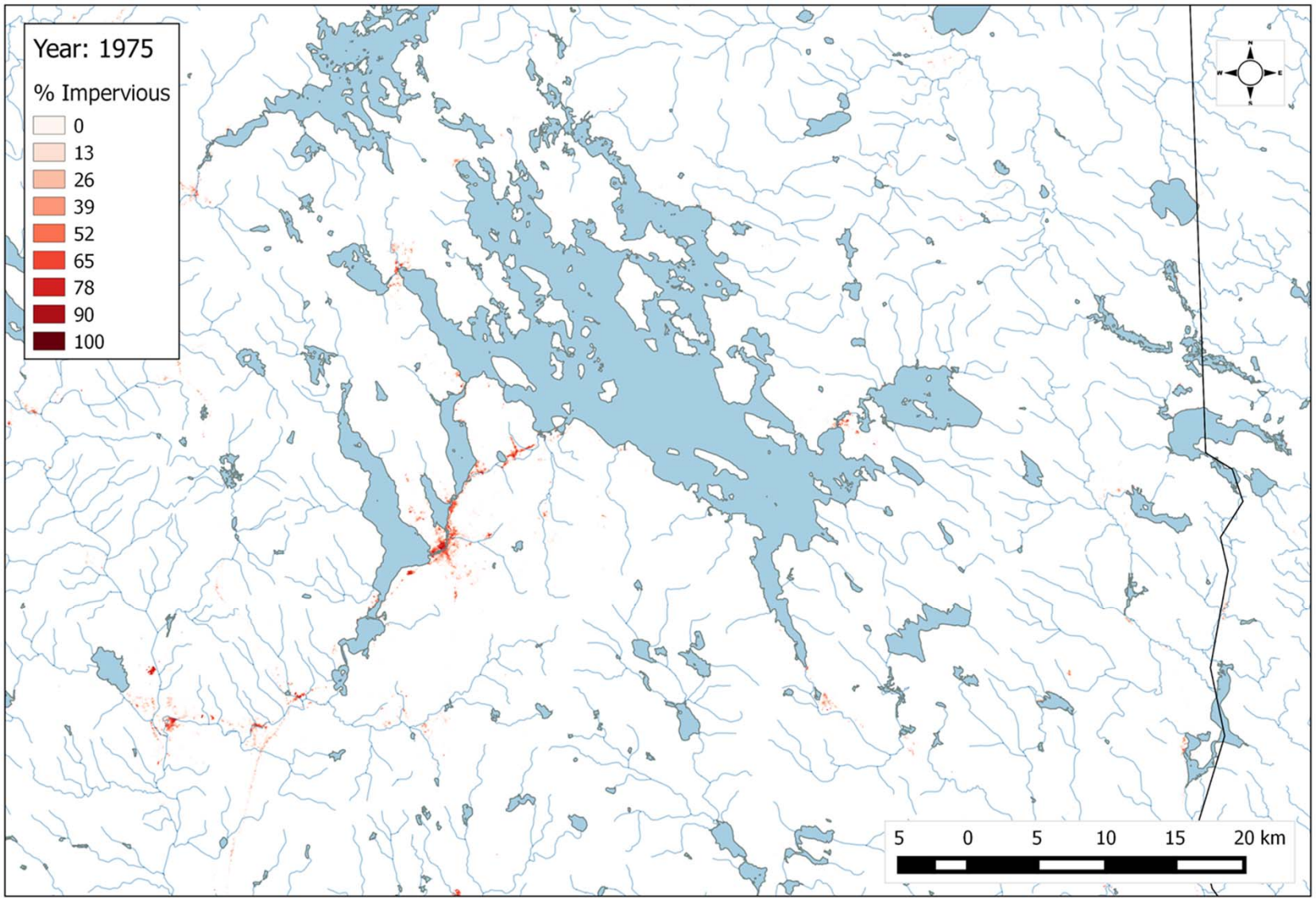
Impervious Surfaces

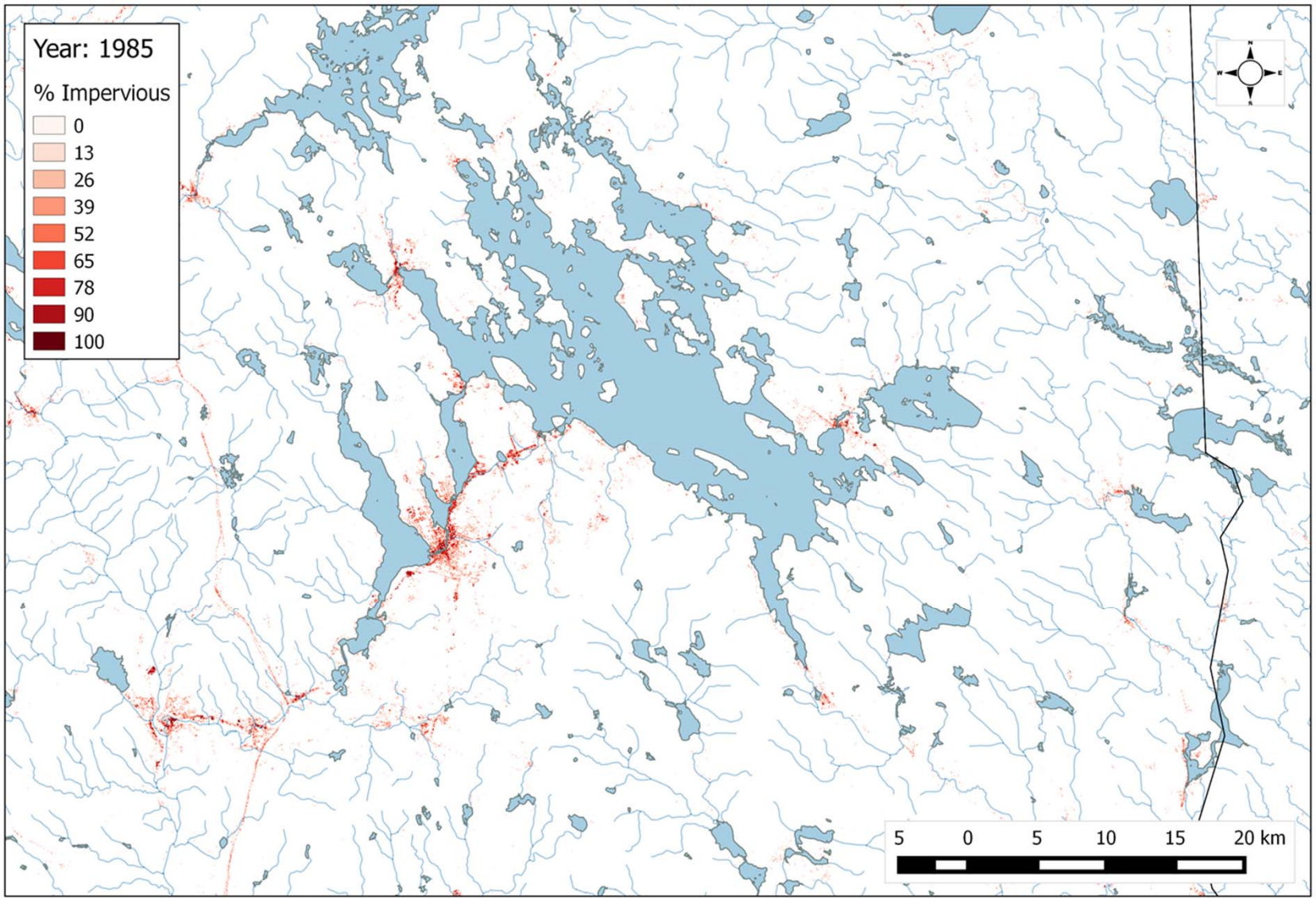
Illustration of Landsat modelled Impervious Surface compared to NLCD

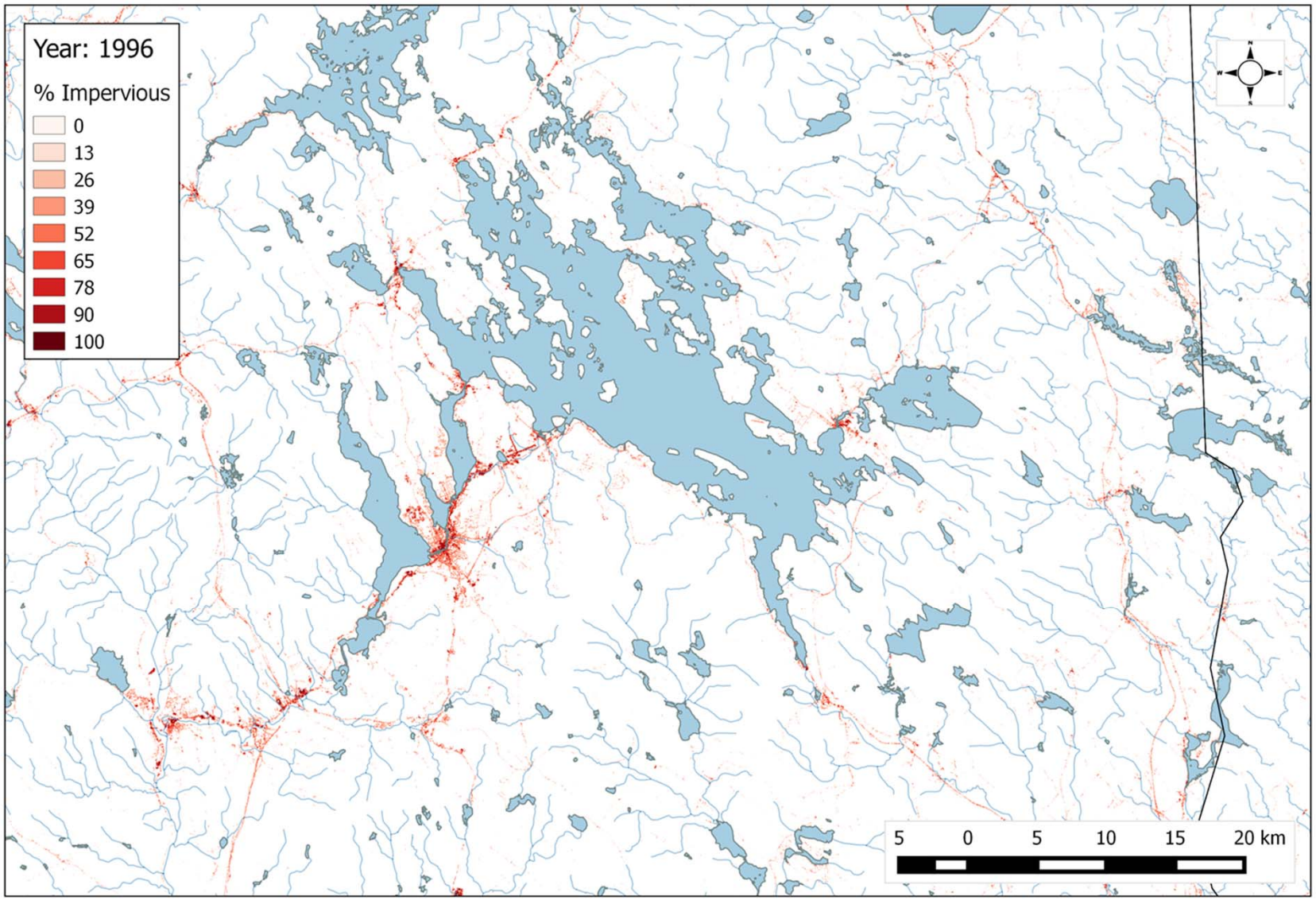


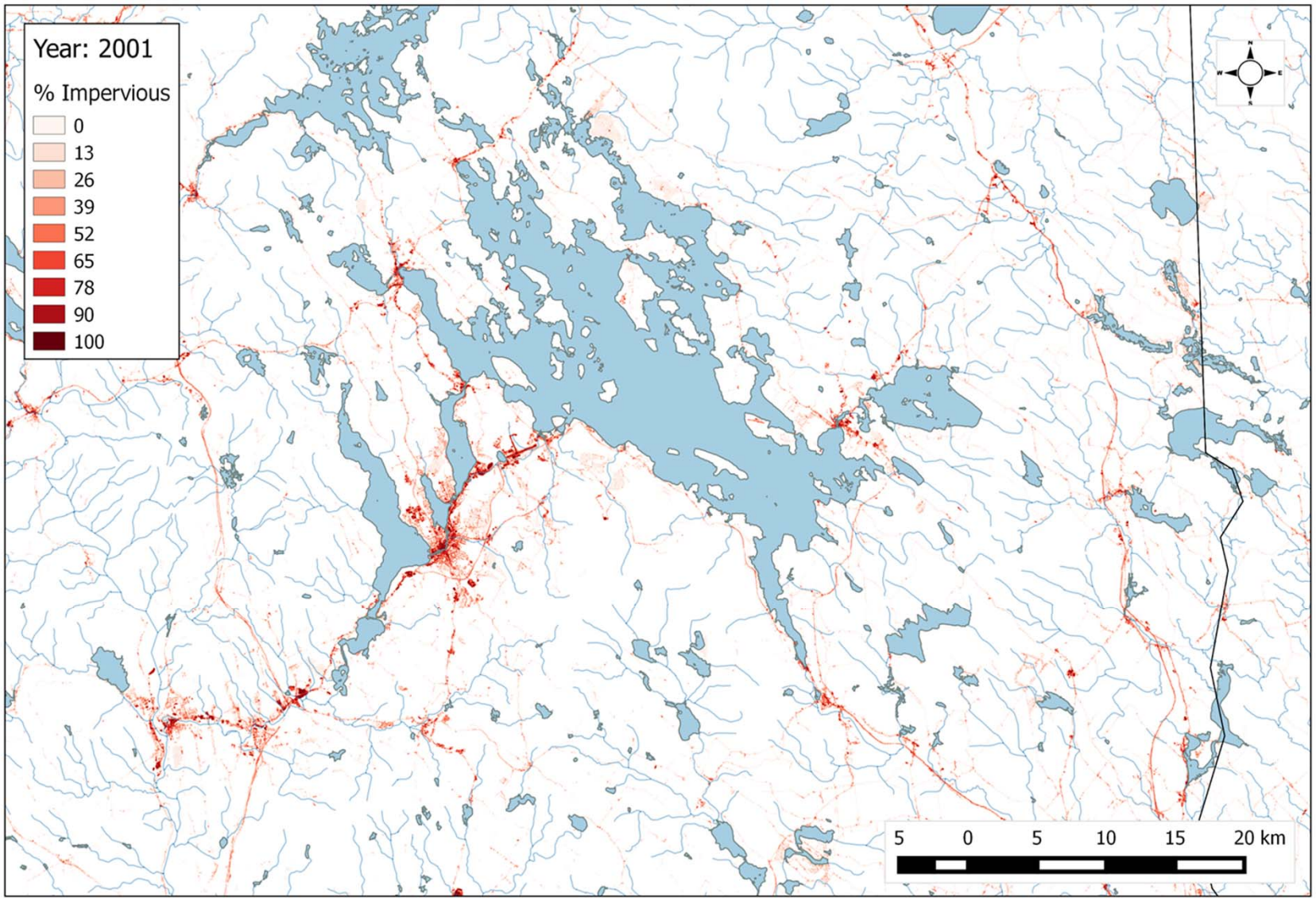
Scatterplot (left) shows the modeled percent IS against the NLCD IS area (red dotted line represents linear fit and green line shows 1:1) with strong agreement (R^2: 0.89) and n-folds validation plot (right) shows relatively robust ability (RSE: 10.92) to map urban percent IS using the Landsat Tasseled Cap OLS regression approach.

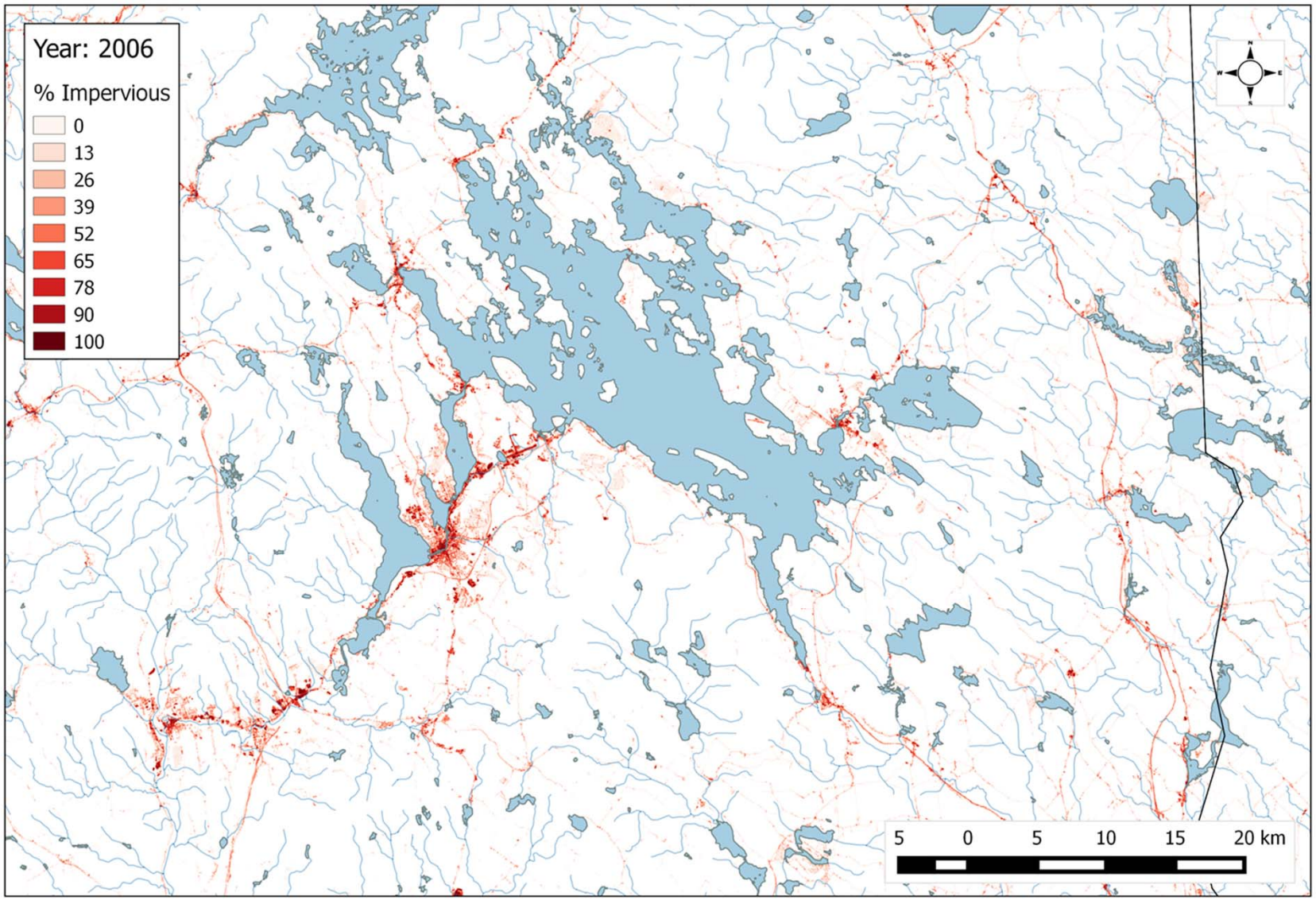

Year: 1975
% Impervious
0
13
26
39
52
65
78
90
100
5 0 5 10 15 20 km

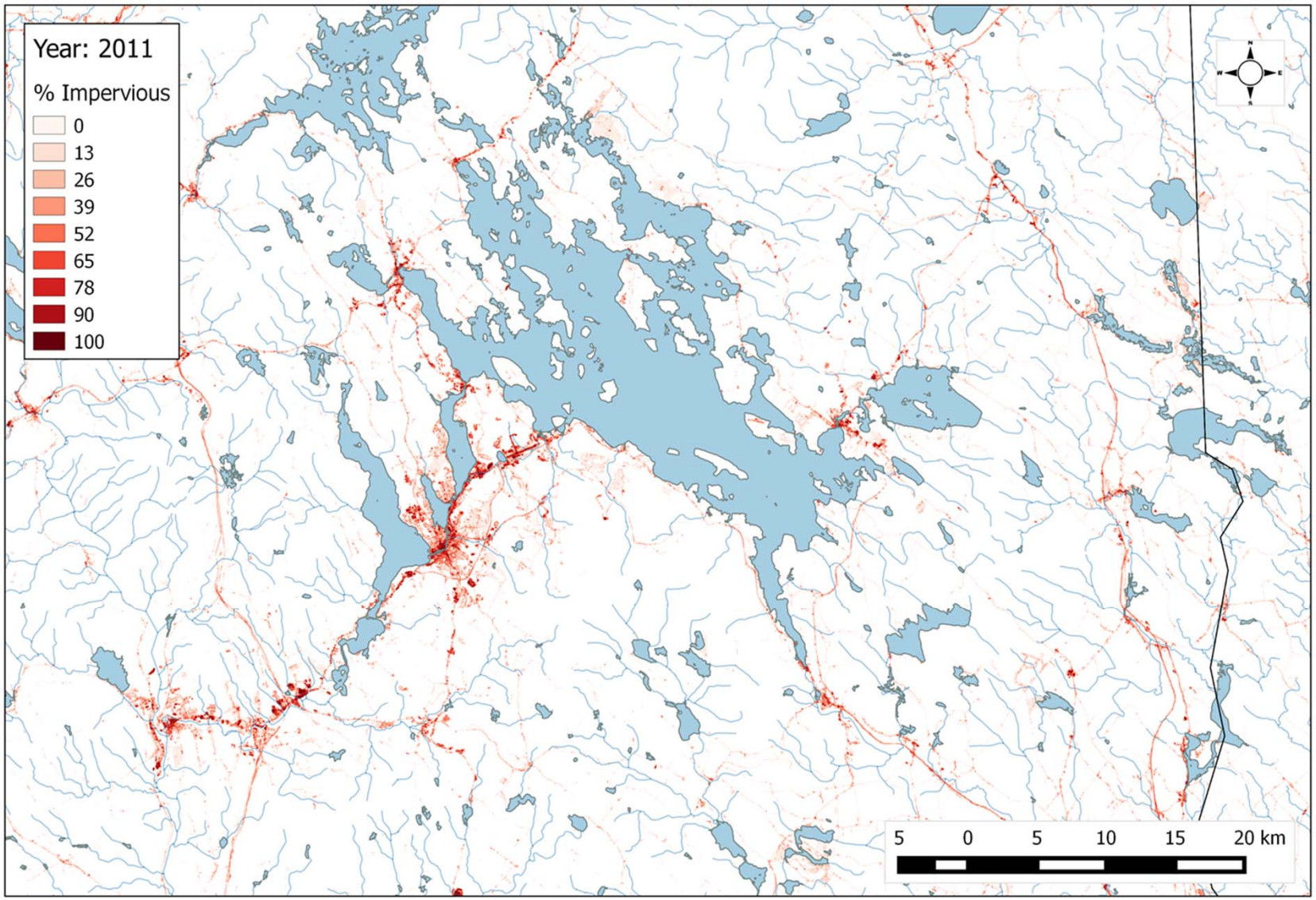

Year: 1975
% Impervious
0
13
26
39
52
65
78
90
100
5 0 5 10 15 20 km


Year: 1985
% Impervious
0
13
26
39
52
65
78
90
100
5 0 5 10 15 20 km

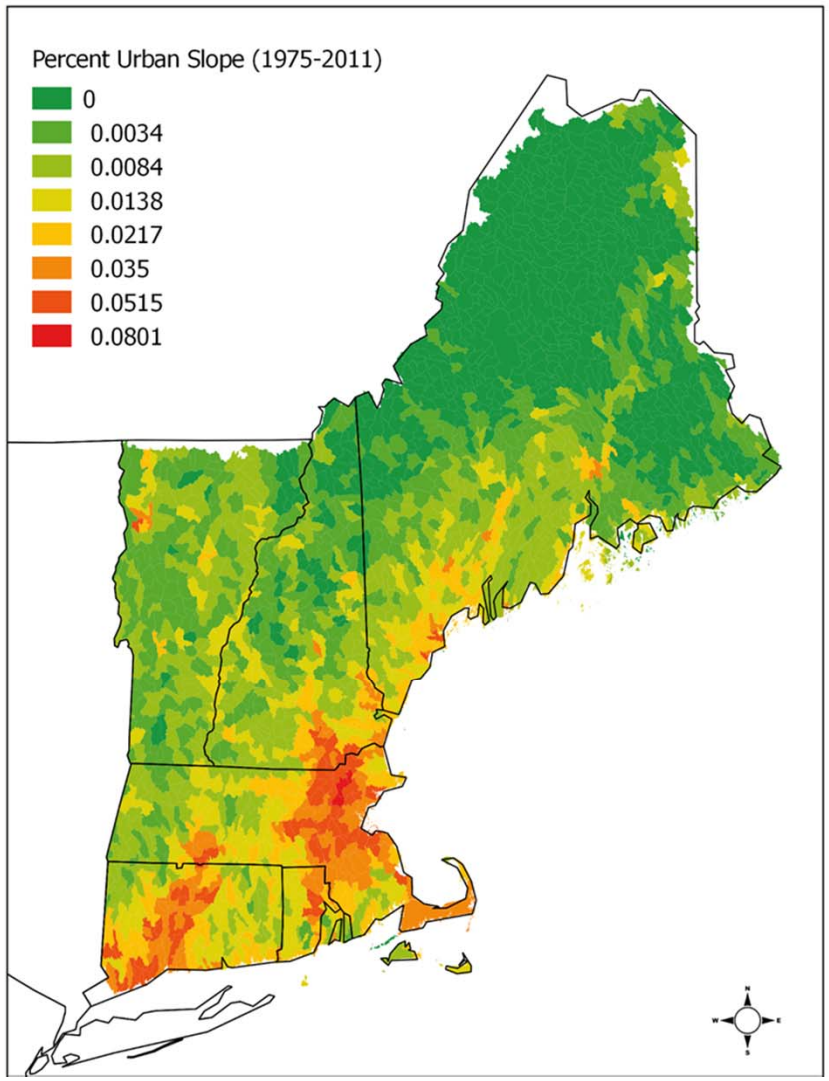

Year: 1996
% Impervious
0
13
26
39
52
65
78
90
100
5 0 5 10 15 20 km

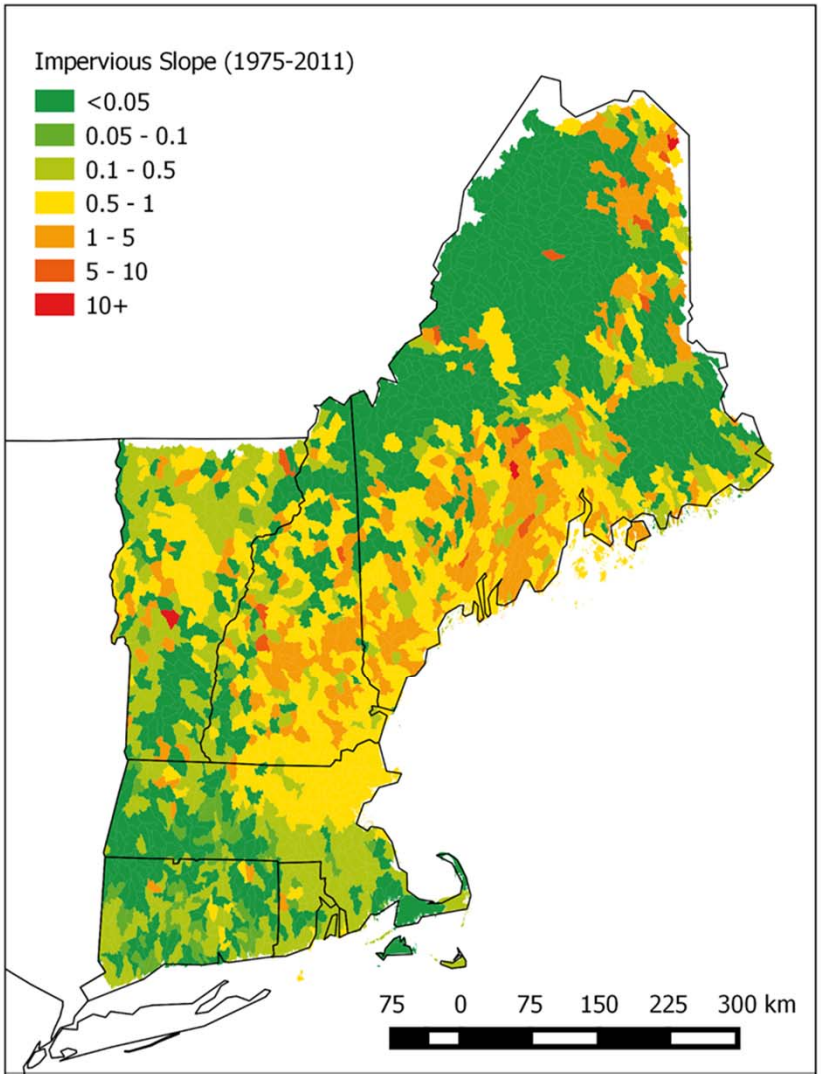

Year: 2001
% Impervious
0
13
26
39
52
65
78
90
100
5 0 5 10 15 20 km


Year: 2006
% Impervious
0
13
26
39
52
65
78
90
100
5 0 5 10 15 20 km


Year: 2011
% Impervious
0
13
26
39
52
65
78
90
100
5 0 5 10 15 20 km

Trend assessment at HUC 12 watershed scale from 1975-2011 of urban extent changes and impervious surface change (masked with urban area from 1975)





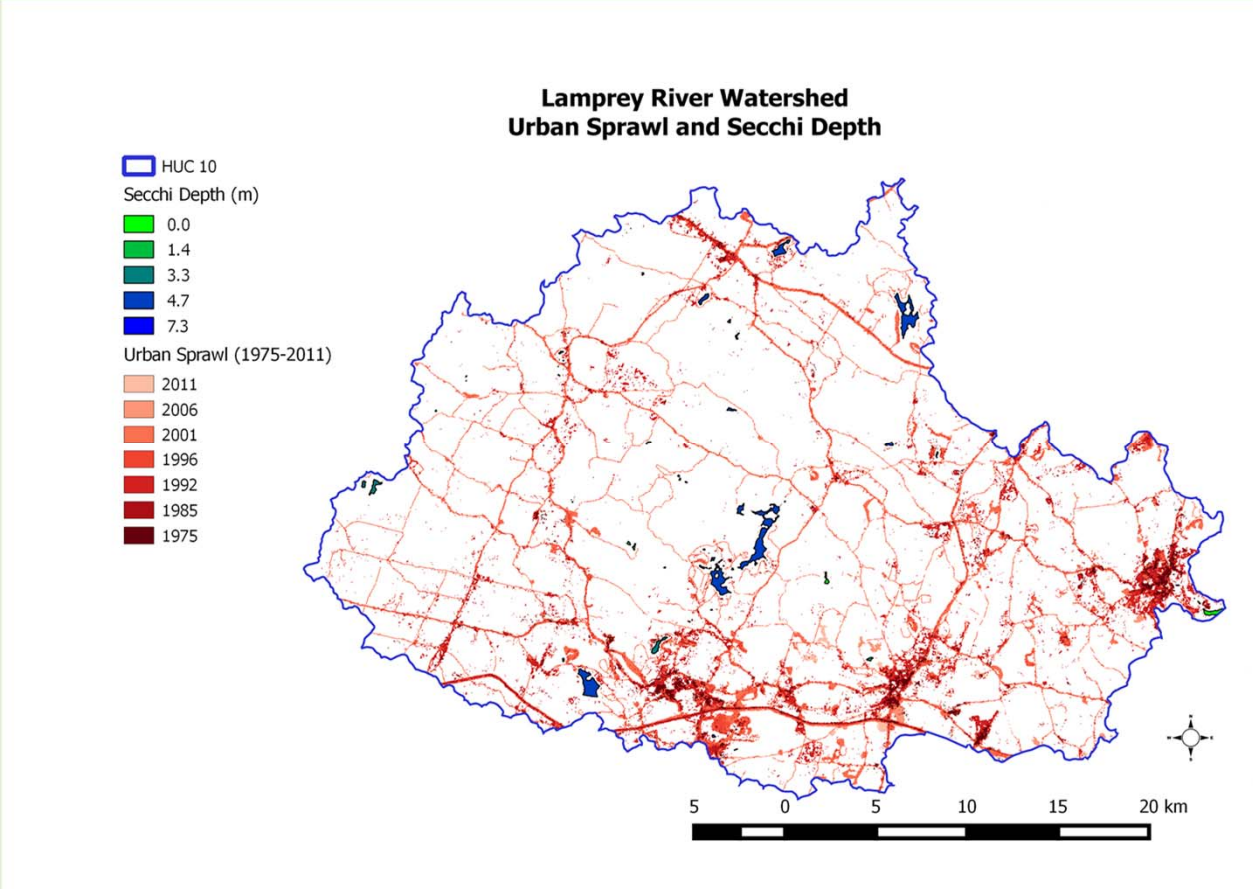
Summary

Maps of:

- Urban sprawl
- Impervious Surfaces
- Watershed Trends
- Water temperature
- Water temperature trend

Future work:

- Land use trends
- Lake water quality



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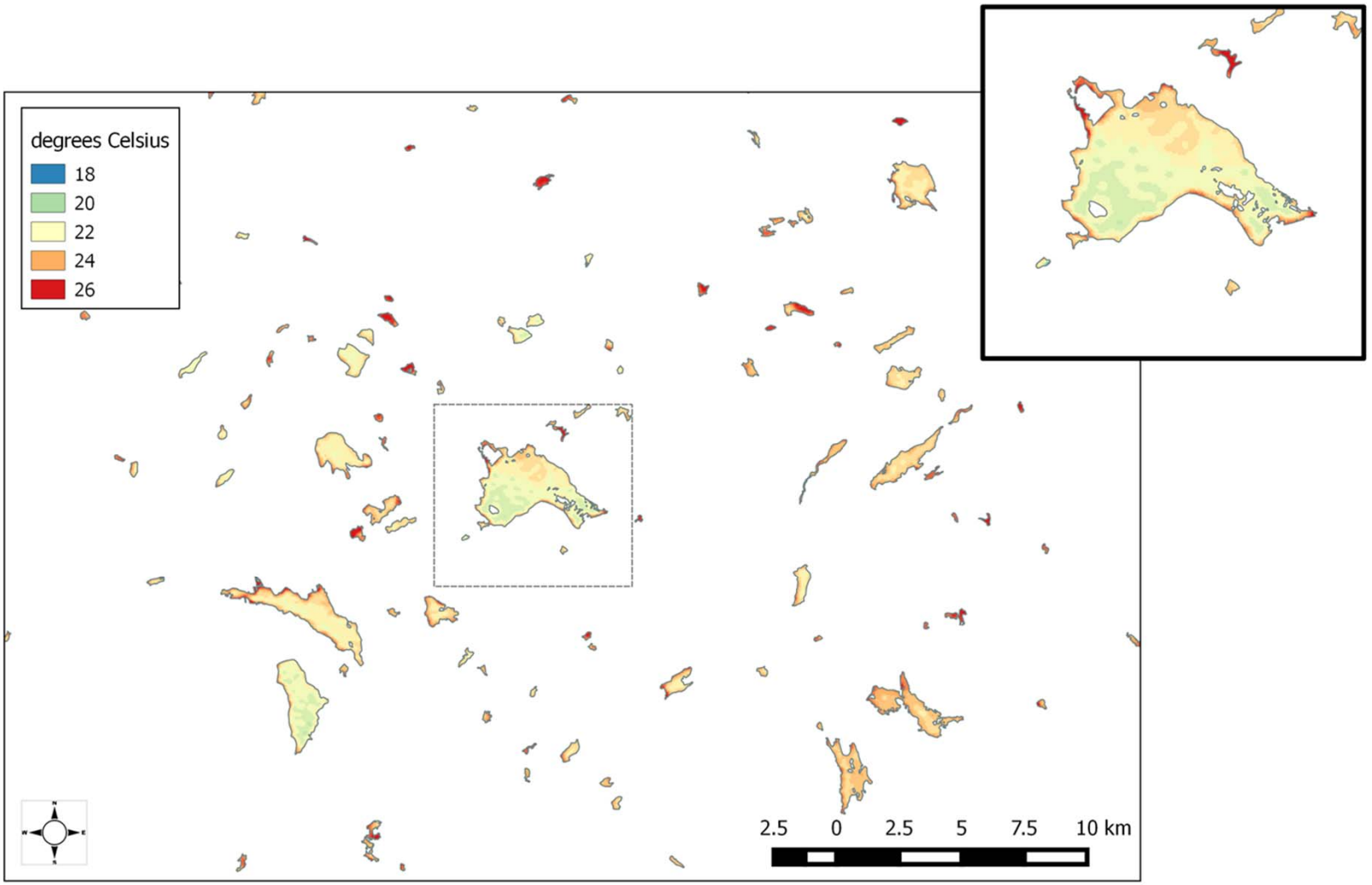
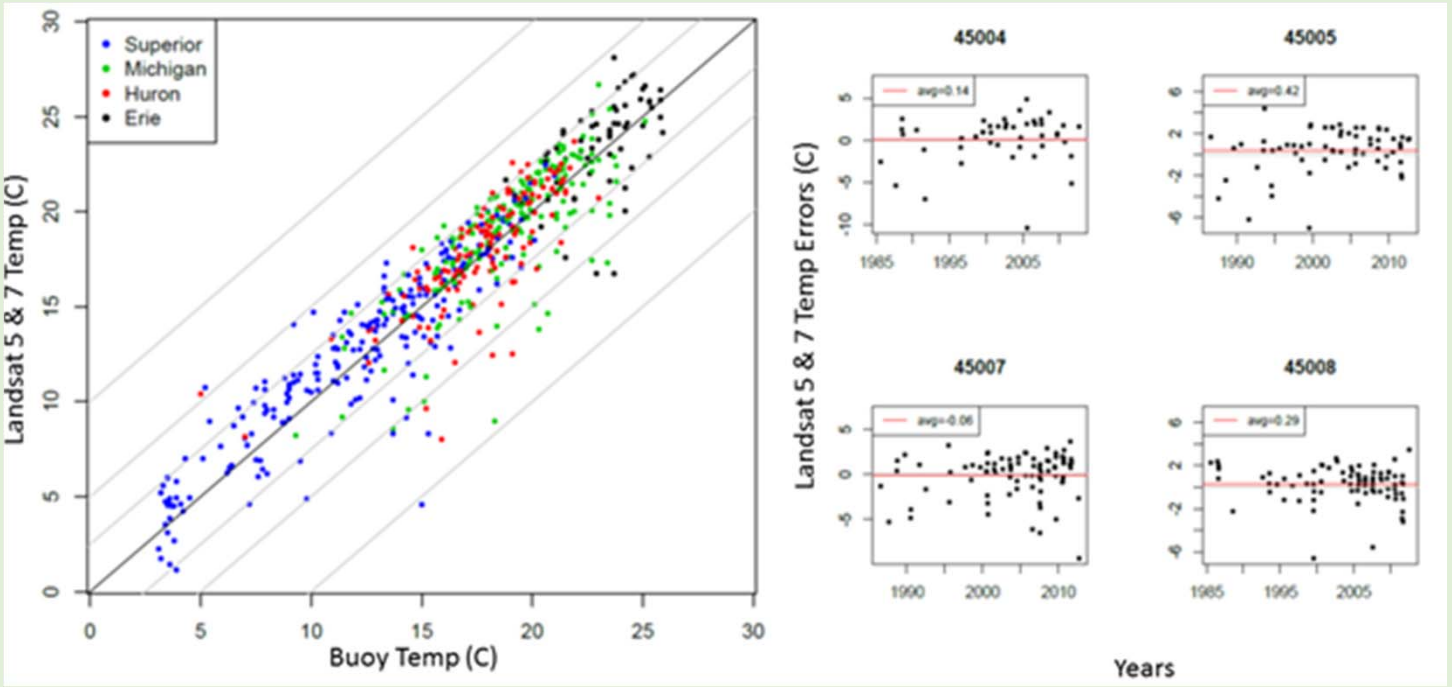
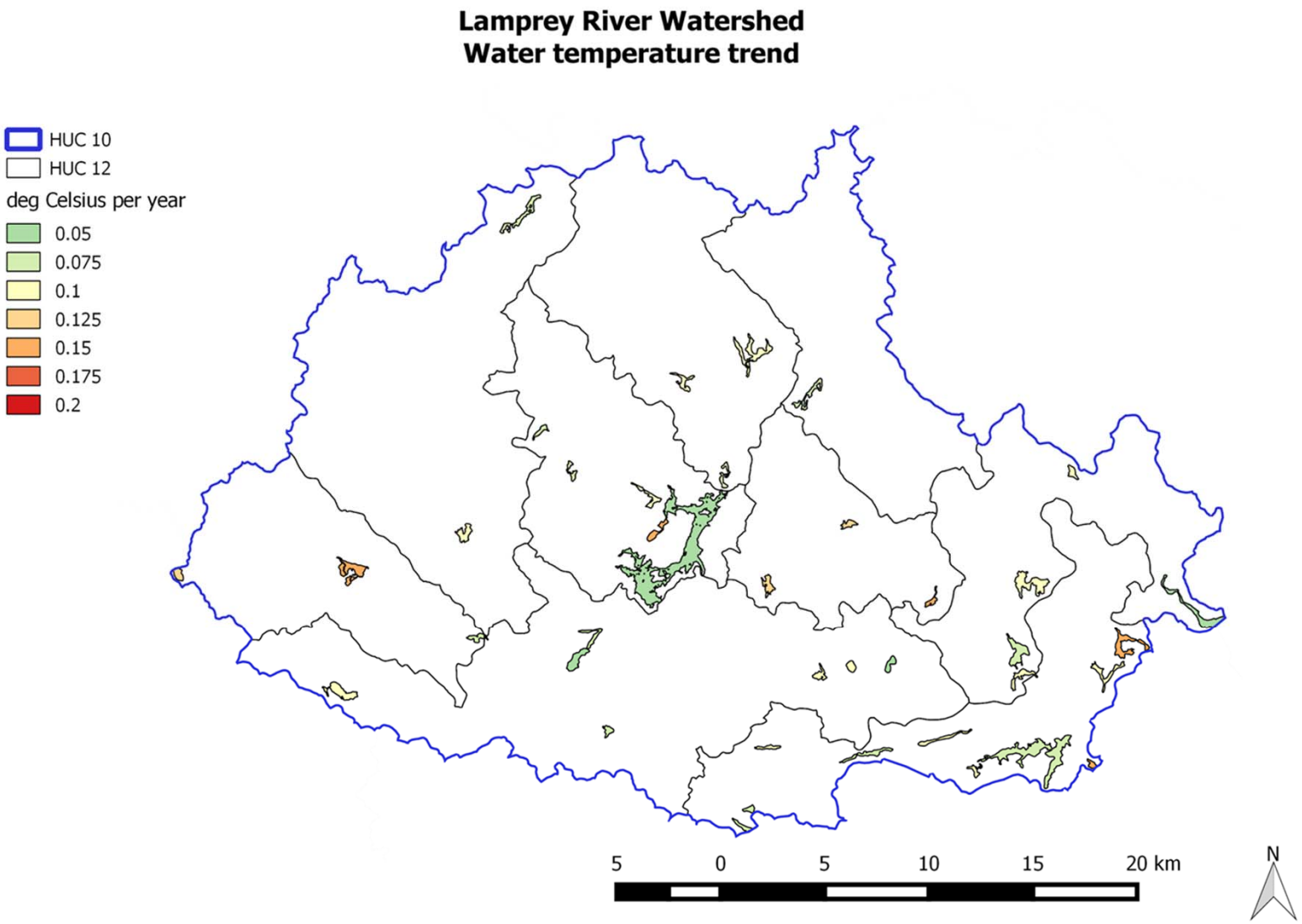
Water temperature in July 2009

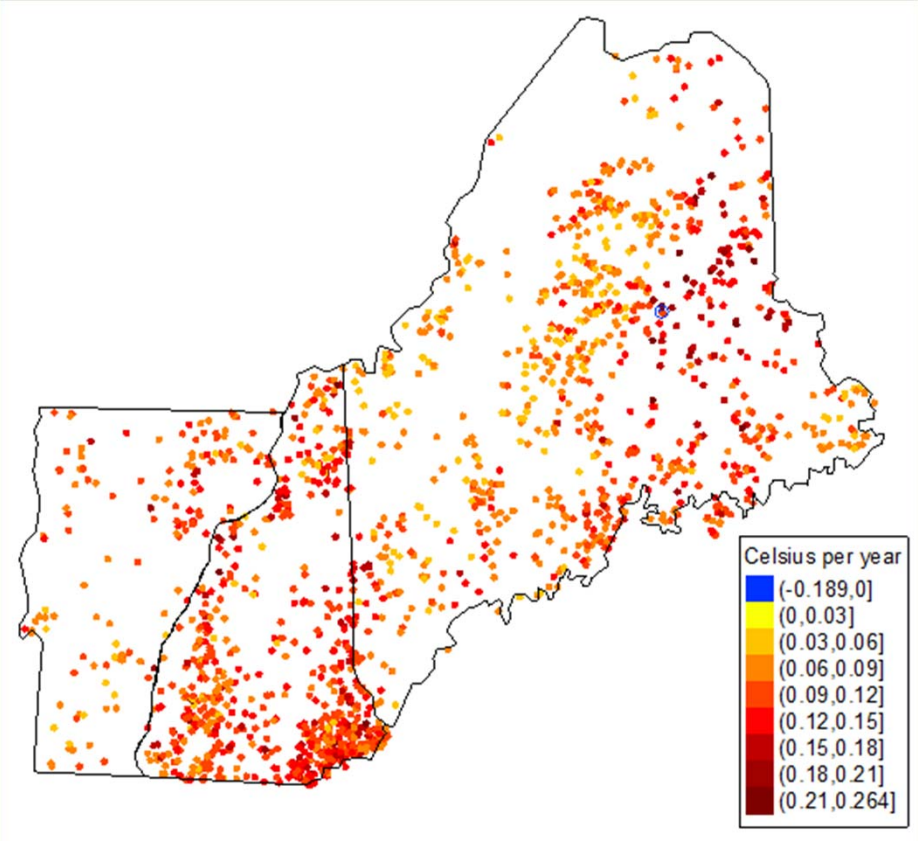


Landsat water temp vs in situ

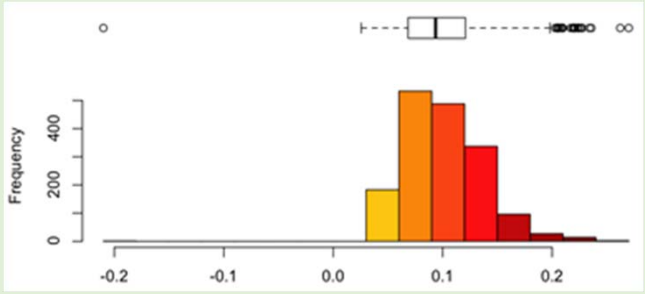



Lamprey River Watershed
Water temperature trend
HUC 10
HUC 12
deg Celsius per year
0.05
0.075
0.1
0.125
0.15
0.175
0.2
5
0
5
10
15
20 km
N

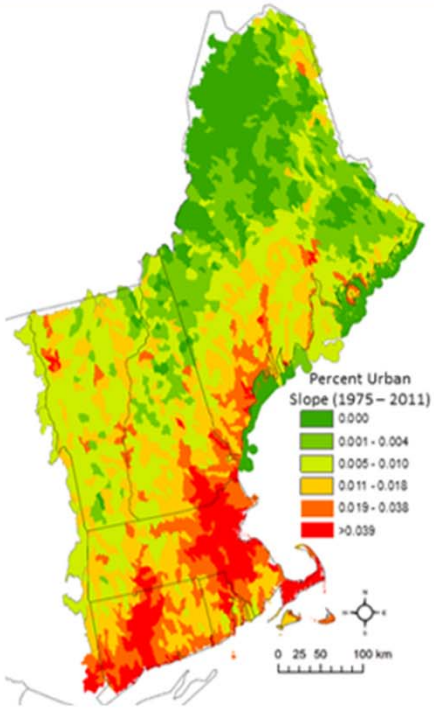
Water temperature



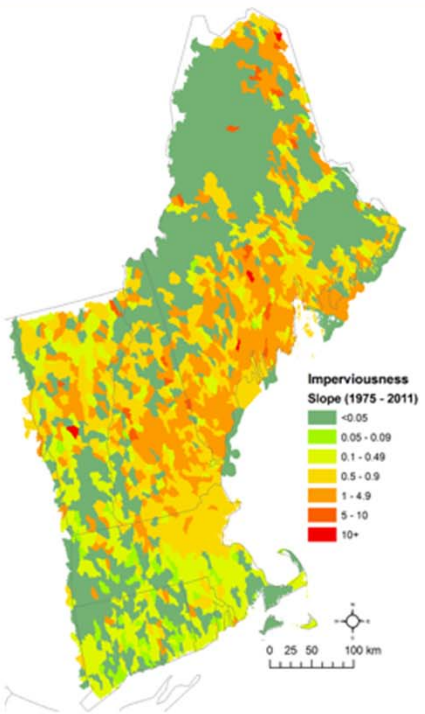
Summary of significant trends (p-value<0.1) where there are not significance violations of the linear model assumptions (Pena&Slate's Global stat p-value>0.01)



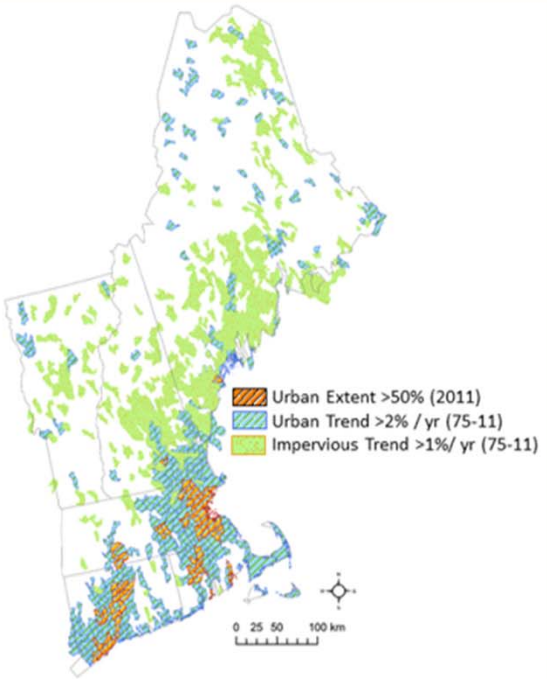
Trends/Risk Maps



Trend assessment of urban extent changes from 1975-2011 at the HUC12 watershed scale

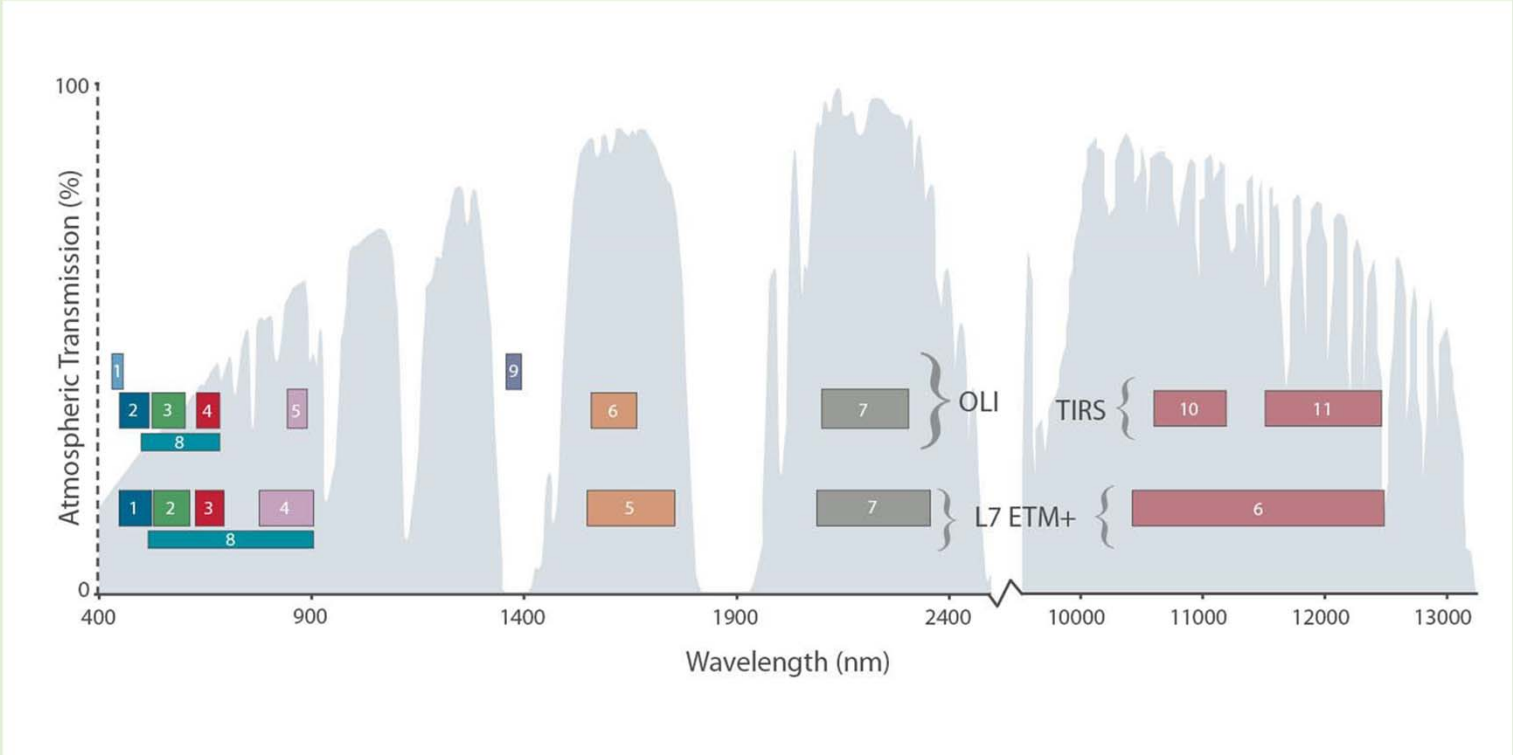


IS trend map from 1975-2011 at HUC12 scale (using only area that was classified as urban in 1975)



Watershed risk map synthesizing HUC12 watersheds across New England

Landsat bands and wavelengths of light

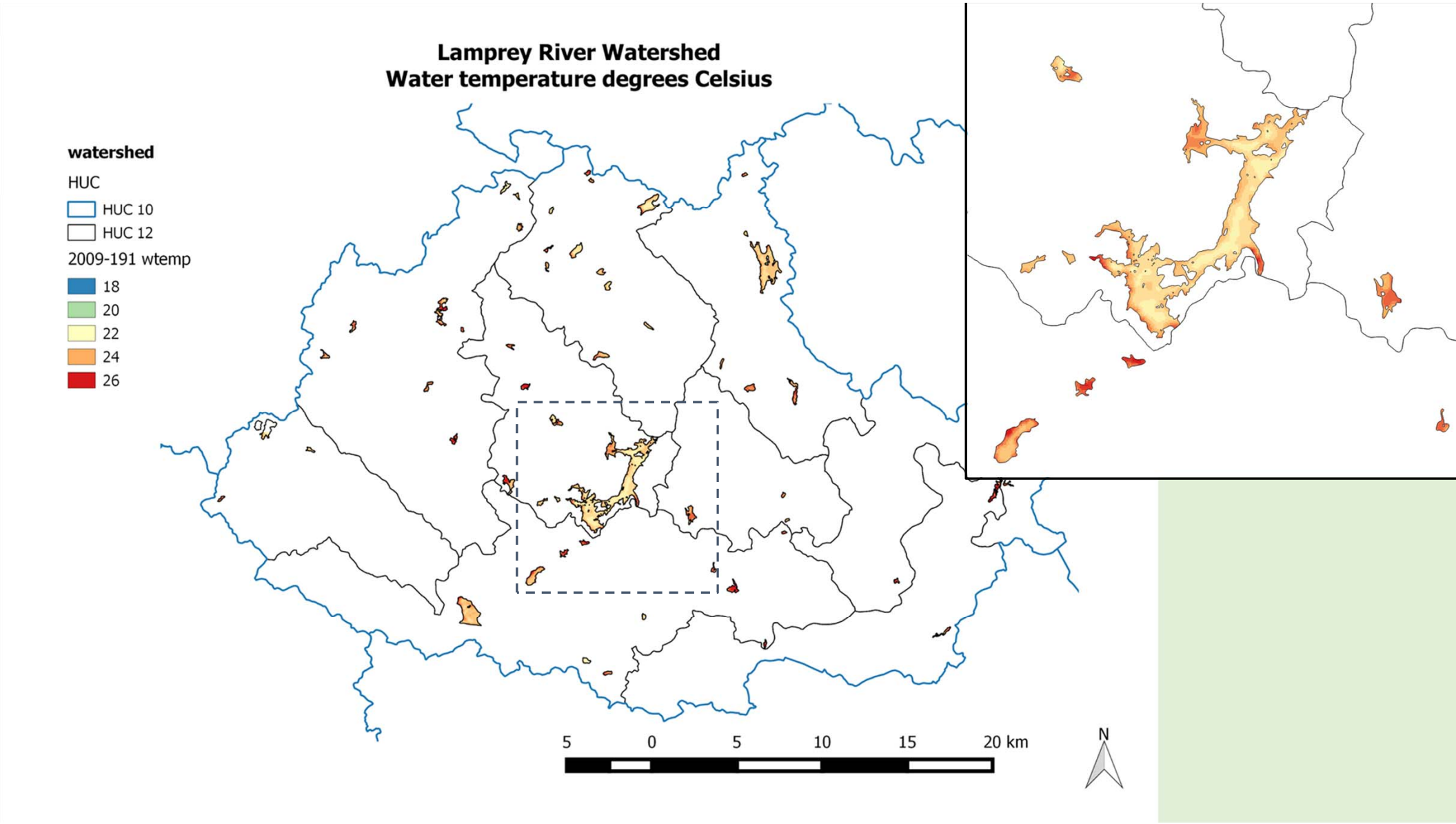


http://landsat.gsfc.nasa.gov/?p=3186

Error Matrix of CART approach

	water	urban	barren	forest	shrub	herb.	crop	wetland
water	31667	739	251	2507	15	1	54	1473
urban	464	110873	516	59229	776	223	5855	7661
barren	593	2120	9715	1173	98	41	407	475
forest	532	23250	109	660357	788	110	6185	9595
shrubland	31	4179	58	21382	3451	66	3543	1976
herbaceous	12	1317	39	2609	137	1415	937	393
crop	20	8266	158	16763	918	191	27999	2300
wetland	2128	16126	159	88743	579	65	2621	33104

Example error matrix using CART approach relying on single Landsat scene NDVI, LSWI, SAVTI, and MSAVI as inputs with reduced classification scheme which had an overall accuracy of 75%.


Lamprey River Watershed
Water temperature degrees Celsius
watershed
HUC
HUC 10
HUC 12
2009-191 wtemp
18
20
22
24
26
5 0 5 10 15 20 km
N

Submitted Abstract - NH watershed

- Urban development and impervious surfaces can adversely impact aquatic ecosystems through disruption of the water cycle. To assess these water quality stressors on a large scale, satellite imagery was used to map urban area characteristics across New England from 1975 to 2011. Historical Landsat images were classified at roughly equal temporal intervals over three decades using a Classification and Regression Tree (CART) approach to map land cover and land use change. A spatiotemporal analysis routine was developed to identify hot spots of urban sprawl. Regression models between satellite-derived Tasseled Cap Brightness and Greenness indices and impervious surface estimates were back-cast to assess dynamics in impervious surfaces across New England at multiple spatial scales. The aggregated urban vs non-urban maps had an overall accuracy of 95% and the impervious surface model had a R2 of 0.89. Our analyses show the highest urban expansion in watersheds along the coasts in southeastern New England and along highway corridors. The urban area of many of these watersheds increased by over 40 percent. The coastal northeast had the steepest increase in imperviousness of urban area, averaging 1-4.9% increase per year over the time period. We are now assessing stressor - response relationships between urban surfaces and a trophic status index derived from satellite remote sensing.

Abstract of paper

- A Classification and Regression Tree (CART) using random forest classified Landsat imagery into a scheme matching the 2011 National Land Cover Database (NLCD). Relationships between NLCD 2011 IS values and corresponding Landsat TM Tasseled Cap transformations were used to map IS values across the study areas. The CART and IS models were applied to modern imagery and backcast to selected archived imagery to generate maps of urban and impervious surfaces. A spatiotemporal analysis routine identified rates of urban sprawl and IS dynamics at pixel and watershed scales. Multiscale spatiotemporal analyses show the highest urban expansion in watersheds along the coasts in southeastern New England and along highway corridors. Imperviousness intensity of urban existing in 1975 was highest in the coastal northeast between 1975 -2011. The products will be used to support lake risk management and help identify potential stressors to lake health in the northeast.

Conclusion

- The CART utilizing random forest and Landsat indices was able to backcast models to Landsat archives to generate urban maps extending back nearly four decades across New England with high overall accuracy. The multiple linear regression technique using Tasseled Cap Brightness and Greenness indices was effective in characterizing Impervious Surfaces for urban land types. The aggregated urban vs non-urban maps had an overall accuracy of 95% and the IS model had a R^2 of 0.89. The techniques were relatively scalable and, to our knowledge, provide the first large area urban and Impervious Surface spatiotemporal assessment across New England. Multiscale assessment highlighted 'hot spot' regions and had related but different results emphasizing the importance of considering scale in applications. Coastal watersheds, major routes, and large cities were shown to have the highest rates of sprawl and increases in impervious intensity. The approach and products help identify patterns and potential threats to lake water quality and can help assist watershed management planning in reducing negative impacts on aquatic ecosystem integrity. This approach is relatively automated and potentially scalable to other regions or large study sites such as CONUS. Our next step will be to analyze the relationship between urban sprawl/IS and aquatic integrity for northern New England, with a focus on public health.