Factors Influencing Riverine Fish Assemblages in Massachusetts

Report to the
WATER RESOURCES COMMISSION
January 12, 2012

Prepared in cooperation with the
Massachusetts Department of Conservation and Recreation, the
Massachusetts Department of Environmental Protection, and the
Massachusetts Department of Fish and Game

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Scientific Investigations Report 2011–5193

U.S. Department of the Interior
U.S. Geological Survey

REPORT UPDATE


USGS
science for a changing world

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U.S. Department of the Interior
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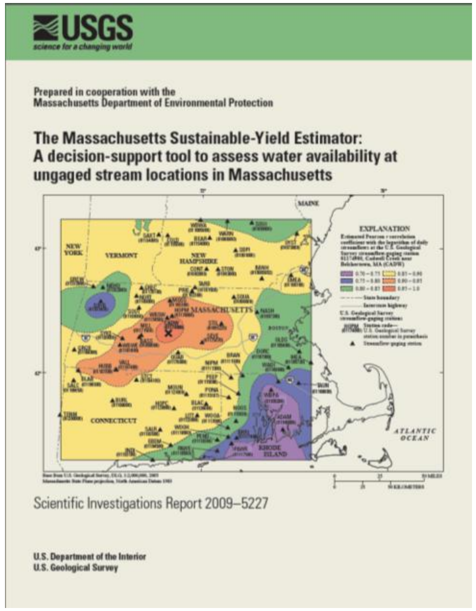
- Funding for this study was provided by the MDCR and USGS, with additional cooperation from the MDEP and the MDFG.

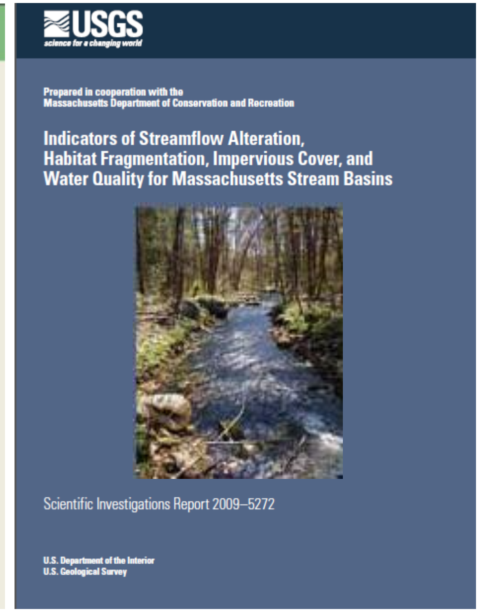
- **Citation**:
Armstrong, D.S., Richards, T.A., and Levin, S.B., 2011, Factors influencing riverine fish assemblages in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2011-5193, 59 p.

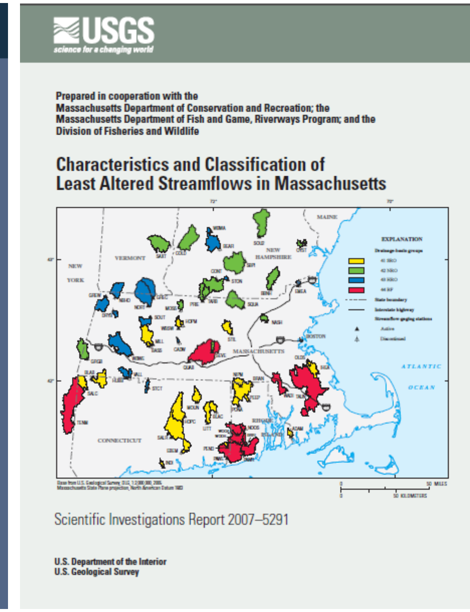
- The report is posted on-line: http://pubs.usgs.gov/sir/2011/5193/

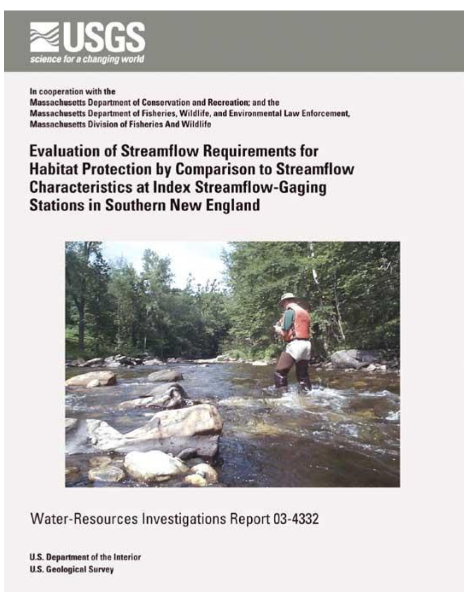
- Printed copies of the report will be available within about a month

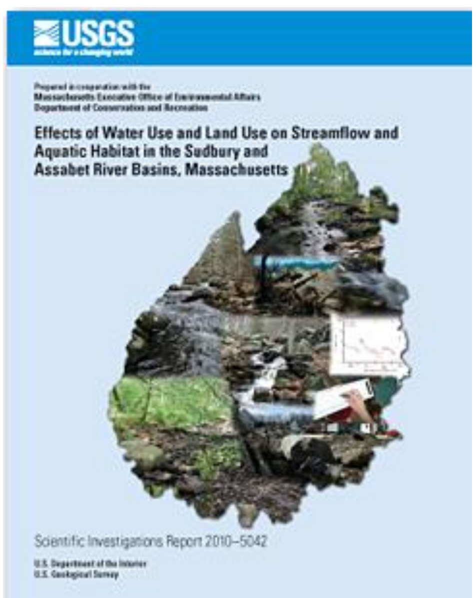
The report is one of a number of USGS reports that have informed the SWMI process on streamflow, habitat, and environmental-flow issues

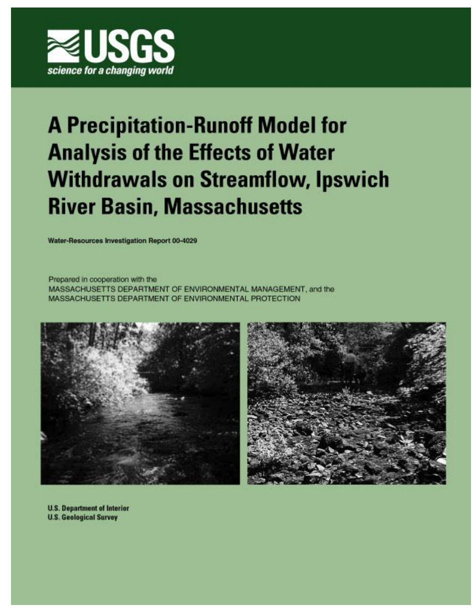


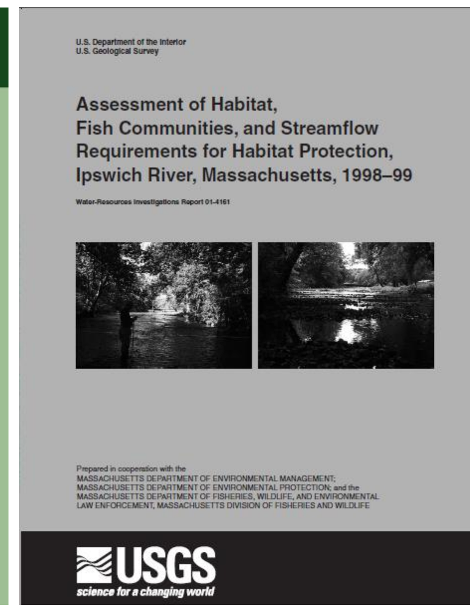












Fluvial Fish

Comparison to Preliminary

Factors Influencing Riverine Fish Assemblages in Massachusetts

INTRODUCTION

DATA

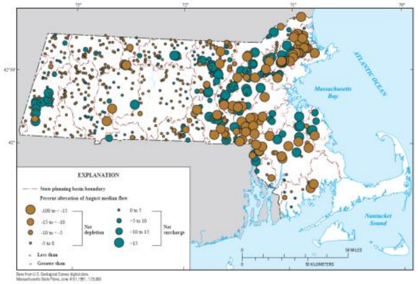
METHODS

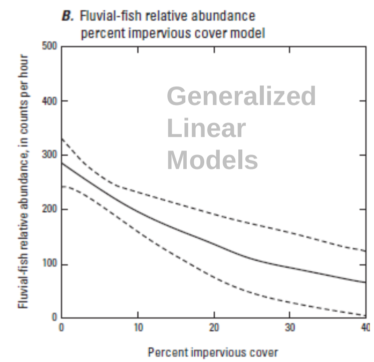
ANALYSIS

COMPARISON TO PRELIMINARY

SUMMARY

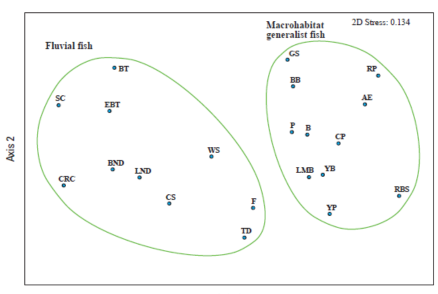
Flow Alteration

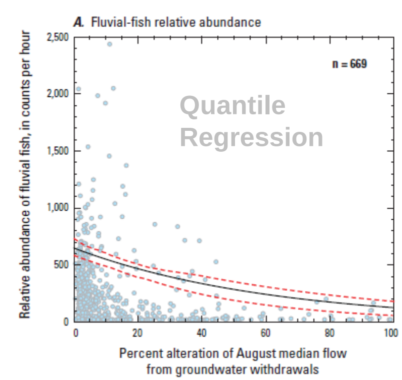




Generalized Linear Models

Metric Selection

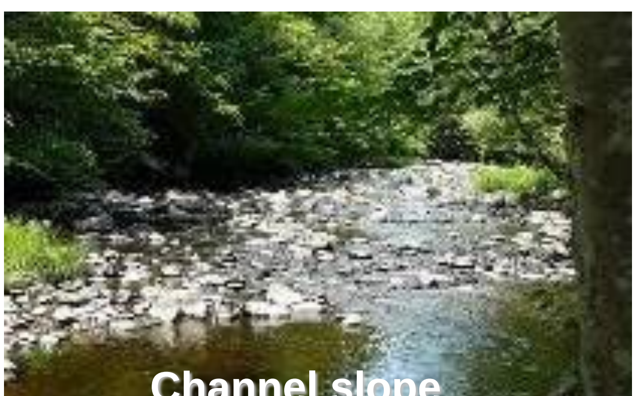


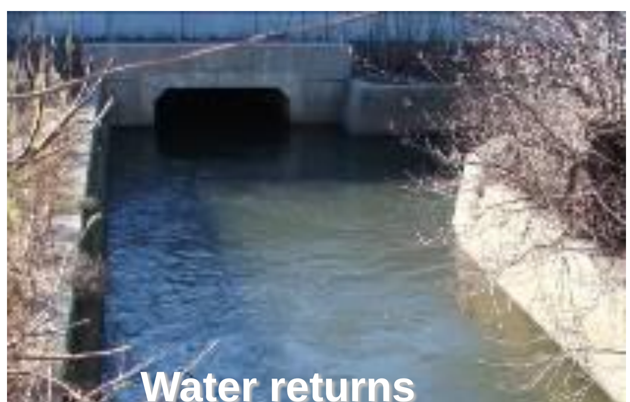


Quantile Regression

Objective:
To better understand the **influence of flow alteration on fish communities** in Massachusetts, relative to the effects of natural basin characteristics and other human stressors such as land-use and dams.

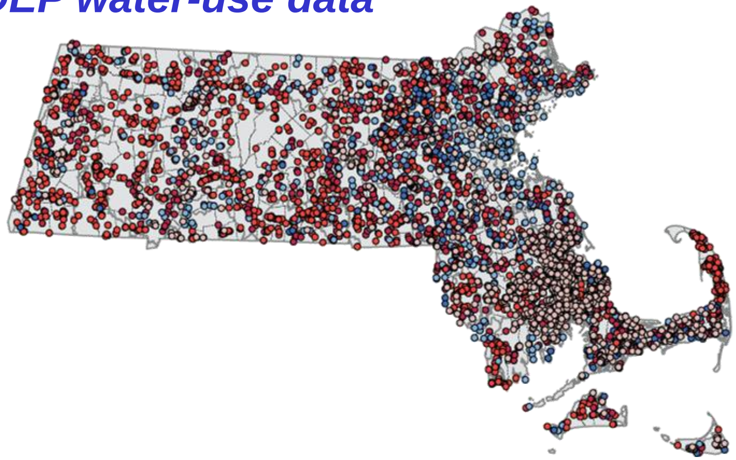
Scope: a statewide effort



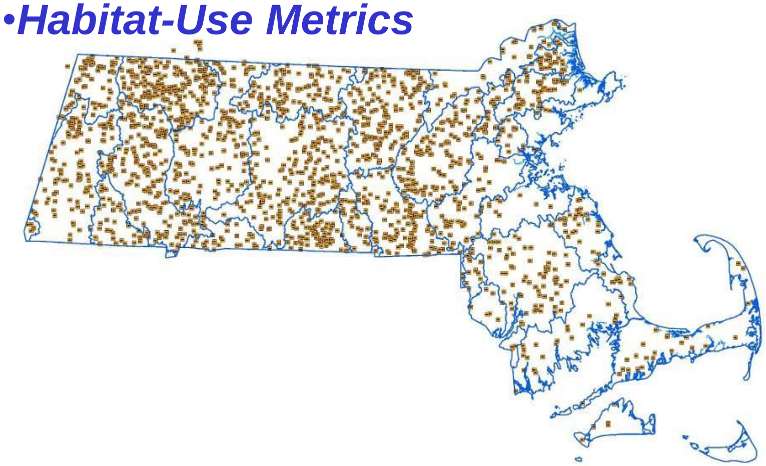


Opportunity: new data and new tools made this project possible

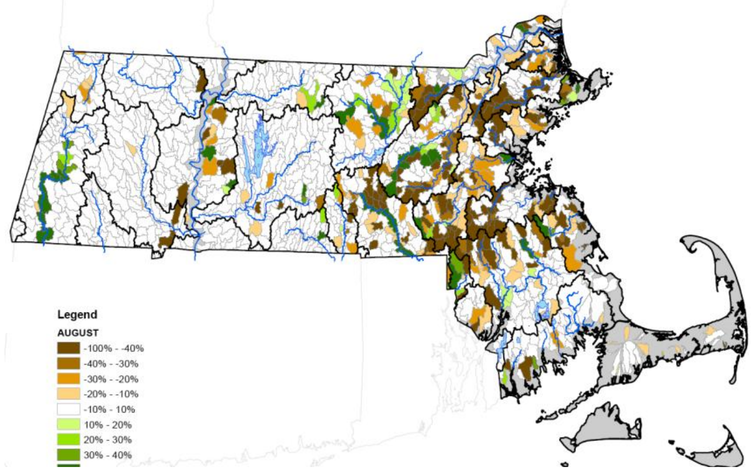
- ***SYE simulated flows for ungaged sites***
- ***MDEP water-use data***



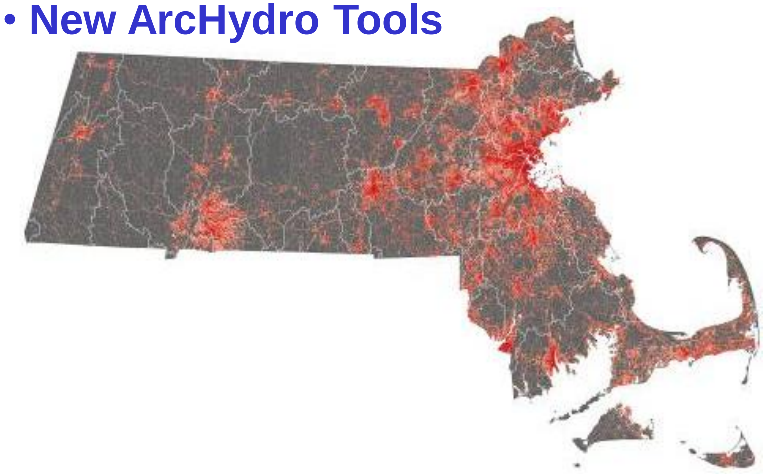
- ***MDFW Fish data***
- ***Habitat-Use Metrics***



- ***Indicators of flow alteration***

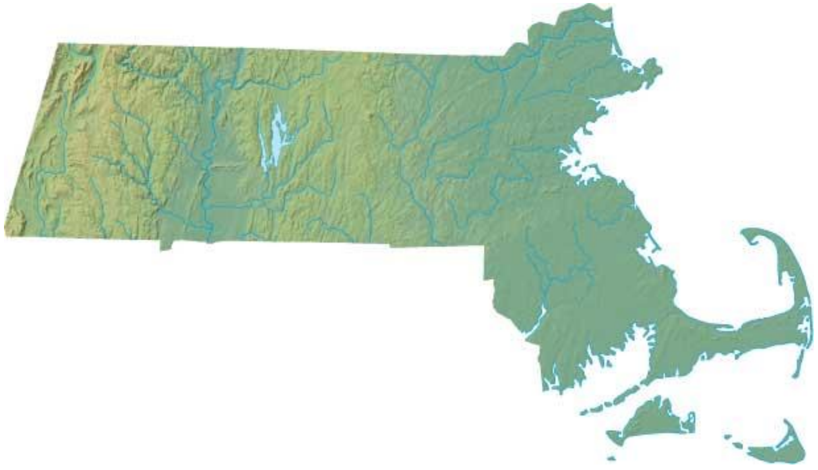


- **New GIS coverages**
- **New ArcHydro Tools**

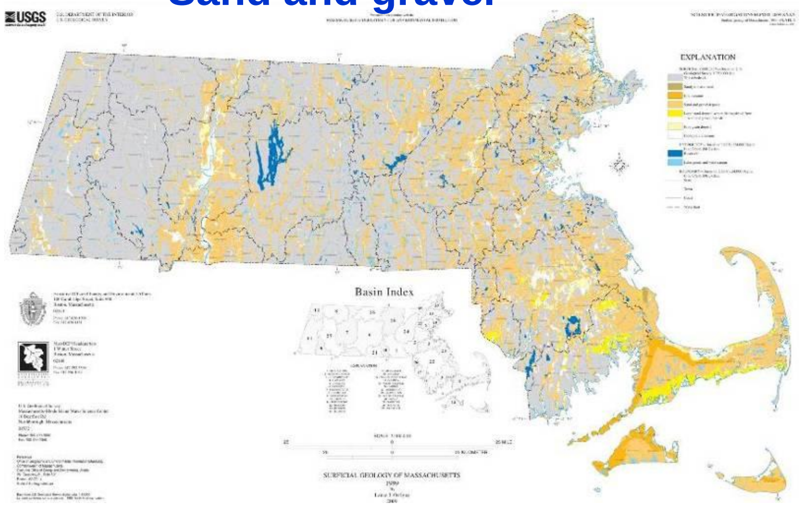


- Opportunity: Numerous other statewide GIS coverages also existed

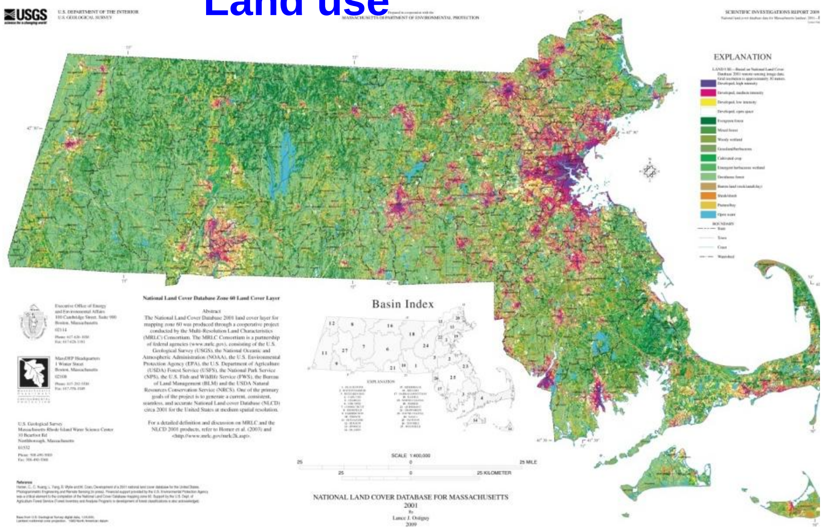
Topography



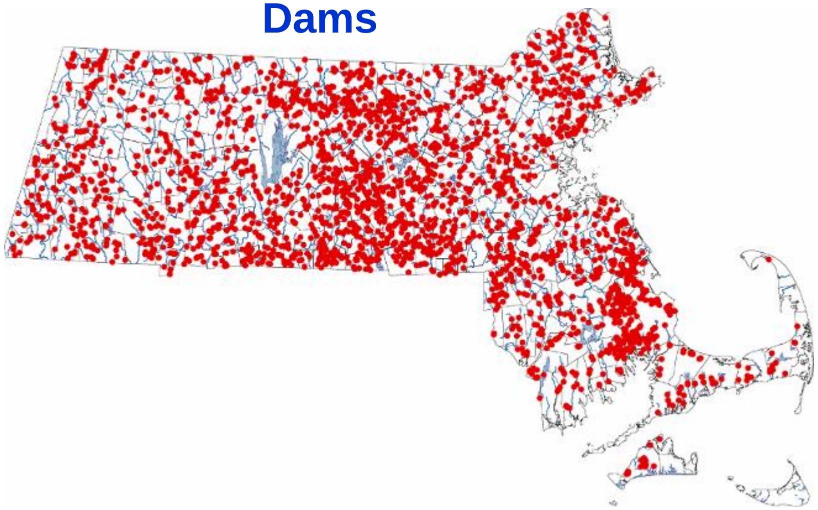
Sand and gravel



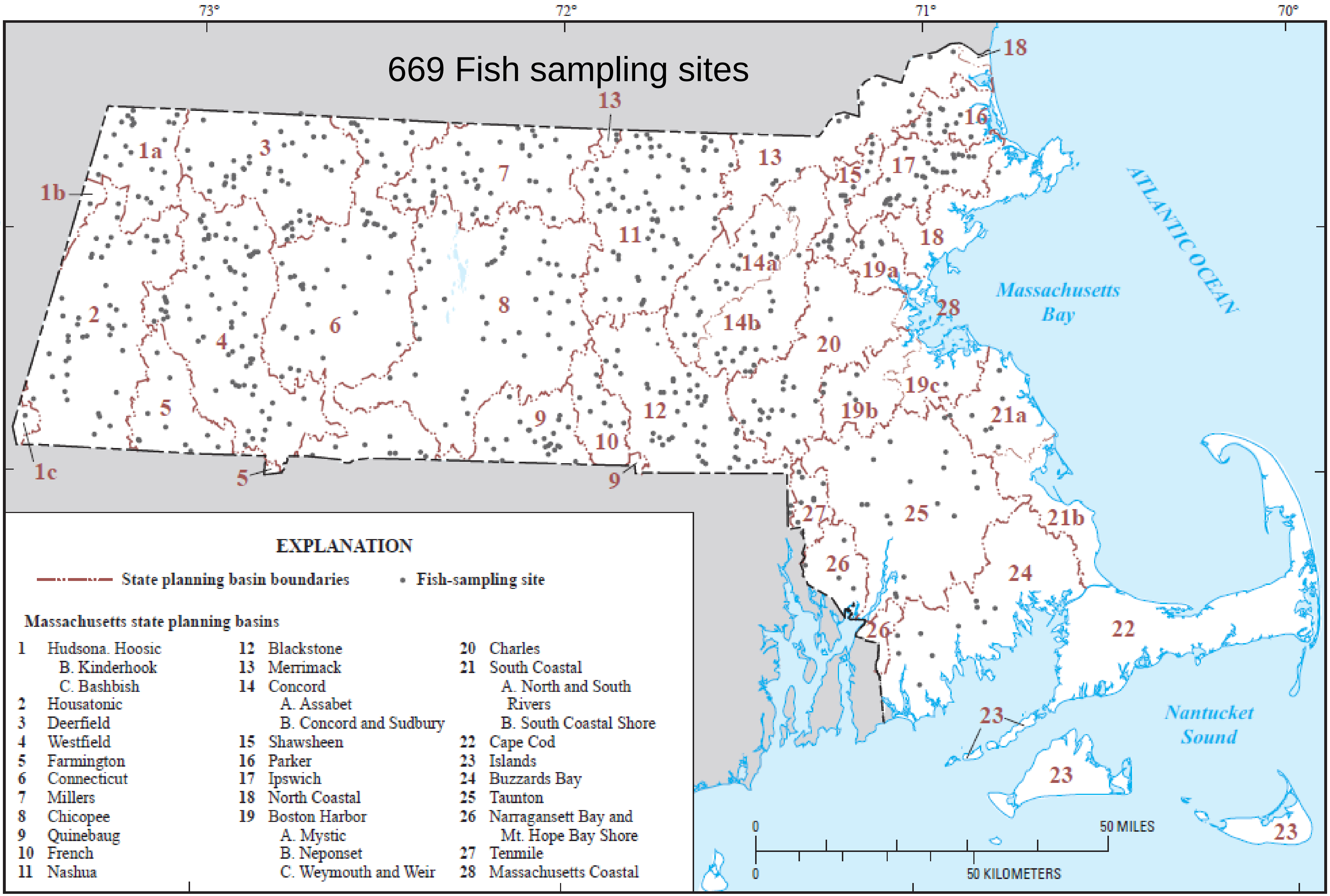
Land use



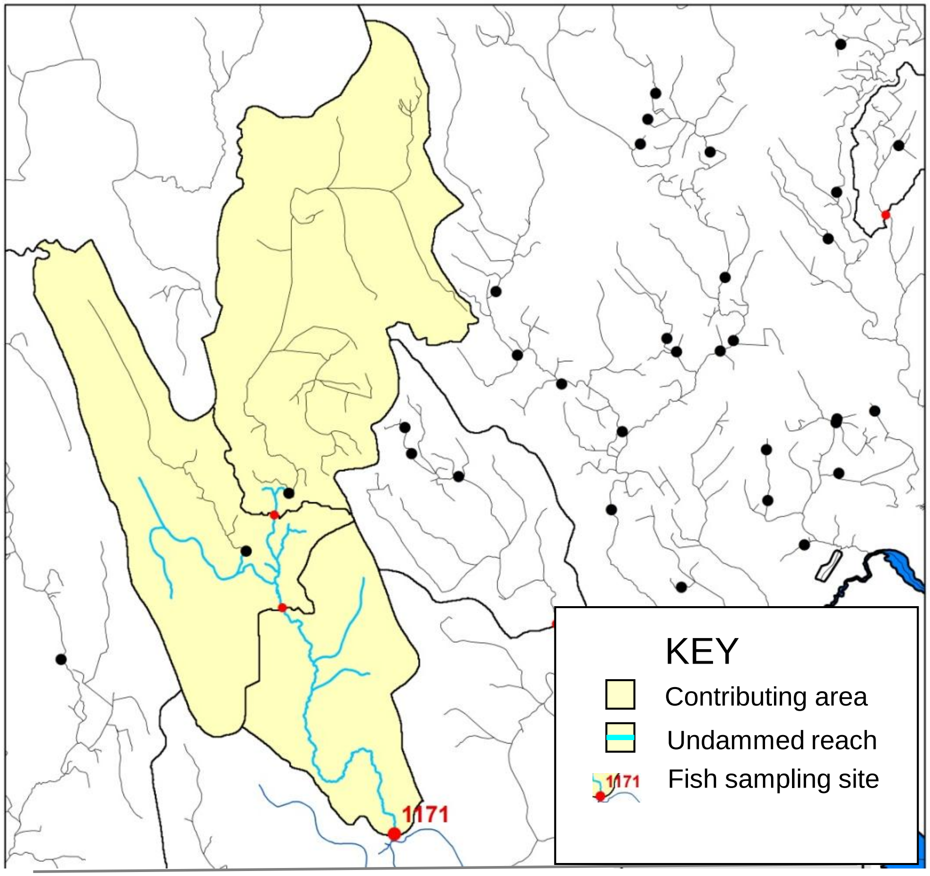
Dams

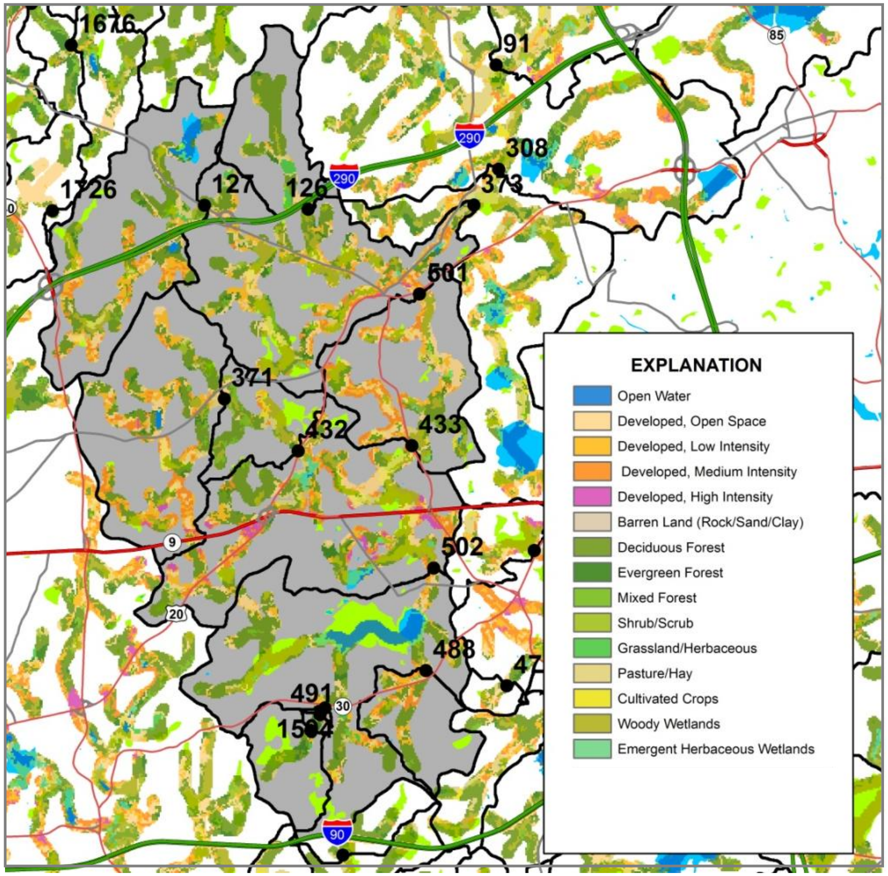


- Fish data were obtained from MDFW Fish Database (1998-2008)

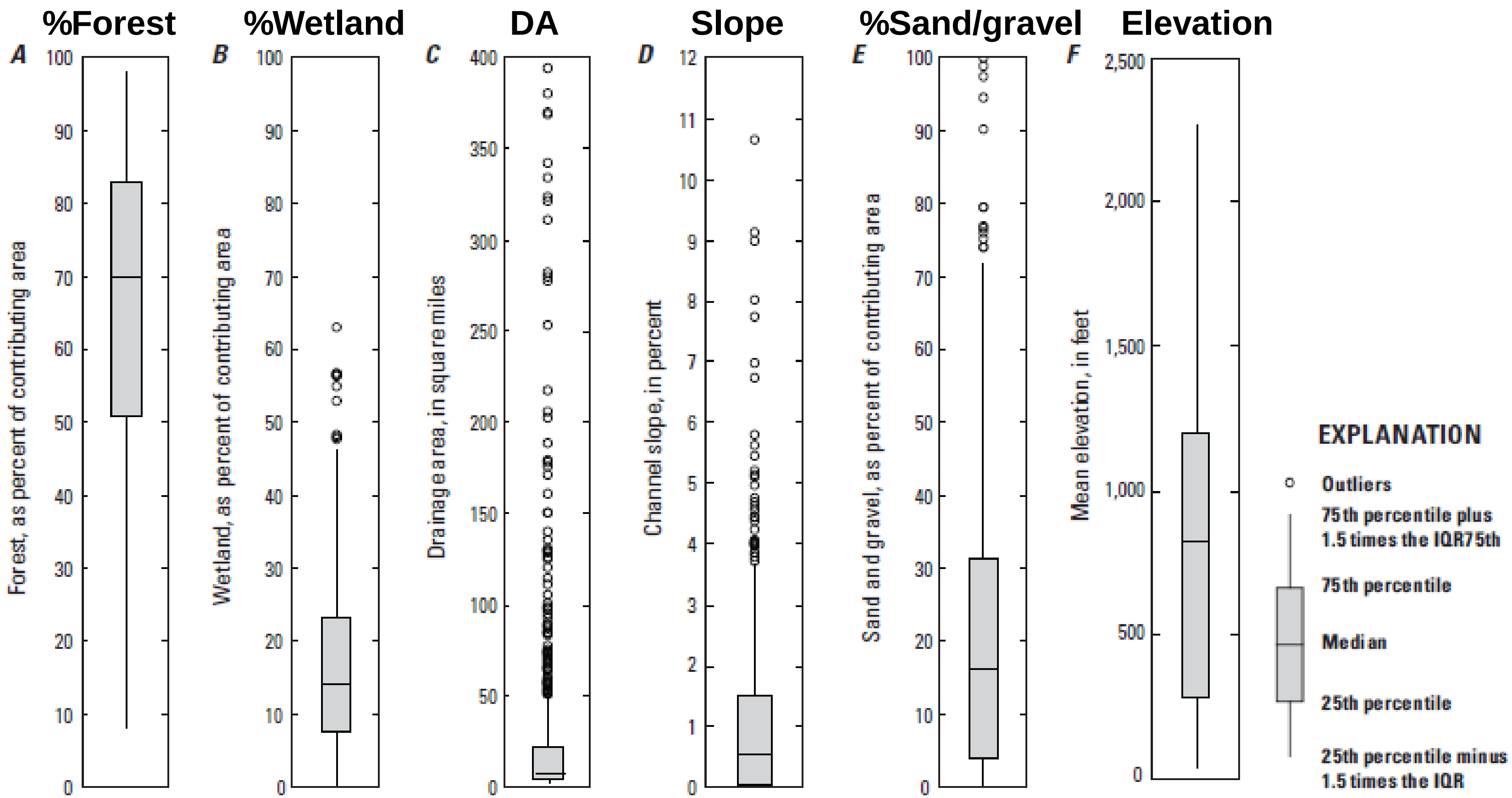


- Variables were determined for the contributing area to fish-sampling sites and also for a 120-meter buffer adjacent to the stream.





• The fish sampling sites were predominantly in small, wadeable streams and represented a range of basin characteristics



Flow data

- Daily streamflow data were simulated for the 1960-2004 period for each fish sampling site using the Sustainable-Yield Estimator (SYE)

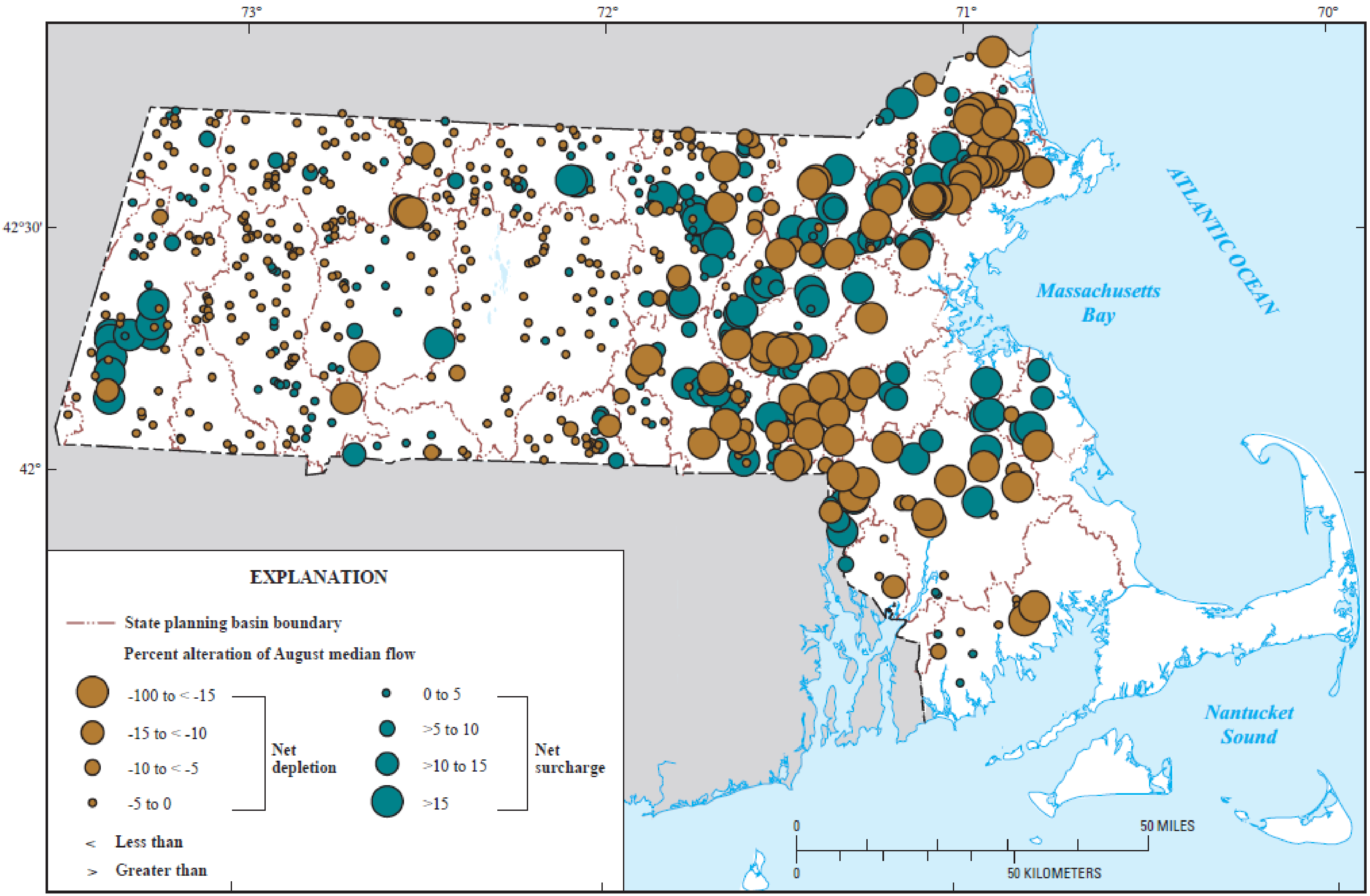
- Daily data were used to calculate medians of monthly median flows and annual mean flow statistics

- Water-use data were summed for the contributing areas to each fish sampling site and used to calculate percent flow alteration variables

  - for individual components of flow alteration, i.e.
    - percent alteration of August median flow from groundwater withdrawals
    - percent alteration of August median flow from surface-water (NPDES) returns
    - percent alteration of August median flow from septic returns

  -and for net flow alteration
    - Net percent alteration August median flows, depleted sites
    - Percent alteration August median flows, surcharged sites

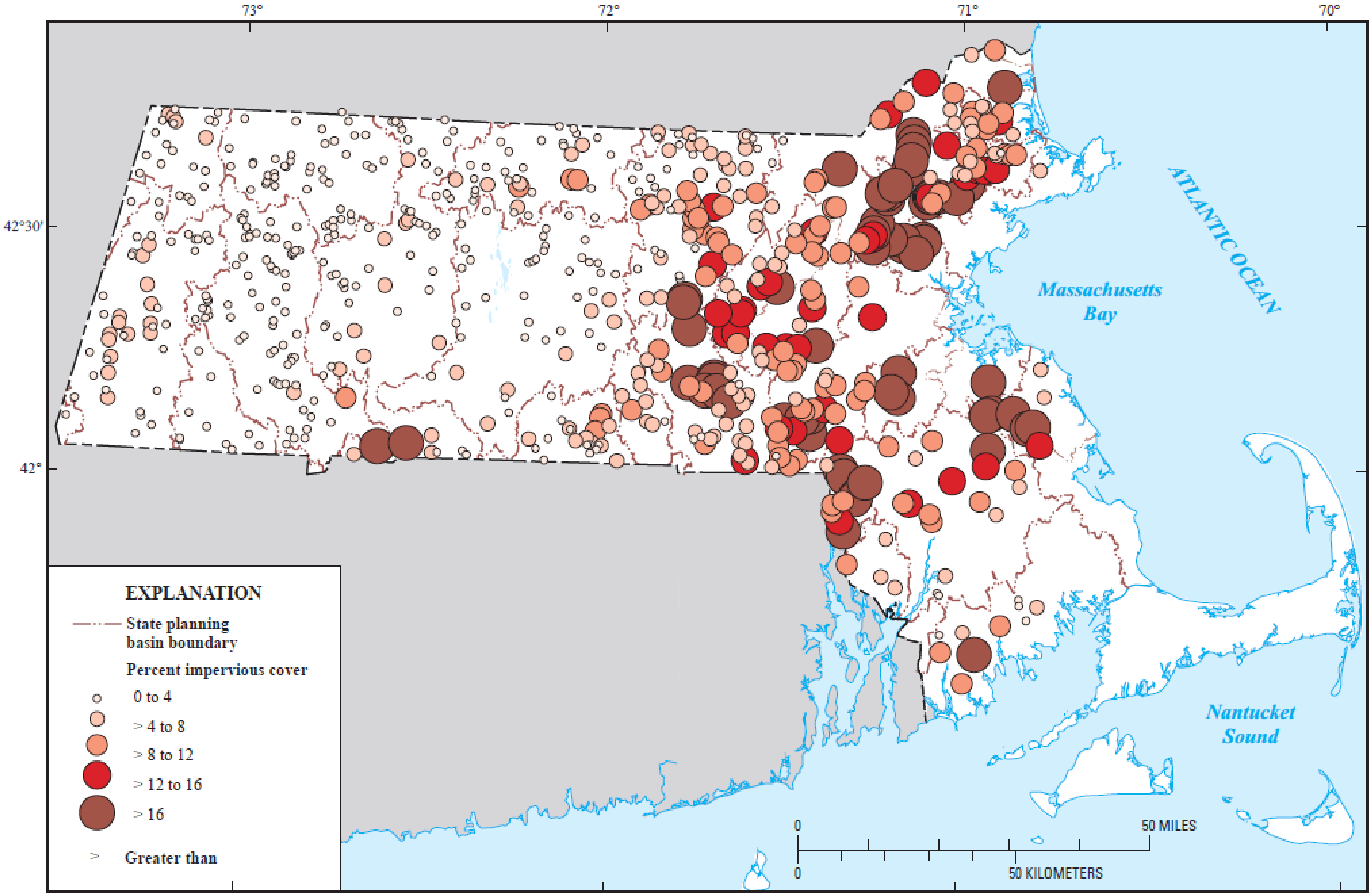
- The fish sampling sites represented a range of flow alteration conditions



Base from U.S. Geological Survey digital data, Massachusetts State Plane, zone 4151,1991, 1:25,000

Figure 7. Percent alteration of August median flows at 669 fish-sampling sites in Massachusetts streams.

• The fish sampling sites represented a range of impervious cover conditions

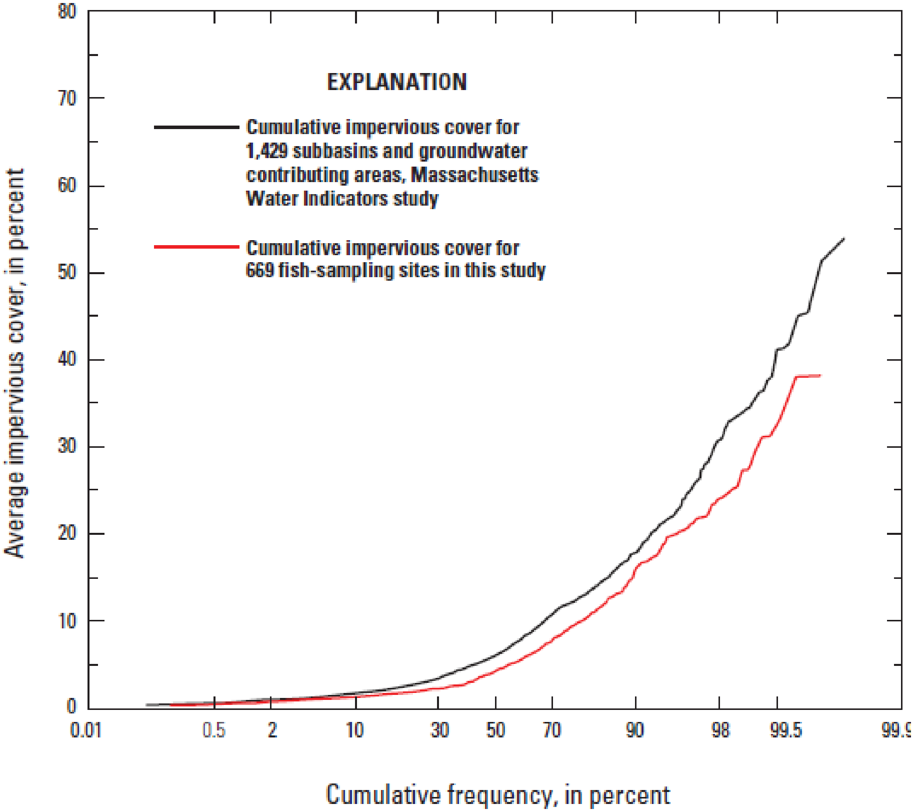


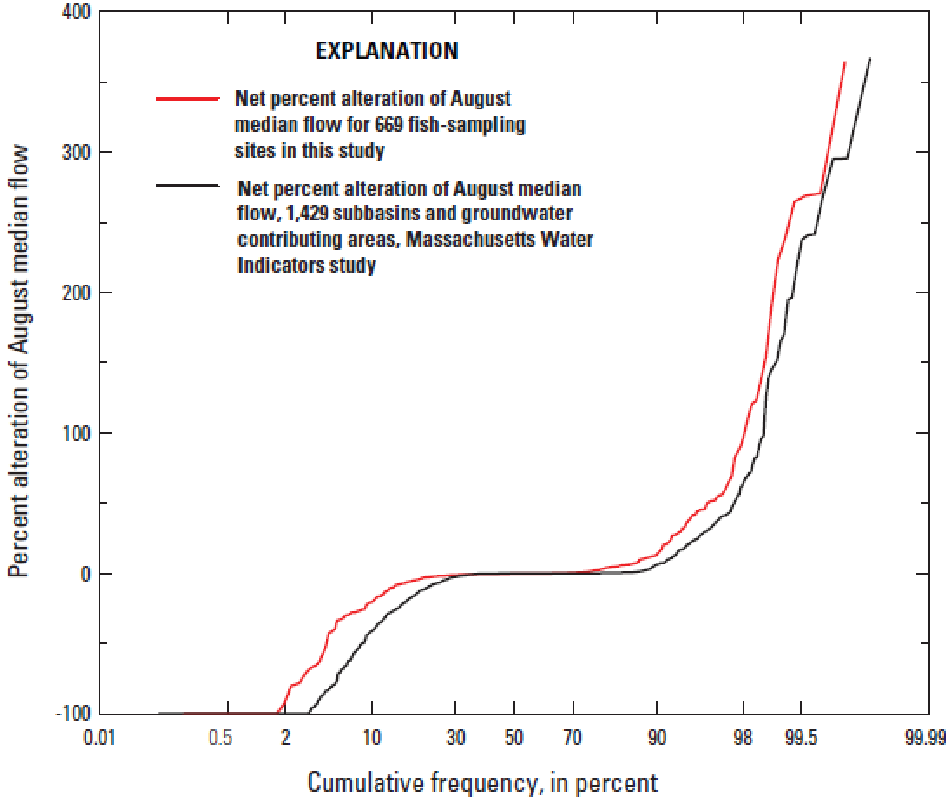
Base from U.S. Geological Survey digital data, Massachusetts State Plane, zone 4151,1991, 1:25,000

Figure 5. Impervious cover for contributing areas to 669 fish-sampling sites in Massachusetts. Impervious cover data from 2005 (Massachusetts Office of Geographic and Environmental Information, 2007).

- Fish-sampling sites were representative of conditions in Massachusetts.

Comparisons to conditions in 1400+ sub-basins in the MA Water Indicators study



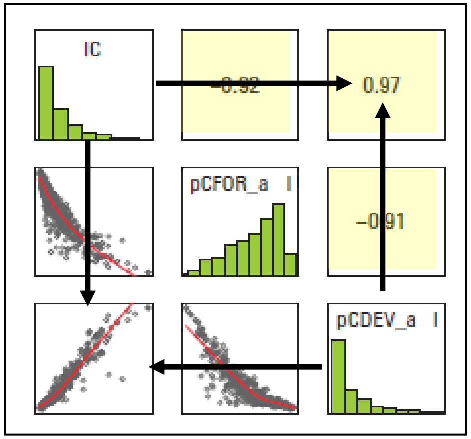


Many variables are correlated

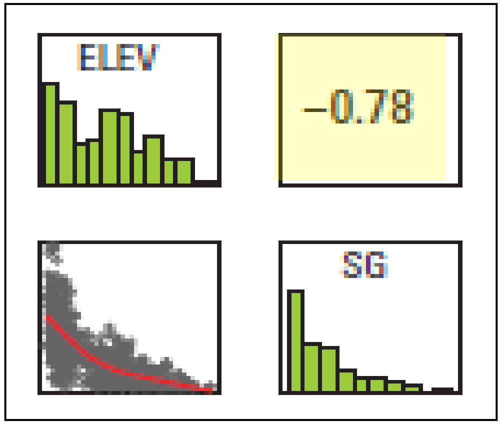
• Highly correlated variables cannot be used together in the same regression equation. Highly correlated variables (rho > 0.70) were identified.

Examples

Percent IC, and Percent Developed Land Use (+)



Elevation, and Percent sand and gravel (-)



Other correlated variables:

Percent IC and Elevation (-)
Elevation and basin slope (+)
Percent IC and Percent alteration from August septic returns (+)
Percent alteration of August median flow and (June, July, September) (+)

Variable Reduction

• Principal components analysis (PCA) and Spearman rank correlation were used to reduce the number of explanatory variables

- To identify variables that contributed the most to the variability of the dataset, variables with the highest loadings in the PCA analysis were retained.

Example: Variables representing individual components of flow alteration had higher loadings than variables representing net flow alteration.

- To reduced multicollinearity and minimize redundancy in the dataset, variables highly correlated (rho > 0.70) with the highly loaded variables were removed.

Example:
percent impervious cover was highly correlated with
percent alteration of August median flow from septic returns.

15 Variables (of 150 potential variables) were retained to use as candidate variables for regression models

Natural basin characteristics
1. Drainage area
2. Channel slope
3. Percent sand and gravel

Land-cover/Land-use variables
1. Percent forest
2. Percent wetland in buffer
3. Percent impervious cover
4. Percent agriculture in buffer

Flow alteration metrics
1. Percent alteration of August median flow from groundwater withdrawals
2. Percent alteration of August median flow from surface-water returns
3. Percent alteration of mean annual flow from surface-water withdrawals
4. Percent alteration of mean annual flow for net depleted sites

Dam/impoundment metrics
1. Dam density
2. Percent open water in the contributing area.
3. Length of undammed stream reach in network
4. Length of undammed stream reach upstream of the sample site along centerline,

- Fish were classified by use of **HABITAT- USE CLASSIFICATIONS (HUCs)**

Fluvial Specialists (FS)

Require flowing water for all portions of their life cycle

Blacknose dace

brook trout

Fluvial Dependents (FD)

Need flowing water for some portion of their life cycle

white sucker

common shiner

Fluvial species

White Sucker
Blacknose dace
Brook trout
Longnose dace
Fallfish
Common shiner
Tessellated darter
Slimy sculpin
Brown trout
Creek chub

Macrohabitat Generalists (MG)

Can live in flowing or ponded water conditions

largemouth bass

pumpkinseed

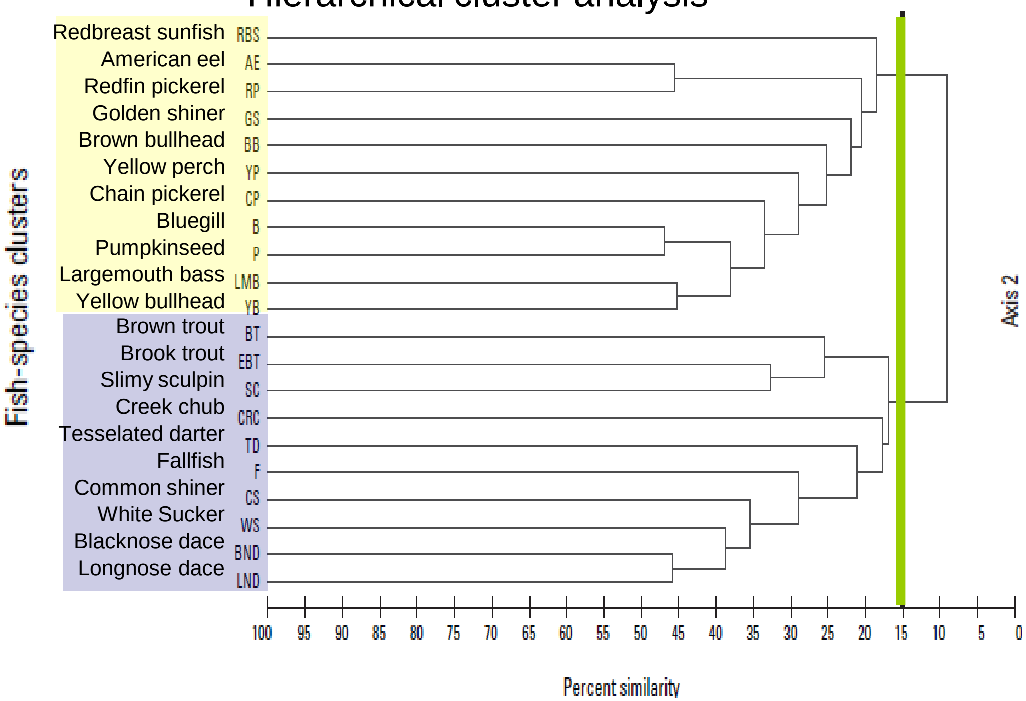
Generalist species

Pumpkinseed
Bluegill
Largemouth bass
American eel
Redfin pickerel
Chain pickerel
Yellow bullhead
Brown bullhead
Golden shiner
Yellow perch
Redbreast sunfish

Fish metrics

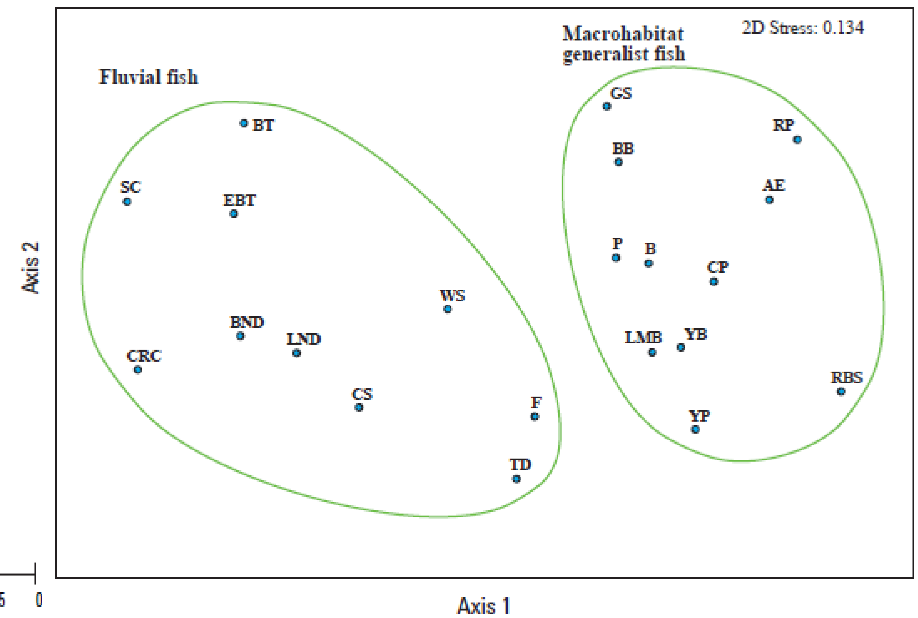
• Multivariate analyses of the fish data, using cluster analysis and ordination, both indicated that fish species could be naturally-grouped into fluvial and generalist habitat-use classes

Hierarchical cluster analysis



EXPLANATION
- Macrohabitat generalist fish
- Fluvial fish
- Indicates a prominent break at two clusters

Non-metric-multidimensional scaling

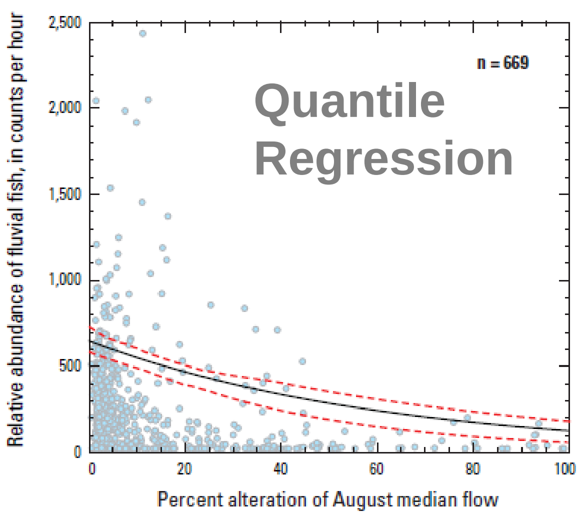


EXPLANATION
15-percent similarity from cluster analysis
EBT Fish species

Two analysis methods were used to associate fish assemblages and environmental factors

1. Quantile regression

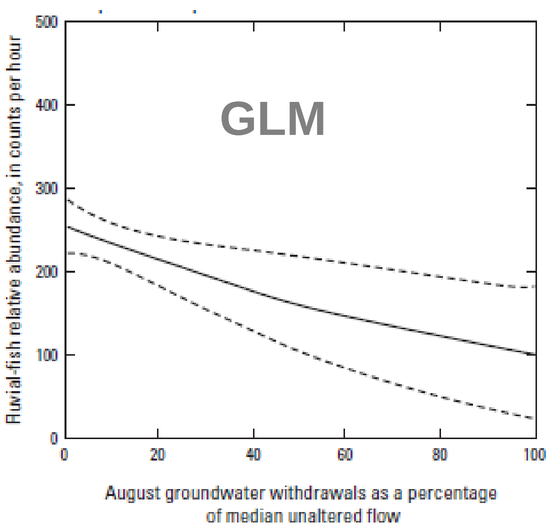
2. Generalized linear models (GLMs)



Quantile regression is univariate

Fluvial-fish relative-abundance model (with IC)

$$E(Y) = e^{6.1523 - 0.0840\, CHSLP - 0.0091\, AUGgwWp - 0.0289\, pBWet - 0.0373\, IC}$$



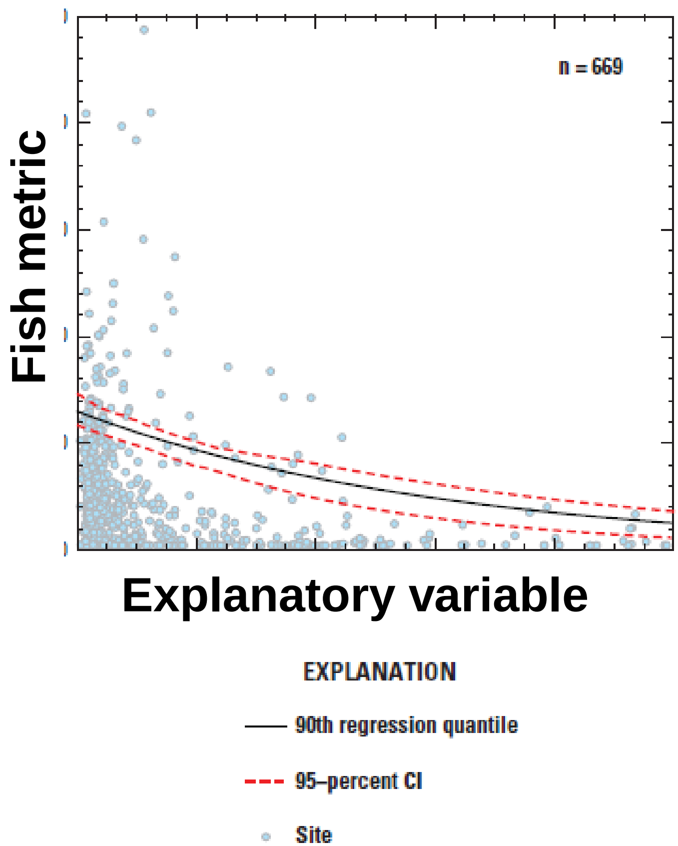
GLMs are multivariate

Quantile Regression

- Ecologic data is highly variable.
- Scatterplots of fish assemblage data and stressors are often wedge-shaped plots.
- Quantile regression is used to define the upper limit of a wedge-shaped relation.

Variability occurs because factors other than the factor of interest limit the response variable.

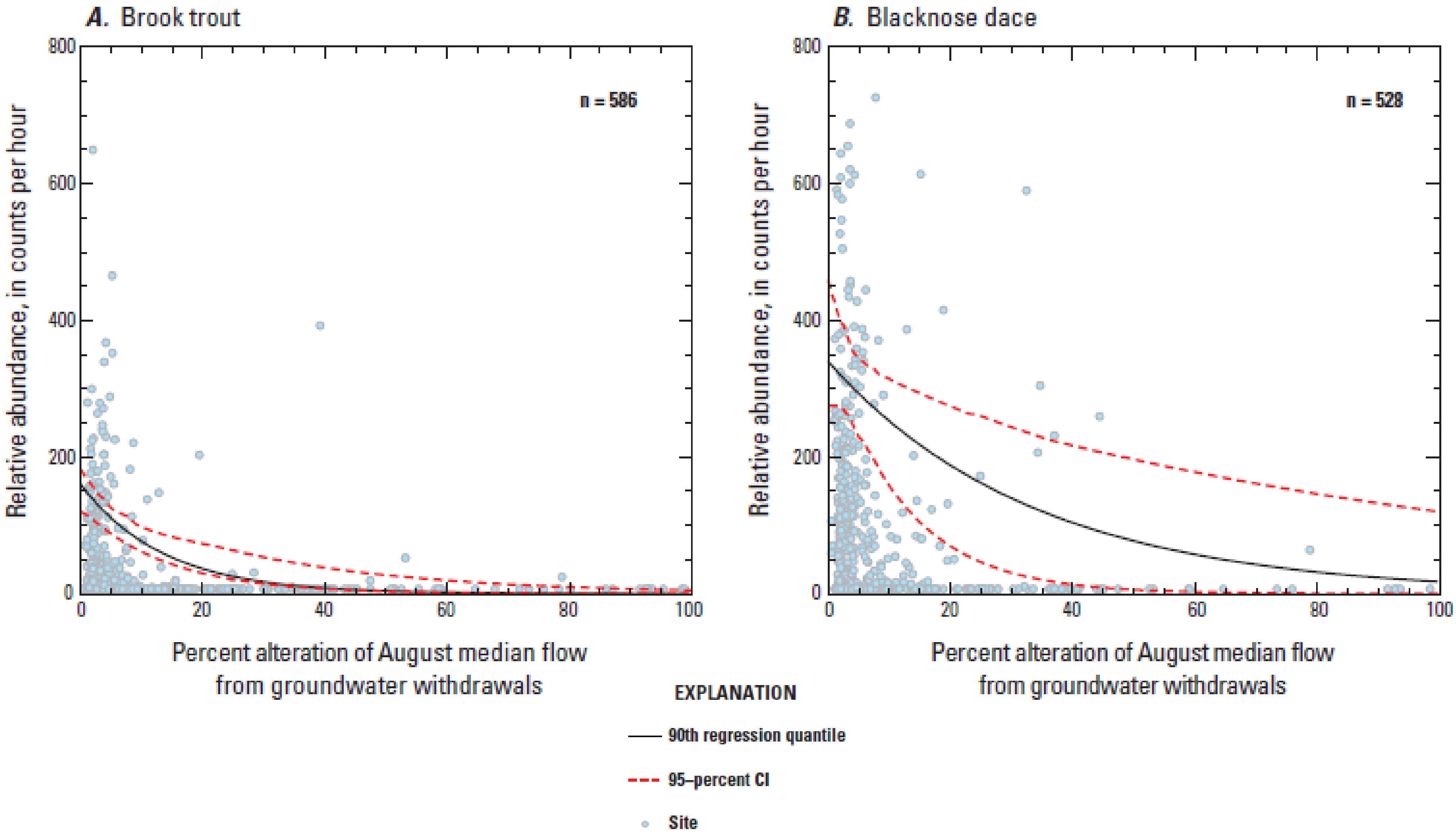
Example:
a site may have no flow alterations, but could have poor water quality or altered habitat conditions.



The declining upper bound indicates that the explanatory variable can act as a constraint on the response variable, and illustrates the maximum abundance of a species given ideal environmental conditions.

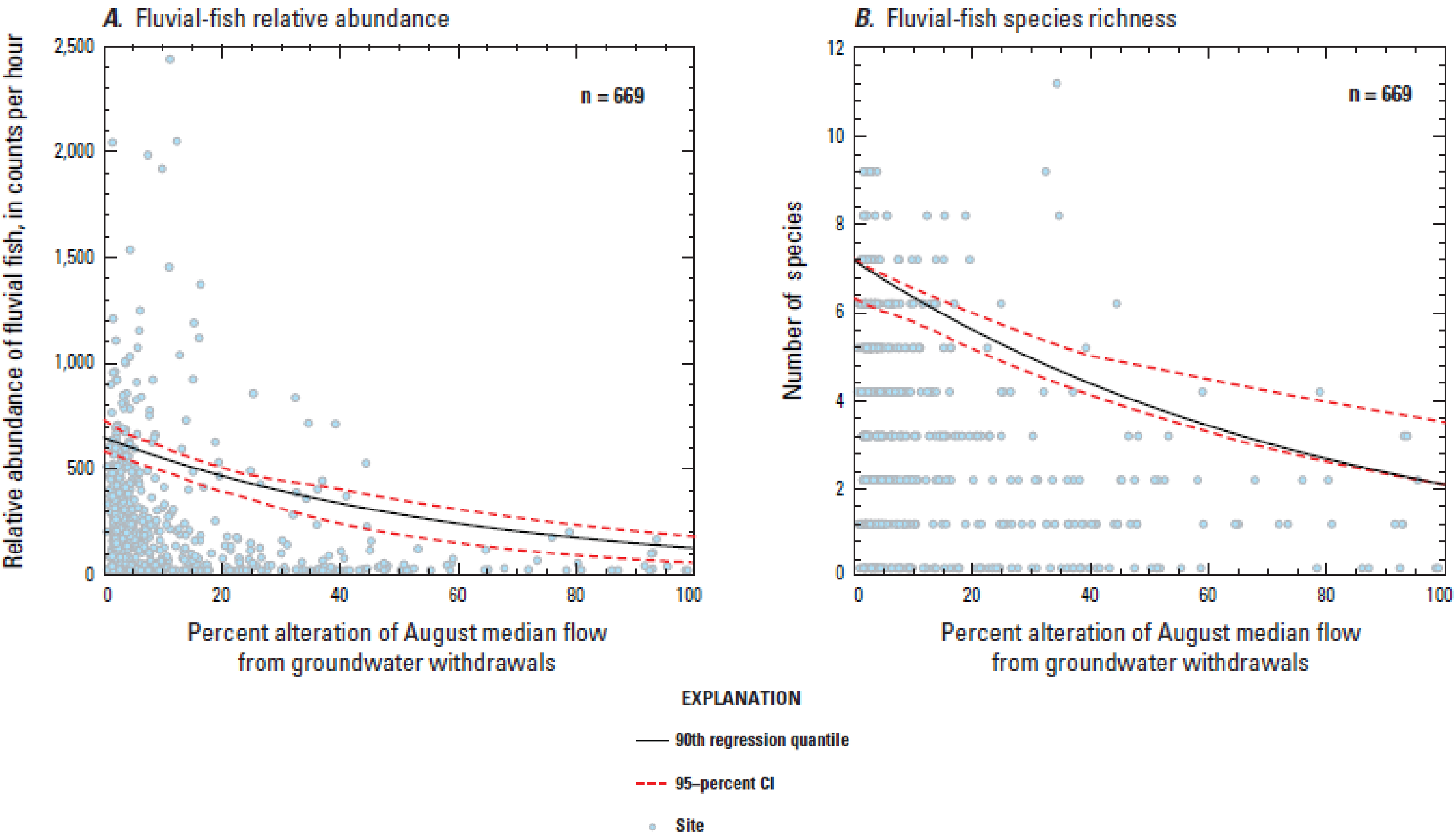
Flow alteration

- Quantile regression shows that **fish species** relative abundance decreases with increasing flow alteration from groundwater withdrawals



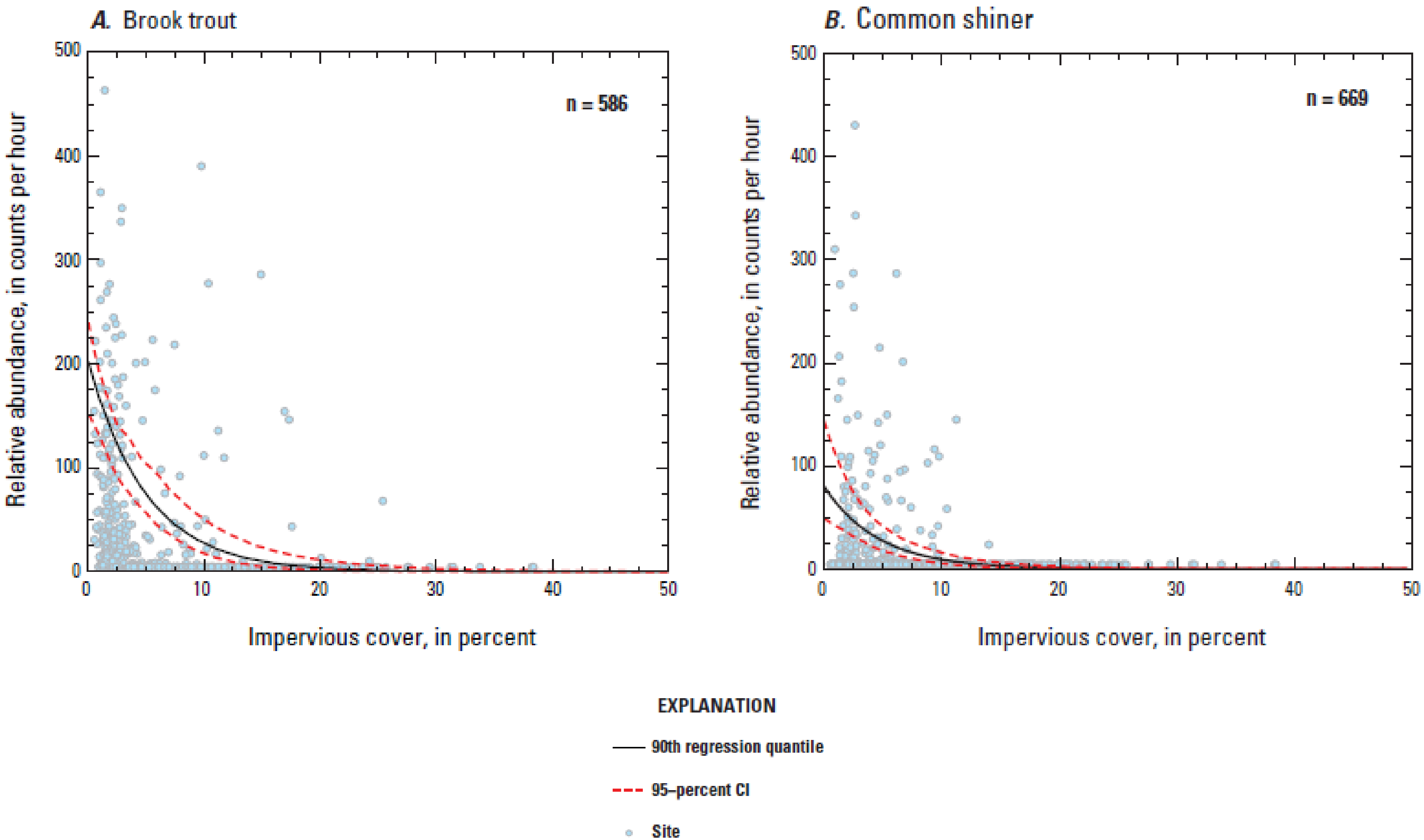
Flow alteration

- Quantile regression shows that **fluvial fish metrics** decrease with increasing flow alteration from groundwater withdrawals



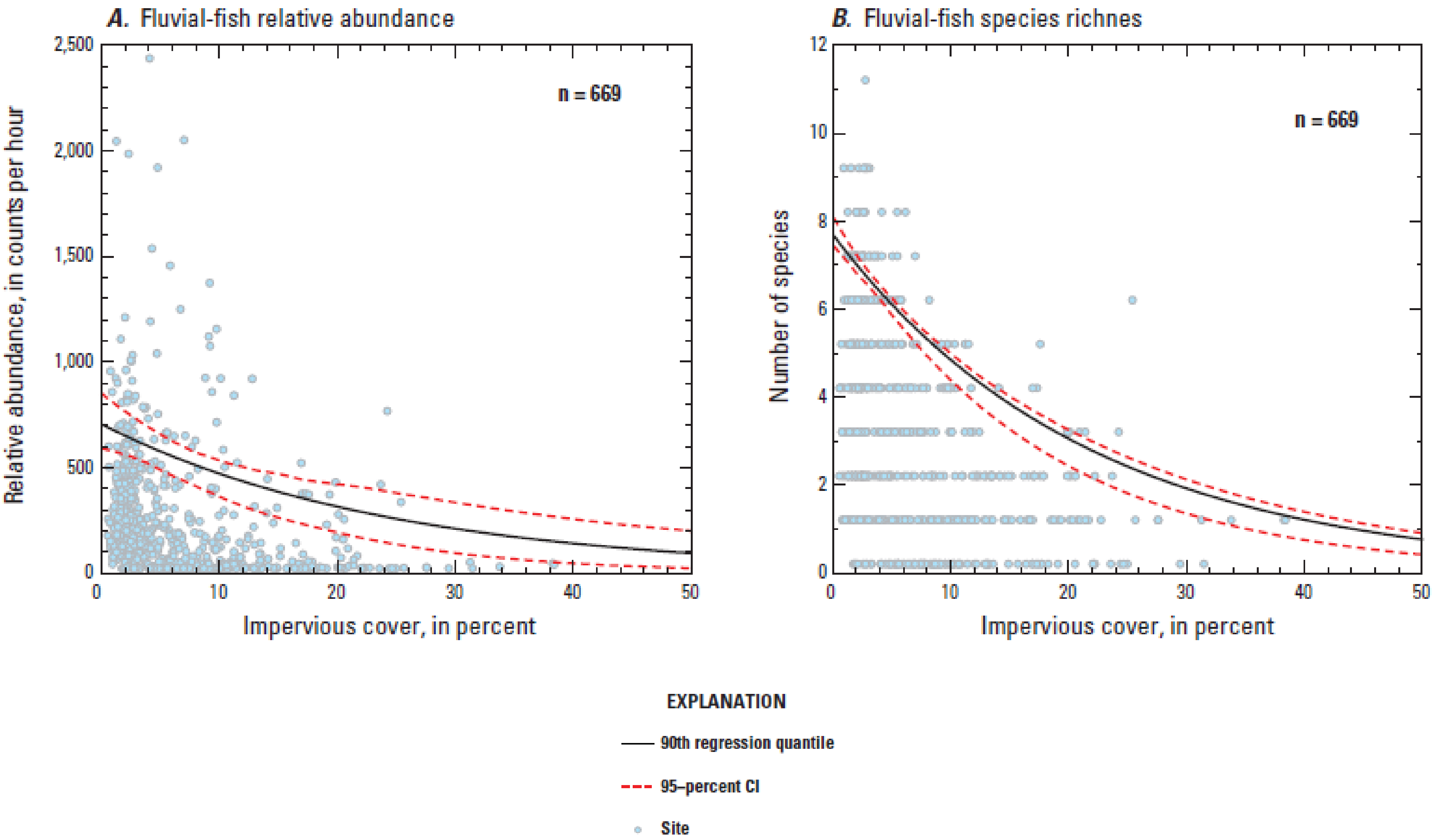
Impervious cover

- Quantile regression shows that **fish species** relative abundance decreases with increasing percent impervious cover



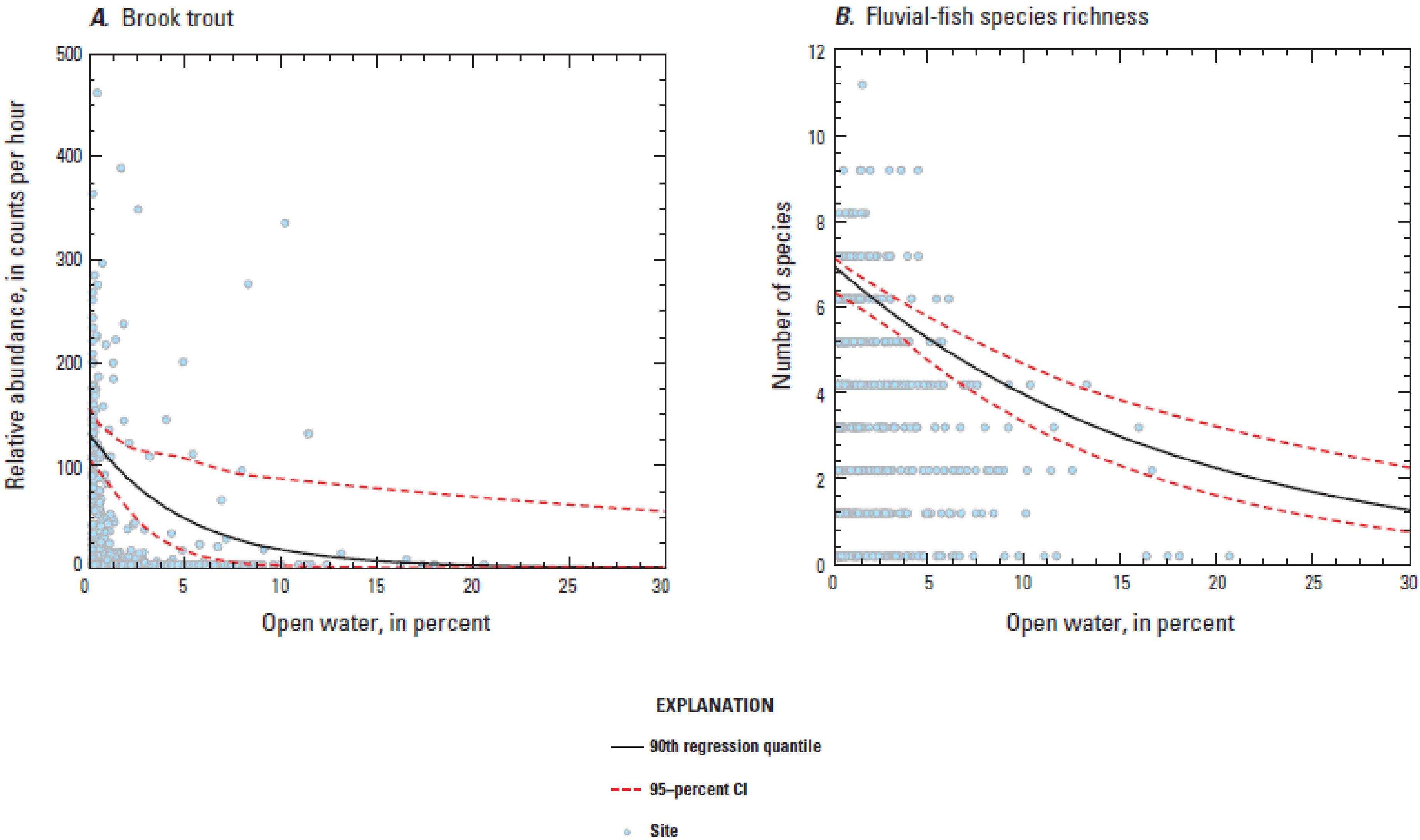
Impervious cover

• Quantile regression shows that **fluvial fish metrics** decrease with increasing percent impervious cover



Dams

• Quantile regression also indicates fluvial fish decrease with increases in **percent open water (an indicator of impoundments)**



Generalized linear models

- Generalized Linear Models (GLMs) were used to relate a suite of multiple explanatory variables to fish-response variables.

- GLMs are the appropriate analytical tool for non-normally distributed data, count data, and data sets with large numbers of zero values.

- A GLM equation predicts the mean response for the fish metric

- GLM equations were developed for

  1. Fluvial-fish species richness
  2. Fluvial-fish relative abundance
  3. Brook trout relative abundance

Fluvial-fish relative-abundance model

$$E\left(Y\right) = e^{6.1523 - 0.0840\ CHSLP - 0.0091\ AUGgwWp - 0.0289\ pBWet - 0.0373\ IC}$$

Table 8. A, Significant variables and coefficients and B, measures of goodness of fit for generalized linear model equations used to determine relations between environmental and anthropogenic factors and indicator species and fish-assemblage metrics in Massachusetts streams.

A. Significant variables and coefficients

Independent variable	code	Coefficient	SE	*p*-value
Intercept		6.1523	0.0942	<0.0010
Channel slope	CHSLP	-0.0840	0.0361	0.0202
Pct alt of Aug median flow from gw withdrawals	AUGgwWp	-0.0091	0.0042	0.0286
Percent wetland in buffer	pBWet_al	-0.0289	0.0059	<0.0010
Impervious cover	IC	-0.0373	0.0132	0.0047

B. Measures of goodness of fit

Model	Pearson's r	Pseudo-R squared (percent)
Fluvial-fish relative abundance	0.5	18.2

- All 3 models were significant at the 95-percent confidence level or greater ($p < 0.05$)

- Measures of goodness-of-fit for the GLM models (Pearson's *r* and Pseudo R^2) are within a typical range for ecologic models

B. Measures of goodness of fit

Model	Pearson's r	Pseudo-R squared (percent)
Fluvial-fish species richness	0.6	33.1
Fluvial-fish relative abundance	0.5	18.2
Brook trout relative abundance	0.50	34.7

- All variables in the equations are significant, but the R^2 indicate that there are other variables that have an effect on fish populations that are not accounted for by the equation

- Unexplained variability could be explained by many causes, including water quality, temperature, local habitat conditions, location of sample sites relative to alterations, use of modeled flow data, and other factors

- Ecological systems are complicated and it is difficult to account for all the variability.

- Impervious cover was also a significant variable in the equations for fluvial-fish species richness and brook trout relative abundance

Fluvial-fish species richness model

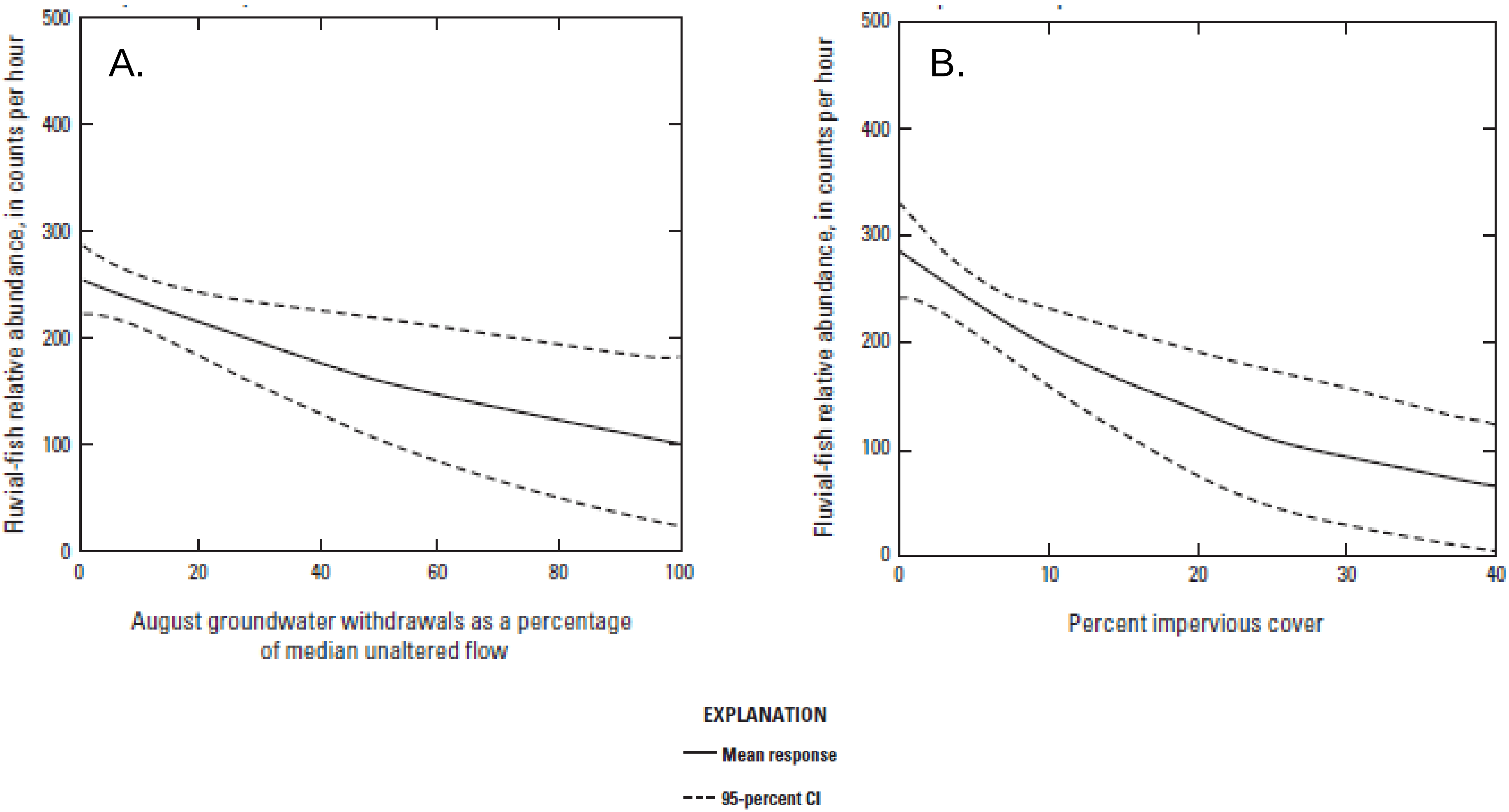
$$E(Y) = e^{1.7911 + 0.0011\,DA - 0.0968\,CHSLP + 0.0008\,UdamTmi - 0.0262\,pBWet - 0.0557\,IC},$$

Brook trout relative abundance model

$$E(Y) = e^{4.9336 - 0.1291\,DA - 0.2172\,pCOW - 0.0916\,IC},$$

Fluvial-fish relative-abundance model

Plots, (developed using median values for environmental factors), illustrate that fluvial fish decrease with increases in percent alteration of August median flow, And with increases in impervious cover



Fluvial-fish relative-abundance model

Results of the fluvial-fish relative-abundance equation indicate that, keeping all other variables the same, …

- a unit increase in the percent alteration of August median streamflow from groundwater withdrawals indicator is associated with
a 0.9-percent decrease in relative abundance of fluvial fish

- a unit increase in impervious cover is associated with
a 3.7-percent decrease in fluvial-fish relative abundance

Comparisons to Preliminary Analysis

- **Variable selection**
  - the Preliminary report used "Best Professional Judgement" to select variables
  - the Final report used a statistical process to select candidate variables
  - statistical analysis in the Final report supported the use of the fluvial fish metric

- **Different flow-alteration variables**
  - the Preliminary report used net flow alteration variables, such as "percent alteration of August median flow at net depleted sites"
  - The Final report used individual components of flow alteration, such as " percent alteration of August median flow from groundwater withdrawals"

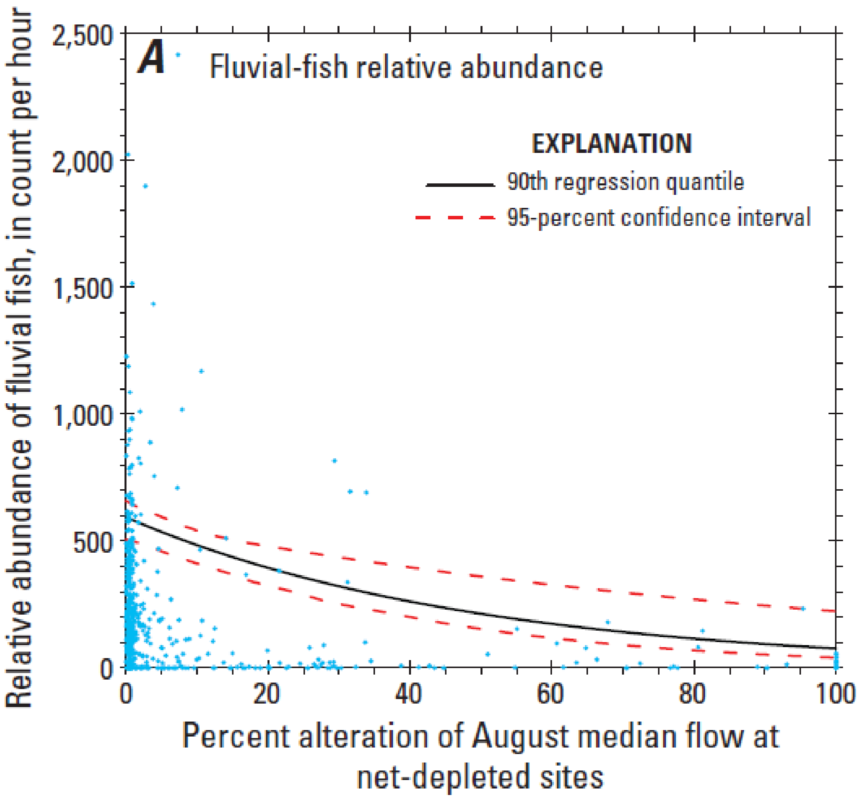
- **Different GLM models**

In comparison to the models used in Preliminary Report, these models:

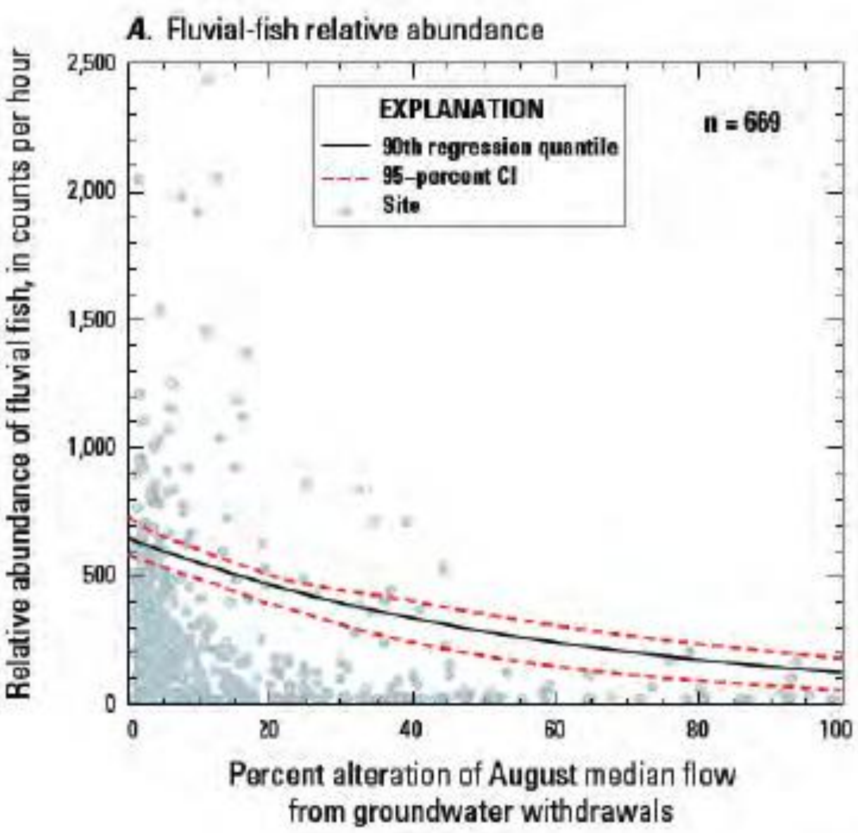
  - are simpler models
  - provide pseudo-R^2 (equivalent to an R^2 for GLMs)
  - provide confidence intervals

- **Similar results**
  - relations shown on quantile regression are similar in the two reports
  - the variables in the GLM equations in the reports were similar

Preliminary report

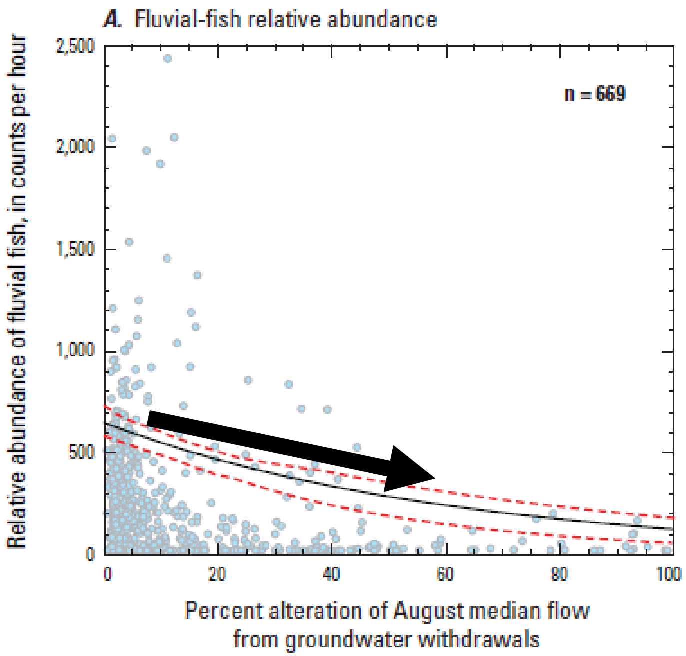


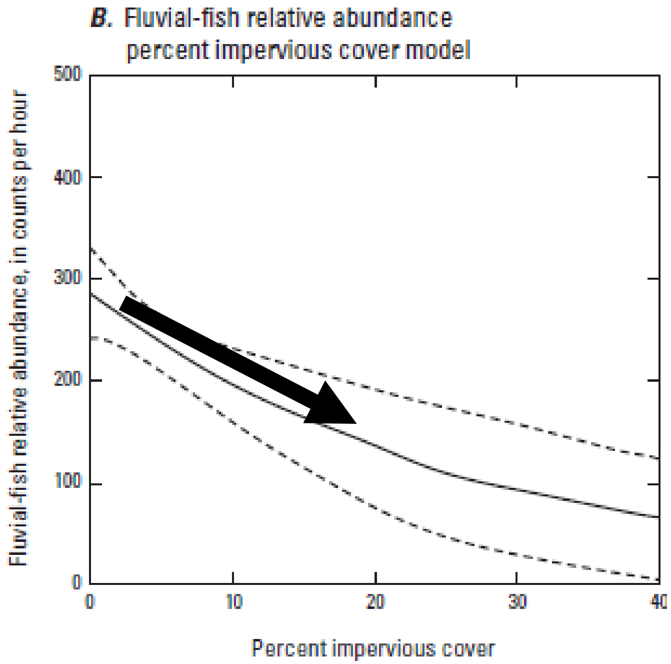
Final report



RESULTS: The report demonstrates that fish metrics decrease with increases in anthropogenic factors such as flow alteration from groundwater withdrawals, impervious cover, and dams.

FISH METRICS





ANTHROPOGENIC GRADIENT

SUMMARY

- The quantile regressions and GLM equations developed during this study illustrate **statewide relations** between fish-assemblage metrics and environmental and anthropogenic factors.

- The GLM equations **quantify these relations**

- Results of this study provide information on fish assemblages that can be used by the Sustainable Water Management Initiative (SWMI) to make more-informed decisions about managing factors that affect aquatic habitat in Massachusetts.

Acknowledgements

• This work has been a cooperative effort between the USGS MA-RI Water Science Center and MA state agencies:

MA Department of Conservation and Recreation
MA Department of Environmental Protection
MA Department of Fish and Game
Division of Fish and Wildlife

• Thank you to report reviewers
C. Konrad, L. Brown, M. Freeman (USGS)
S. Wenger, (TU/USFS),
N. Detenbeck (EPA)

L. Hutchins, A. Carroll (MDCR)
T. Lamonte, W. Kimball, G. Szal (MDEP)
M. Tisa, (MDCR)
J. Magee, A. Paul (IFC),
K. Baskin, V. Rao (EOEEA)

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QUESTIONS ?