GeoCod

Geomatics for the Sustainable Management of Fish Stocks

La Géomatique au Service de la Gestion Durable des Stocks de Poissons

Spatial-temporal variations in shifting ecosystems: A Geographically Weighted Regression (GWR) analysis in the Northwest Atlantic

Matthew Windle[1],

George A. ROSE[2], Rodolphe DEVILLERS[3], and Marie-Josée FORTIN[4]

[1] Centre for Fisheries Ecosystem Research, Fisheries and Marine Institute, Memorial University

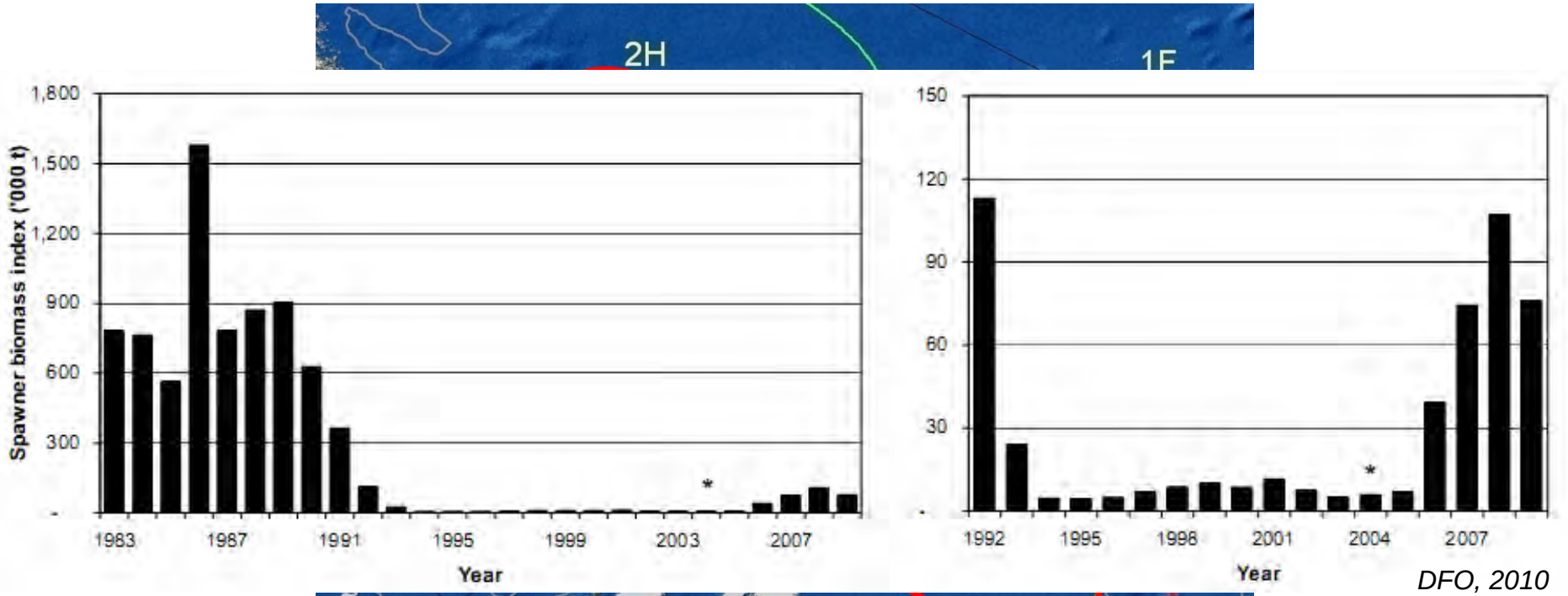
[2] Department of Geography, Memorial University

[3] Department of Ecology and Evolutionary Biology, University of Toronto

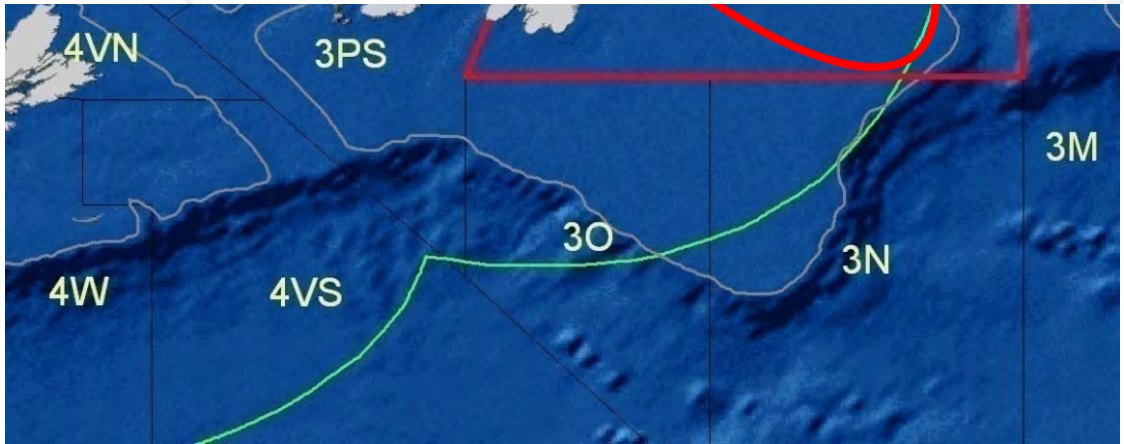
GEOIDE

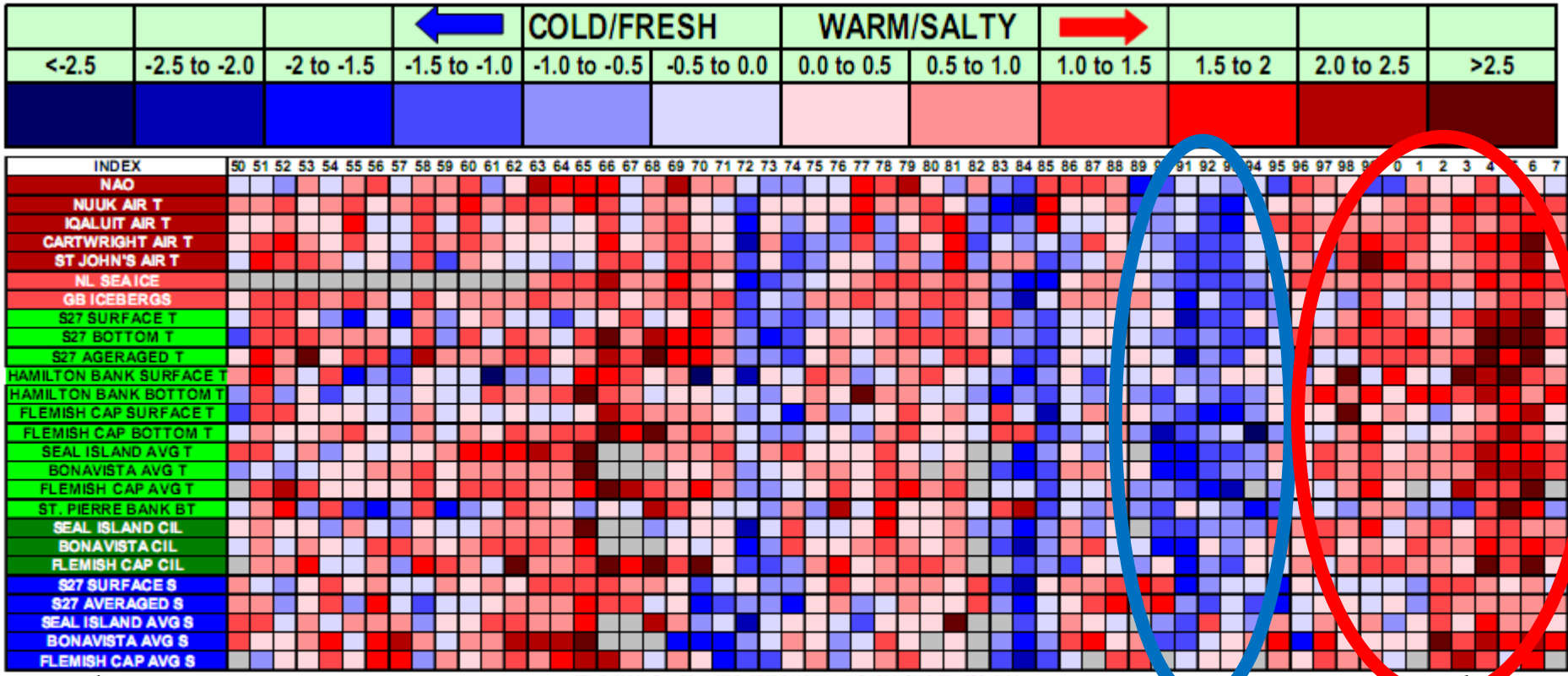
MEMORIAL UNIVERSITY

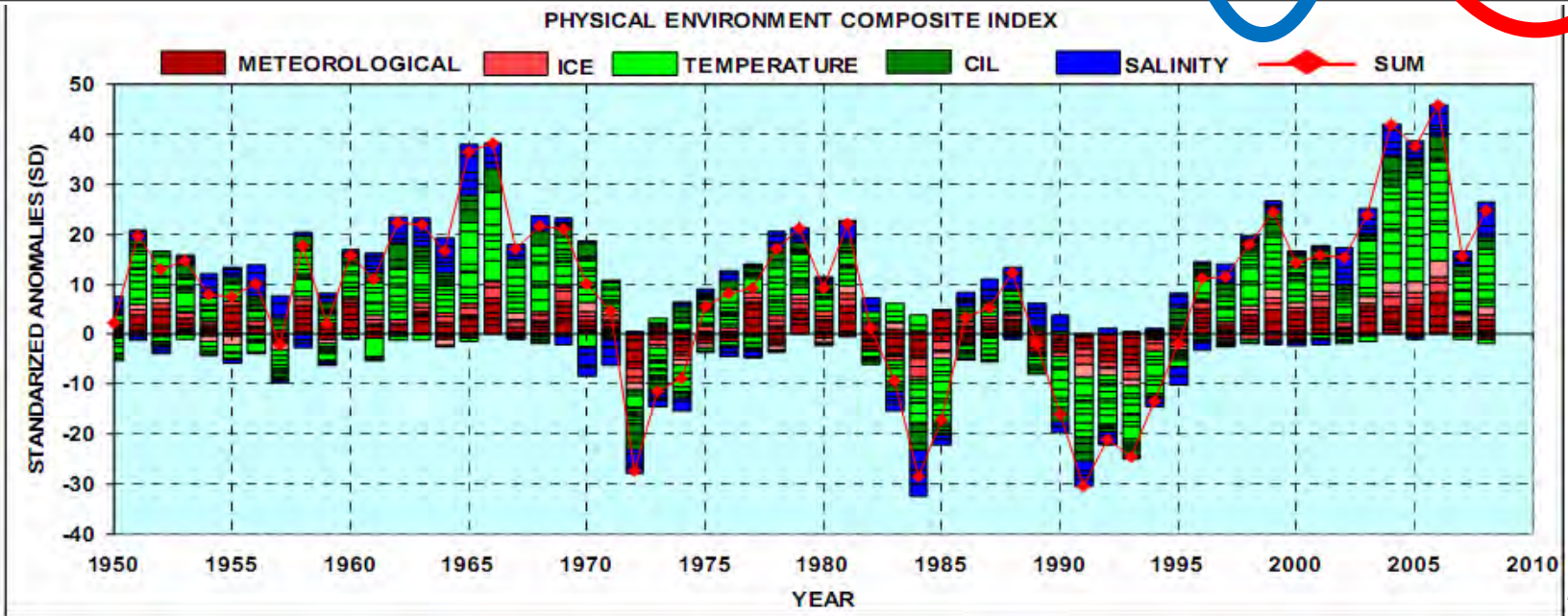
Northern cod collapse



DFO, 2010

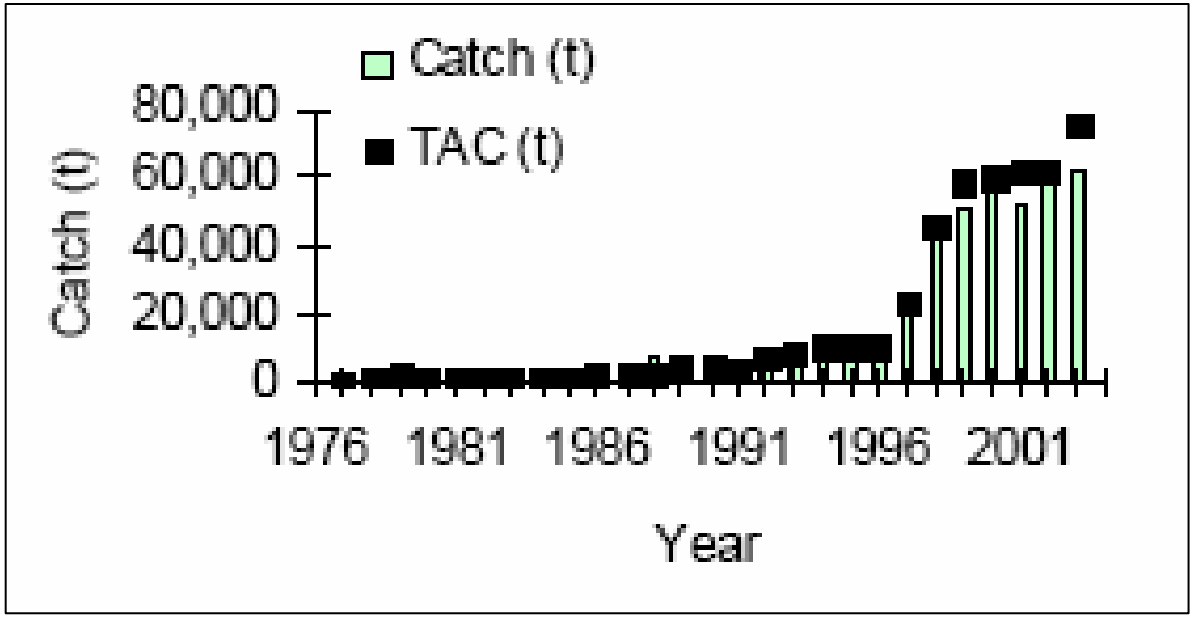



COLD/FRESH
WARM/SALTY
<-2.5
-2.5 to -2.0
-2 to -1.5
-1.5 to -1.0
-1.0 to -0.5
-0.5 to 0.0
0.0 to 0.5
0.5 to 1.0
1.0 to 1.5
1.5 to 2
2.0 to 2.5
>2.5
INDEX
NAO
NUUK AIR T
IQALUIT AIR T
CARTWRIGHT AIR T
ST JOHN'S AIR T
NL SEA ICE
GB ICEBERGS
S27 SURFACE T
S27 BOTTOM T
S27 AGERAGED T
HAMILTON BANK SURFACE T
HAMILTON BANK BOTTOM T
FLEMISH CAP SURFACE T
FLEMISH CAP BOTTOM T
SEAL ISLAND AVG T
BONAVISTA AVG T
FLEMISH CAP AVG T
ST. PIERRE BANK BT
SEAL ISLAND CIL
BONAVISTA CIL
FLEMISH CAP CIL
S27 SURFACE S
S27 AVERAGED S
SEAL ISLAND AVG S
BONAVISTA AVG S
FLEMISH CAP AVG S

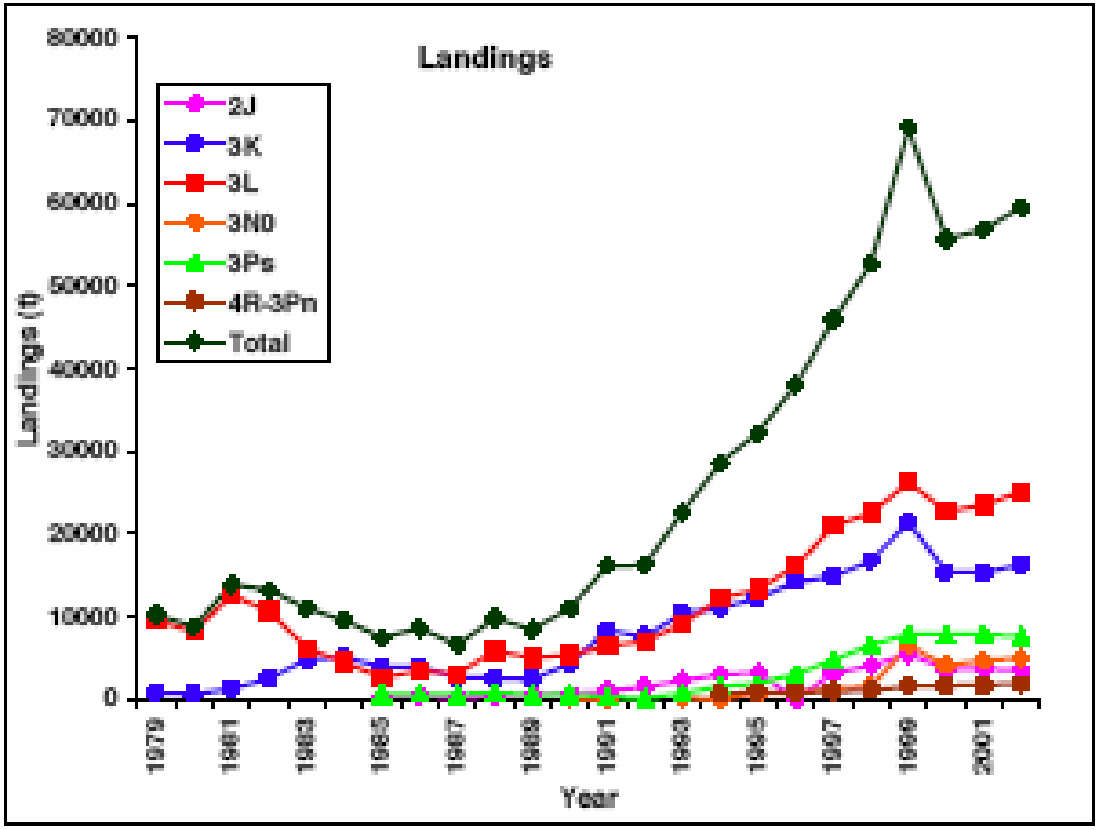

PHYSICAL ENVIRONMENT COMPOSITE INDEX
METEOROLOGICAL
ICE
TEMPERATURE
CIL
SALINITY
SUM
STANDARIZED ANOMALIES (SD)
YEAR
50
40
30
20
10
0
-10
-20
-30
-40
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010

DFO, 2009

Northern Shrimp (*Pandalis borealis*)



Snow Crab (*Chionoecetes opilio*)



DFO SSR 2003/021

Factors that affect Northern cod spatial distribution

Climate

- NAO
- Bottom temperature
- Salinity
- Currents

Mortality

- Fishing
- Predation (adult and larval)
- Intra-species competition

Prey

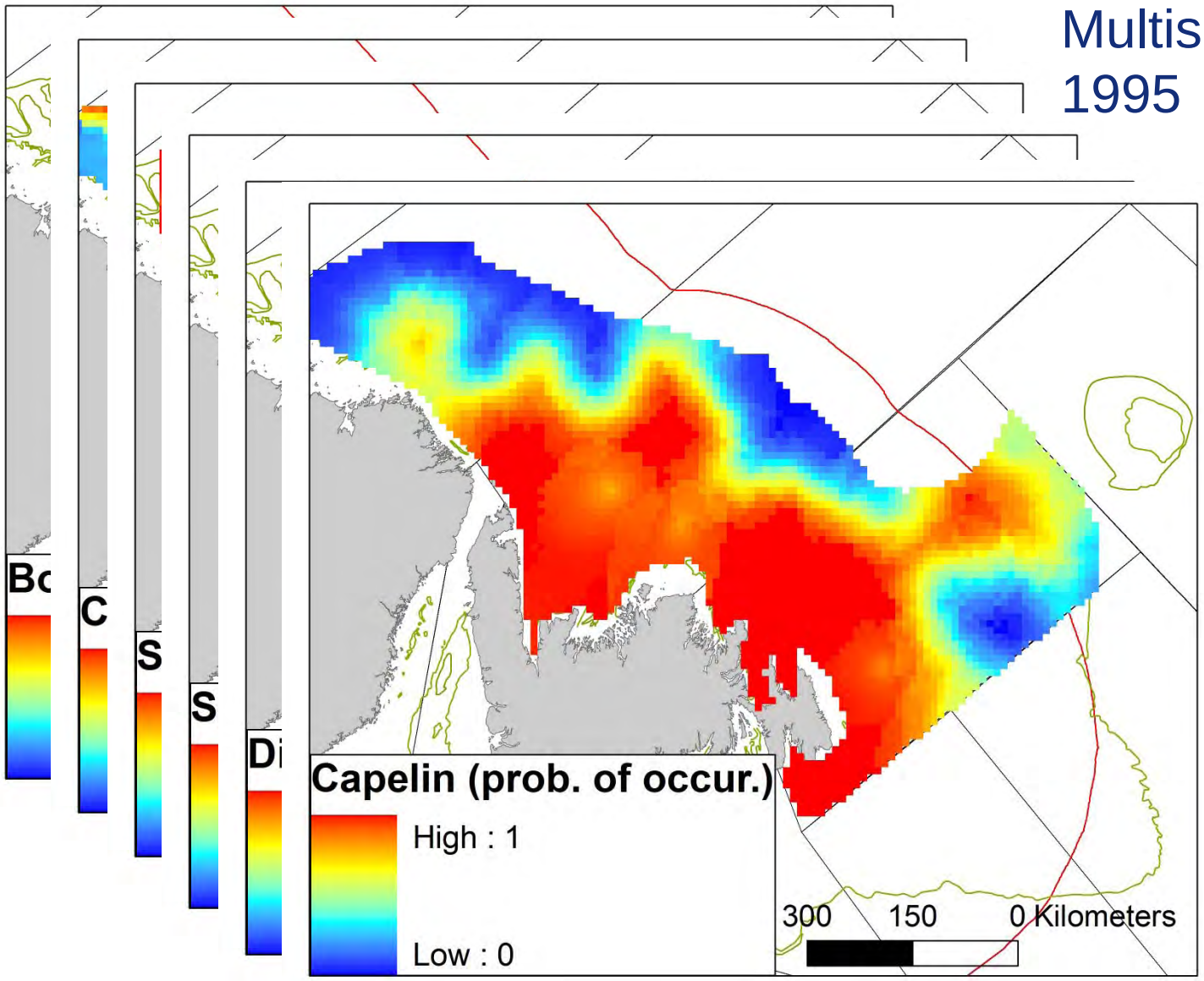
- Capelin (most important)
- Shrimp
- Sand lance
- Crab (small)
- Others (e.g. Arctic cod)

Other

- Migrations
- Spawning/feeding
- Life stage

Spatial Variability of Variables

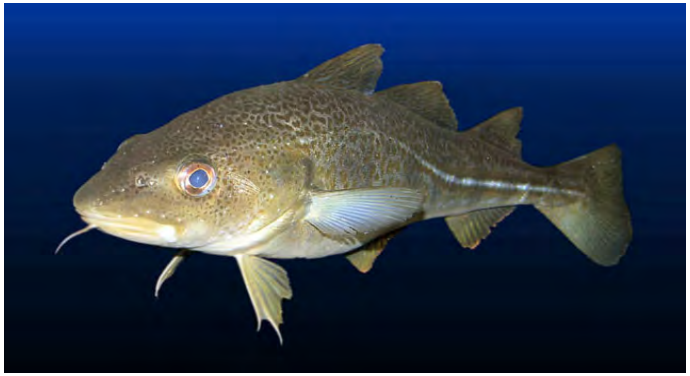
Multispecies Survey
1995



How well do these variables predict cod distribution across space and time?

Study Objectives

1. To model the spatial relationships between cod biomass and environmental and trophic variables through time
2. To investigate spatial non-stationarity of relationships between cod and explanatory variables within 2J3KL
3. To compare Ordinary Least Squares (OLS) regression, Generalized Additive Models (GAM) and Geographically Weighted Regression (GWR) model performances



A Tale of Two Time Periods

1985-1994

- Dependent variable:
  - Cod biomass [log(kg)]
- Independent variables:
  - Cod biomass (t-1)
  - Capelin prob. occurr. (0-1)
  - Capelin (t-1)
  - B. Temperature (C)
  - Shannon diversity index
    - Species richness/evenness

1995-2009

- Dependent variable:
  - Cod biomass [log(kg)]
- Independent variables:
  - Cod biomass (t-1)
  - Capelin prob. occurr. (0-1)
  - Capelin (t-1)
  - B. Temperature (C)
  - Shannon diversity index
    - Species richness/evenness
  - Crab biomass [log(kg)]
  - Shrimp biomass [log(kg)]

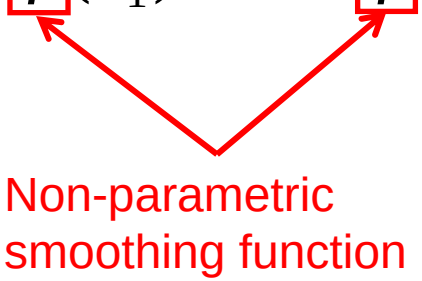
Global Regression Models

- Ordinary Least Squares (OLS)

$$\gamma = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p + \varepsilon$$

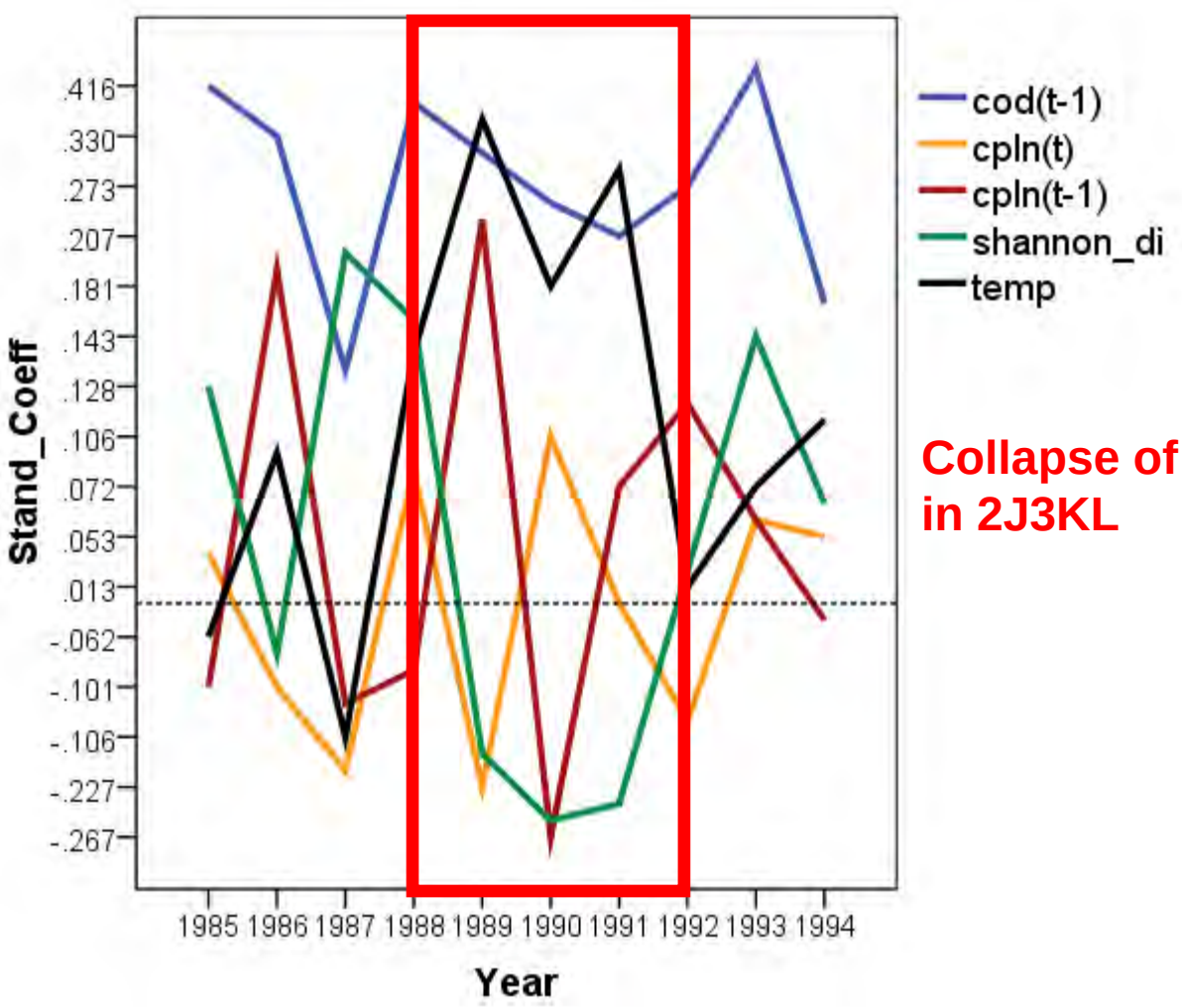
- Generalized Additive Models (GAM)

$$\gamma = \beta_0 + f(x_1) + \ldots + f(x_p) + \varepsilon$$



  - Gaussian, Identity link function

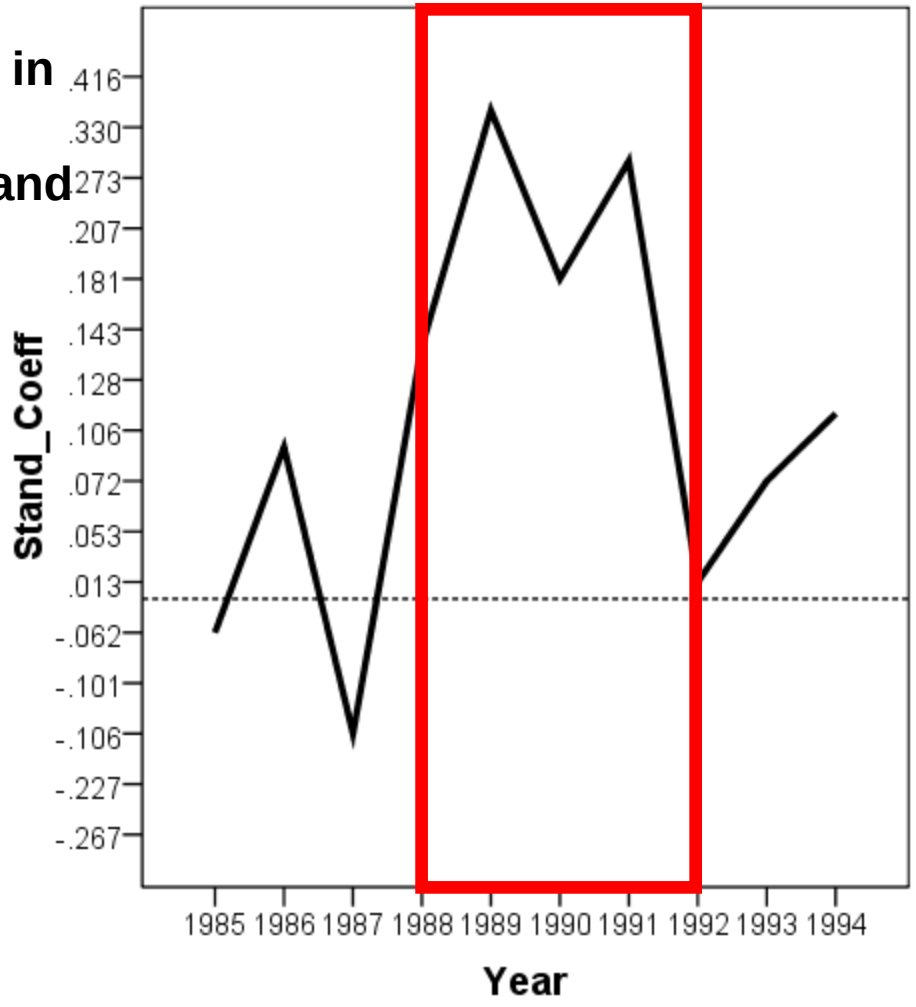
Standardized OLS Coefficients



Collapse of cod stock in 2J3KL

Standardized OLS Coefficients

Significant positive trend in relationship between cod and bottom temperature



Collapse of cod stock in 2J3KL

Standardized OLS Coefficients

Collapse of cod stock in 2J3KL

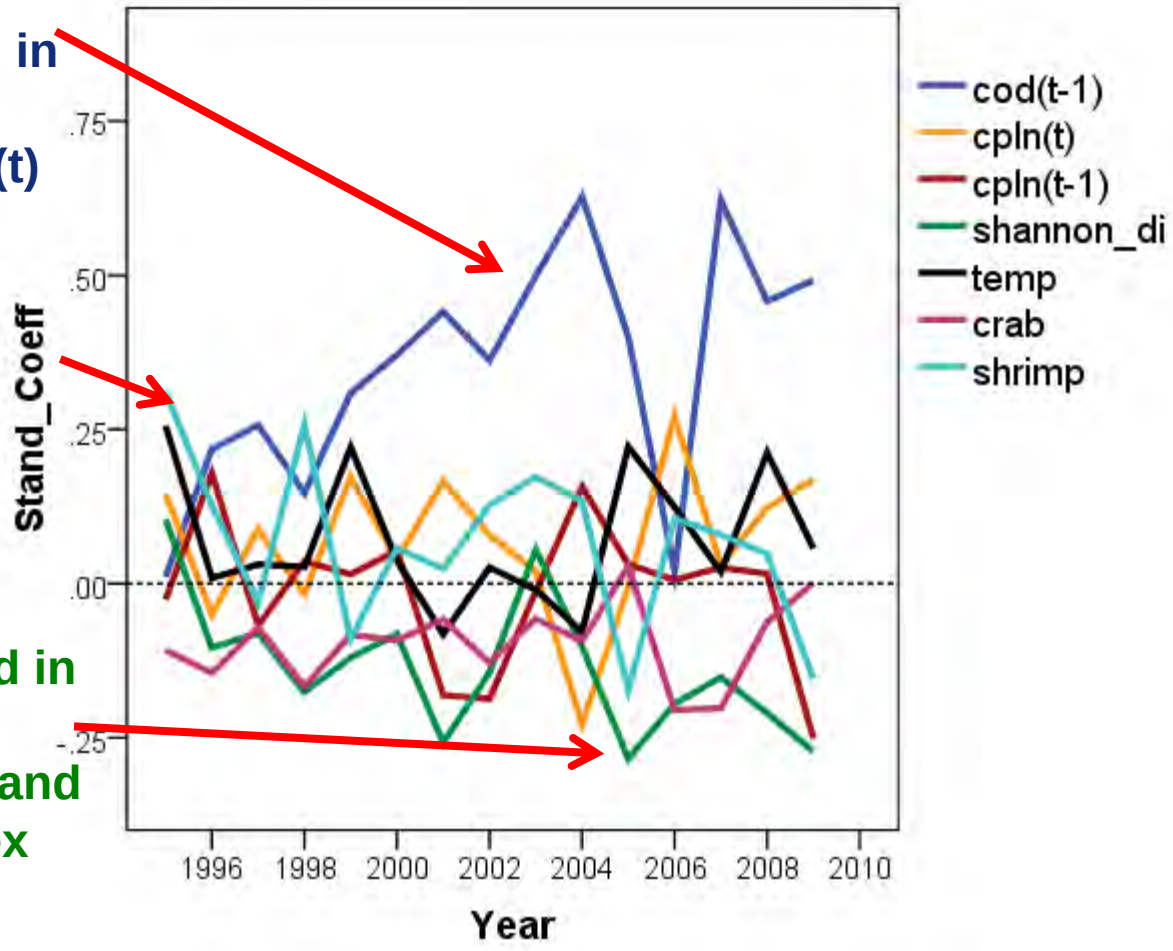
Significant negative trend in relationship between cod and diversity index

Standardized OLS Coefficients

Significant positive trend in relationship between cod (t) and cod (t-1)

Decreasing trend in relationship between cod and shrimp

Significant negative trend in relationship between cod and diversity index



Local Regression Models

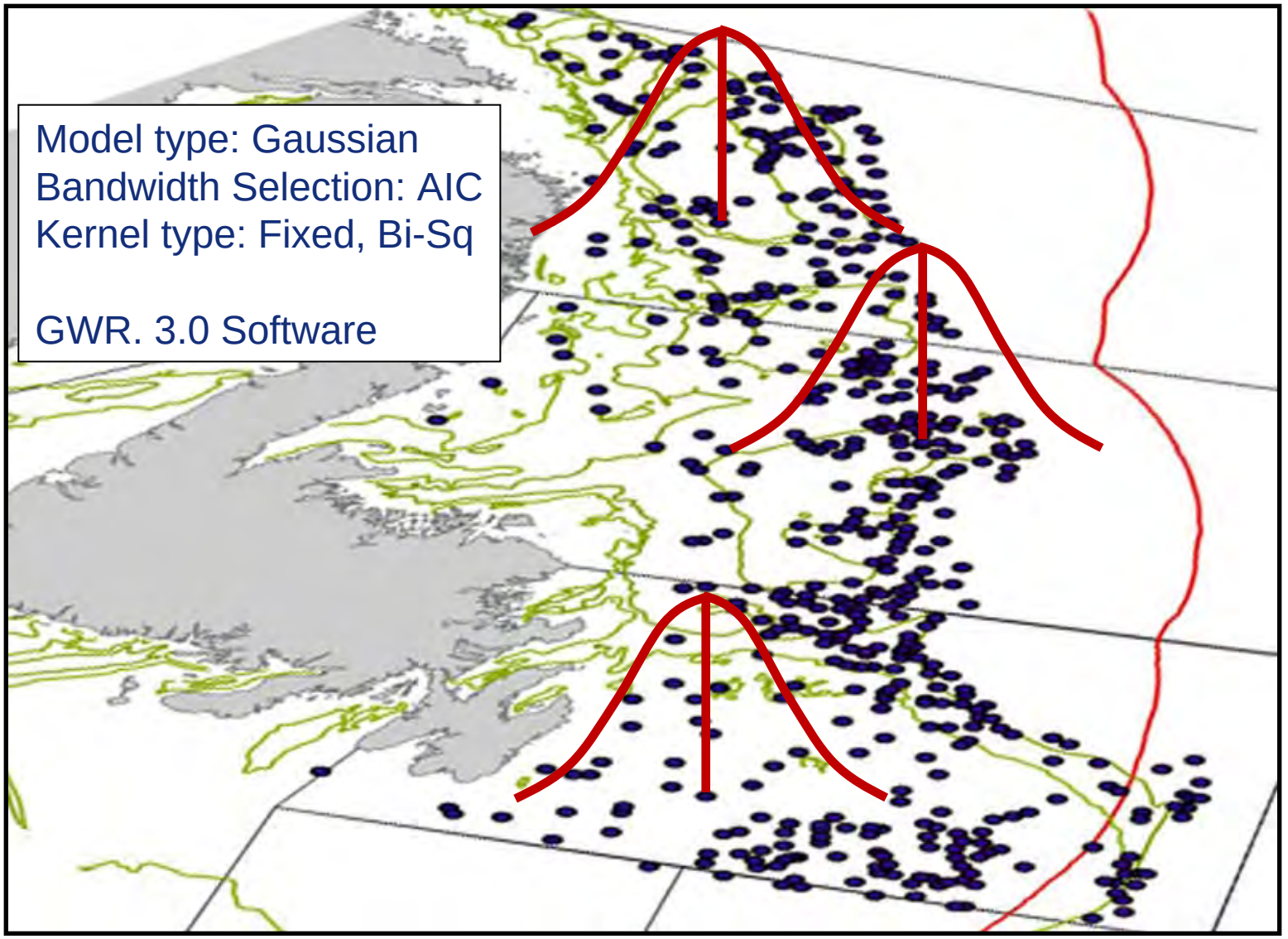
Geographically Weighted Regression (GWR)

$$\gamma = \beta_0(\mu,\nu) + \beta_1(\mu,\nu)x_1 + \ldots + \beta_p(\mu,\nu)x_p + \varepsilon$$

Coordinates of Samples

- Estimates a set of local regression coefficients for each observation point
- Observations closer to location being predicted are given more weight (using spatial kernel)
- Shows how regression coefficients (relationships) can vary across space

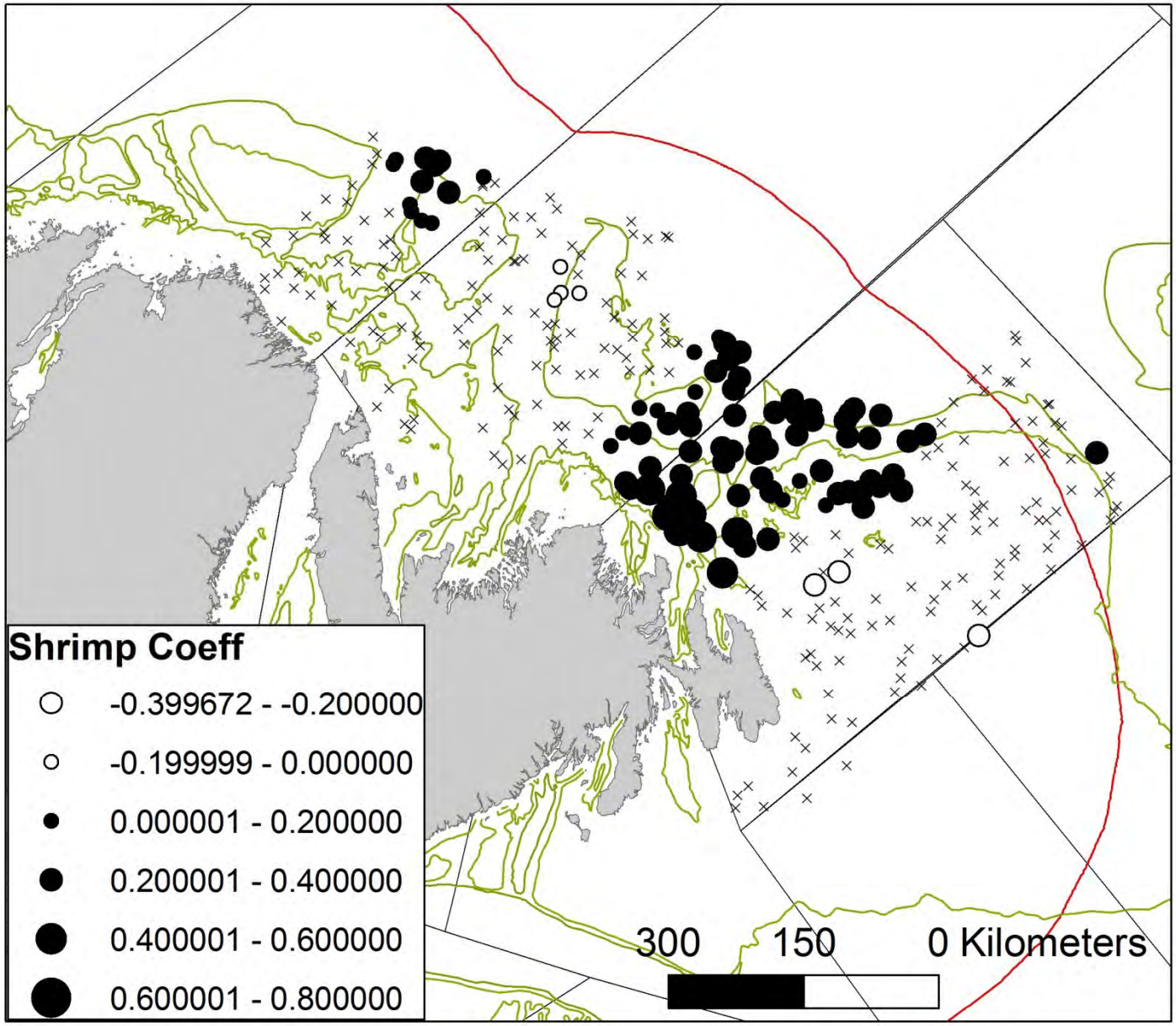
GWR Fixed Spatial Kernels



GWR local regression coefficients

- GWR generates a set of regression coefficients for each regression (trawl) location
- Plot coefficients on a map to visualize spatial variation of coefficients
- Examples:
  - Shrimp coefficients (1995-2009)
  - Crab coefficients (1995-2009)

GWR – Shrimp Coefficients



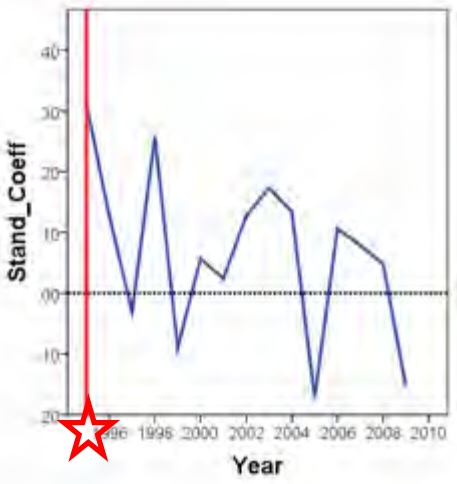
1995

Positive

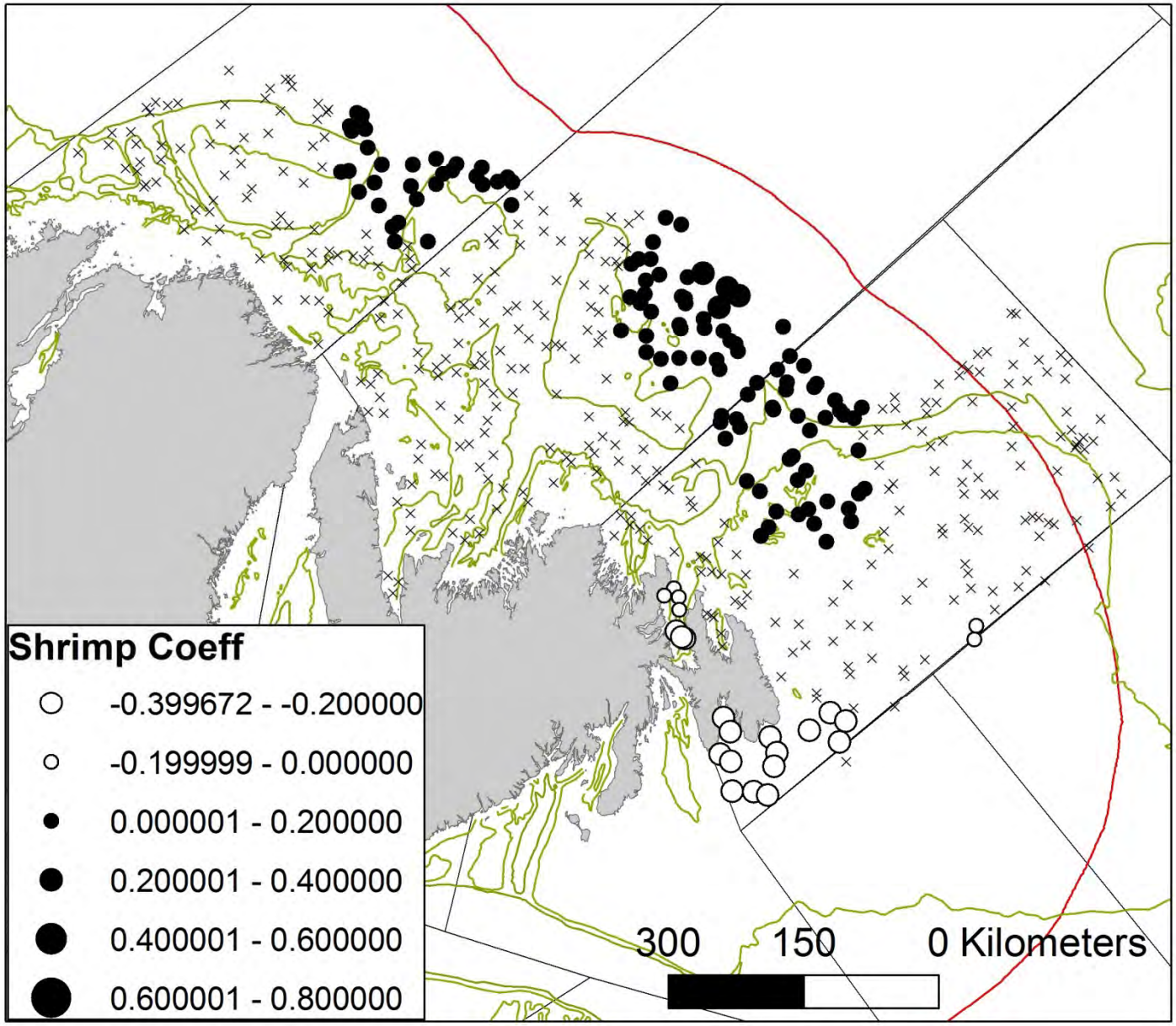
Negative

x Not Significant

OLS Stand. Coeff



GWR – Shrimp Coefficients



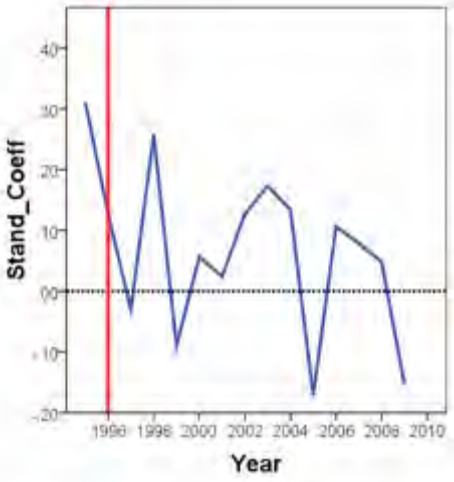
1996

Positive

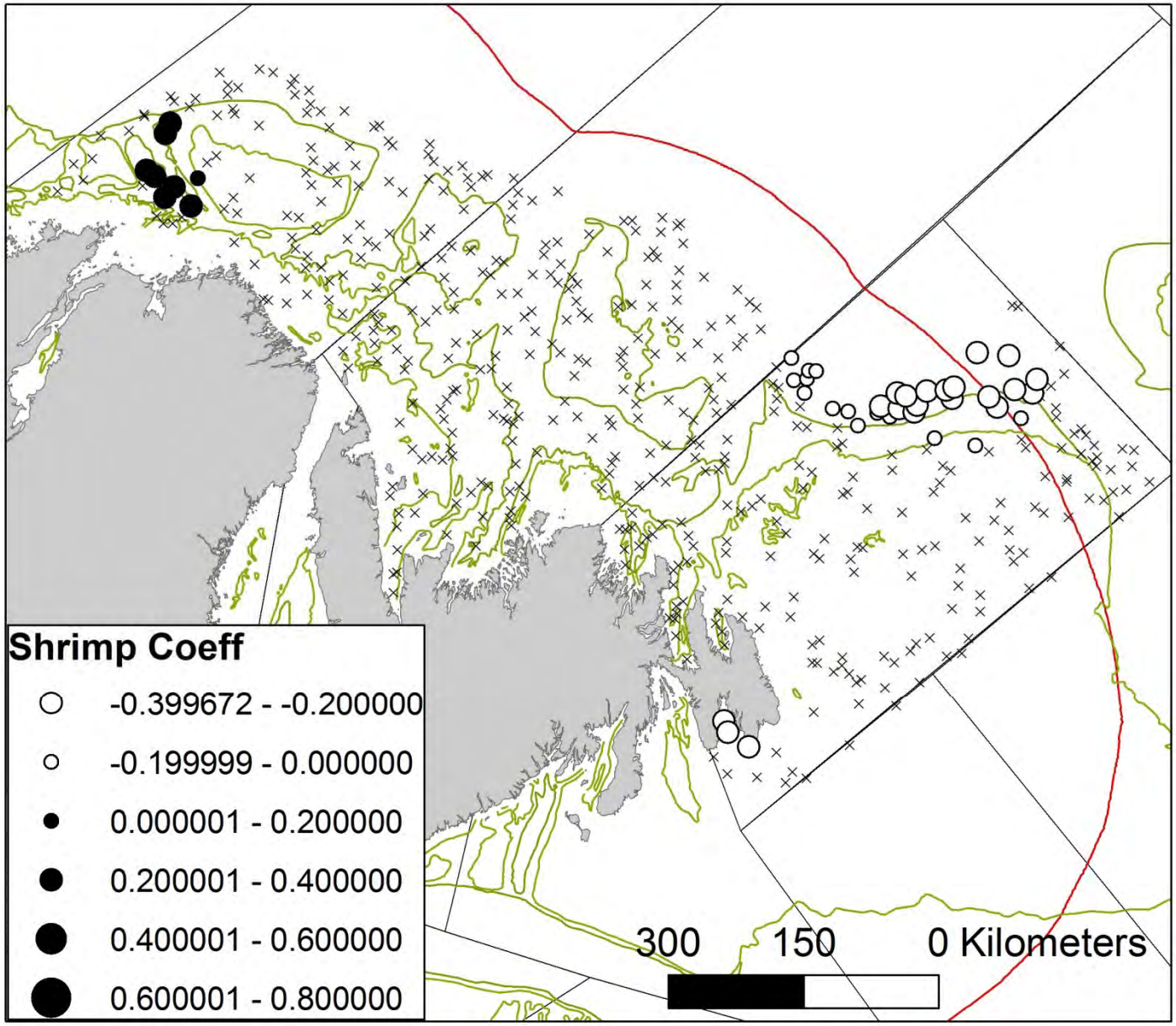
Negative

x Not Significant

OLS Stand. Coeff



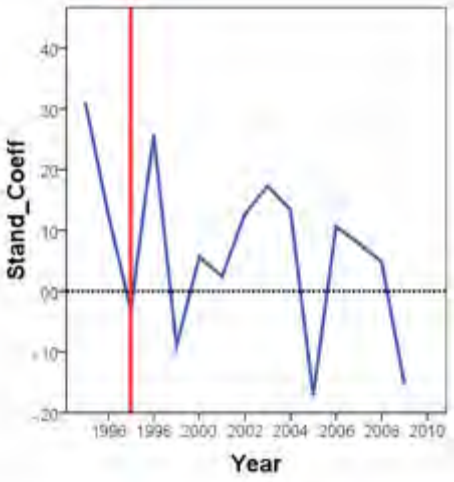
GWR – Shrimp Coefficients



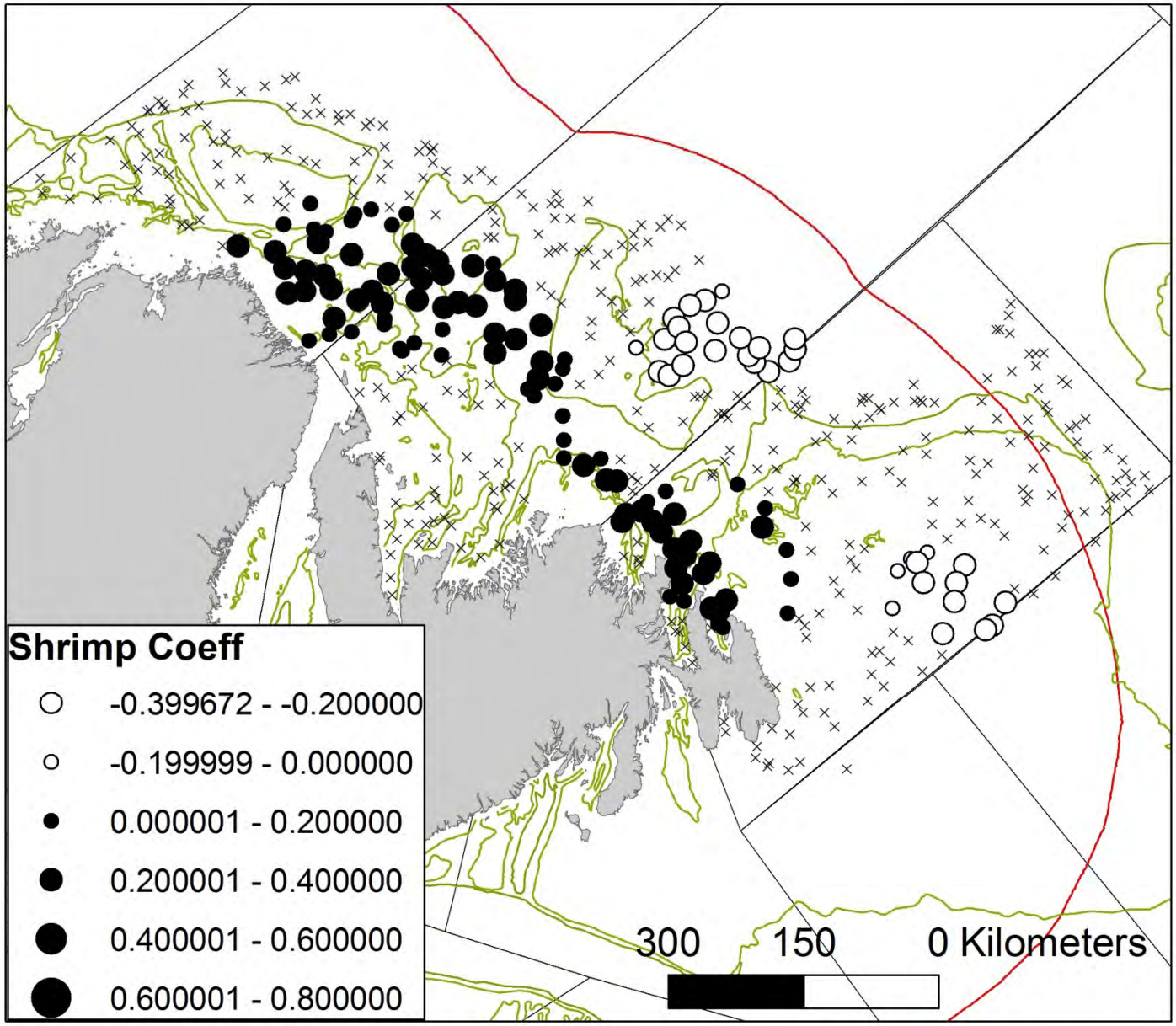
1997

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



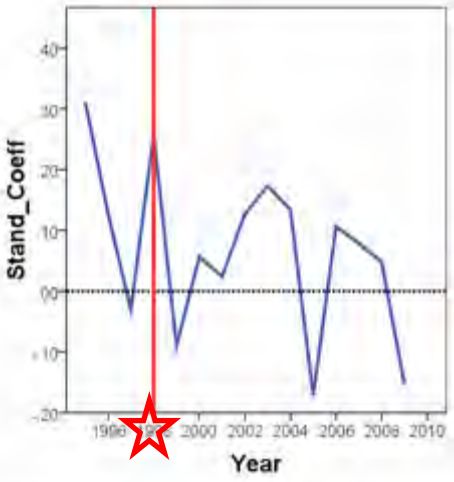
GWR – Shrimp Coefficients



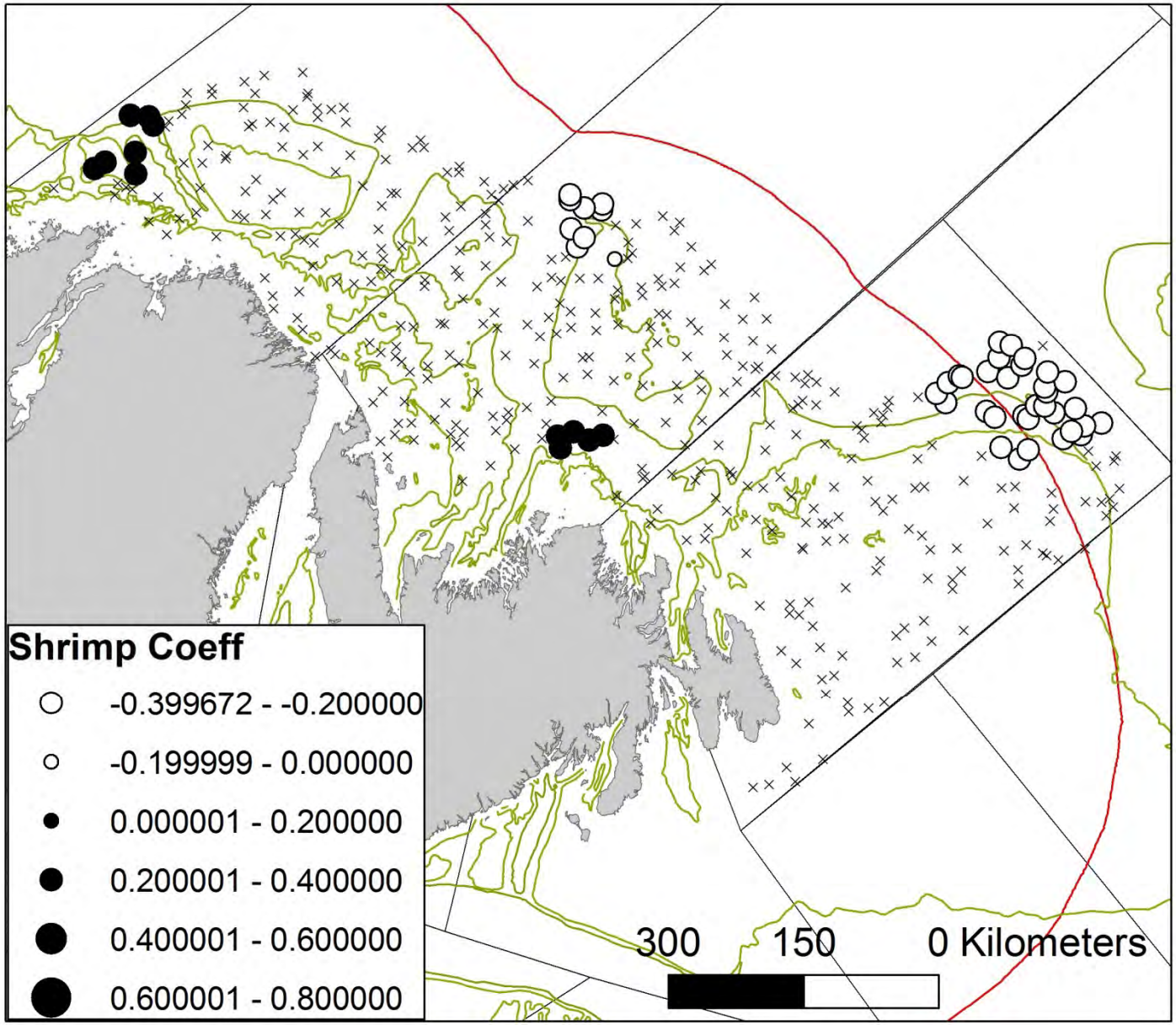
1998

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



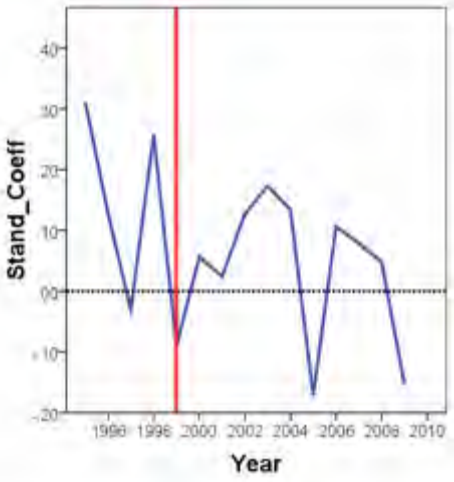
GWR – Shrimp Coefficients



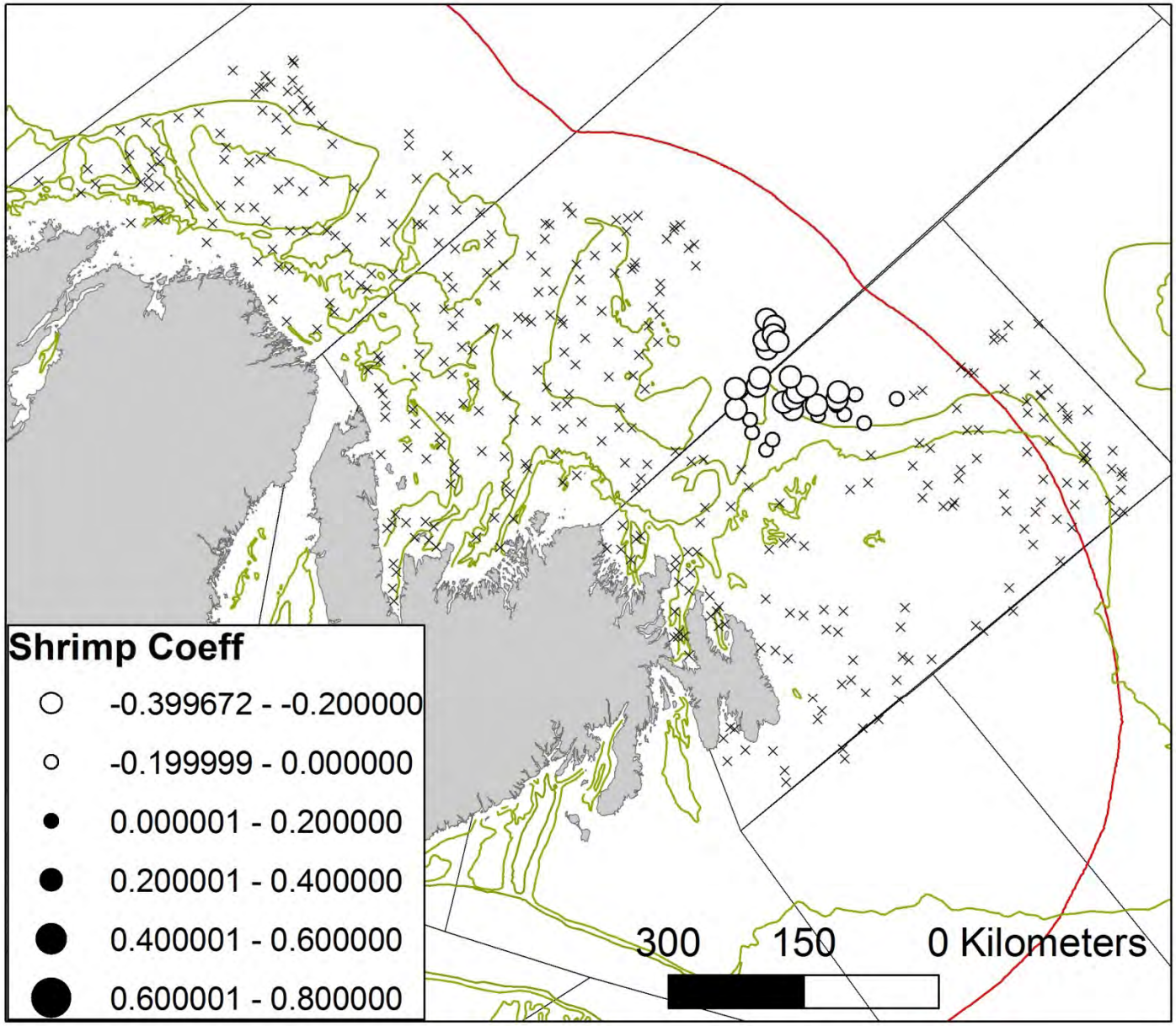
1999

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



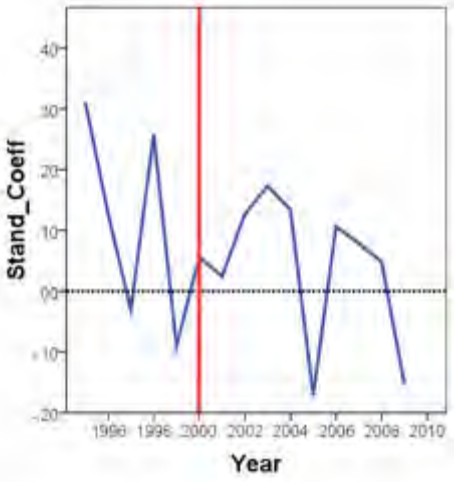
GWR – Shrimp Coefficients



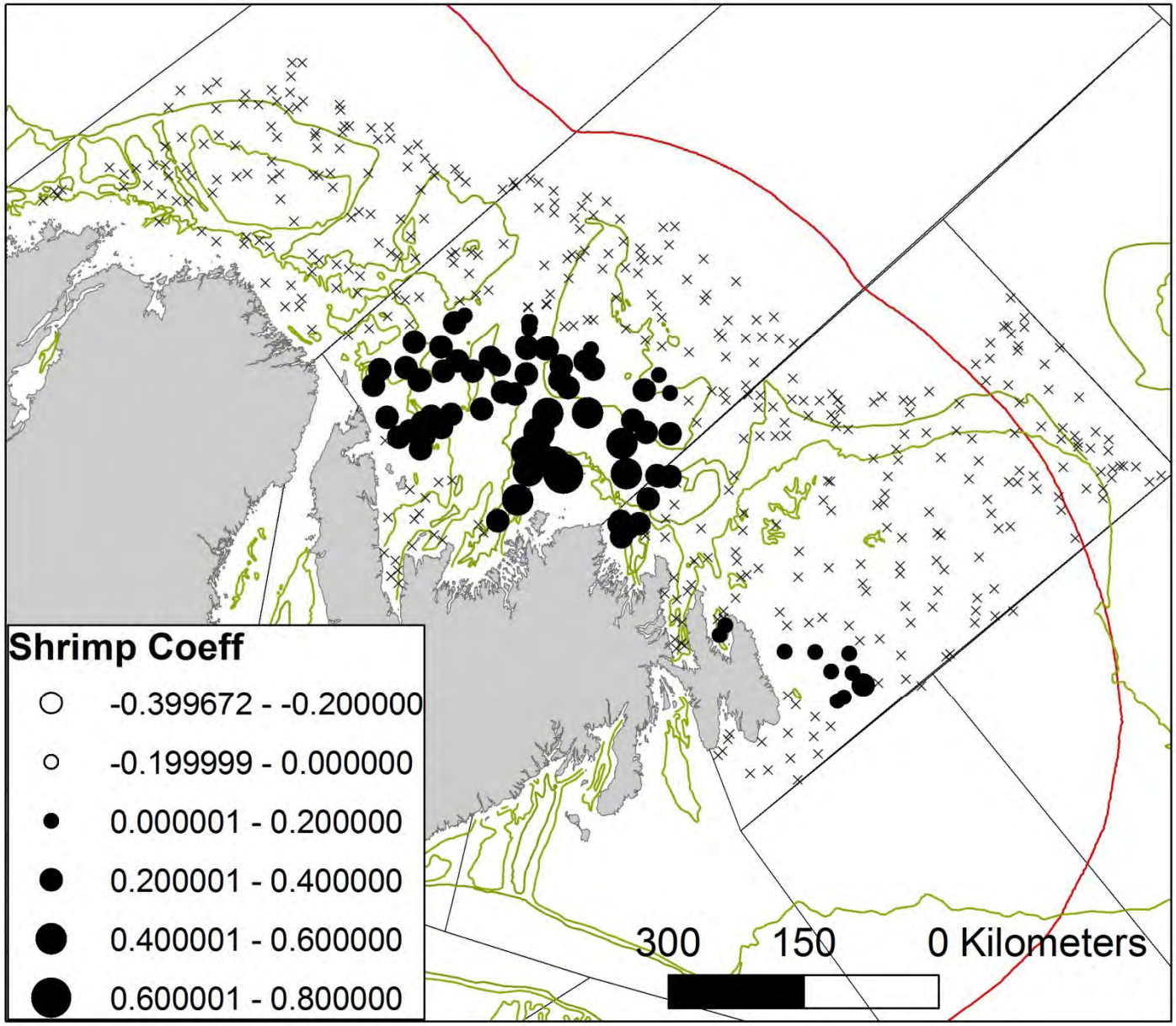
2000

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



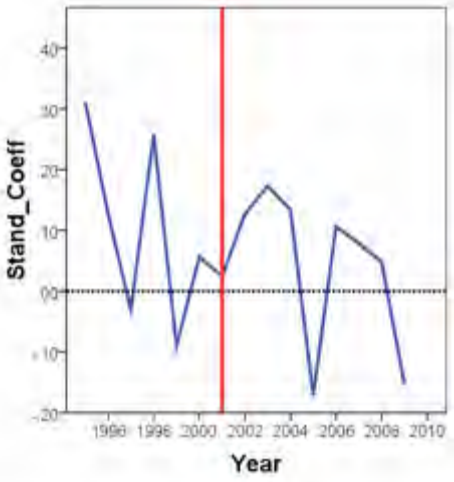
GWR – Shrimp Coefficients



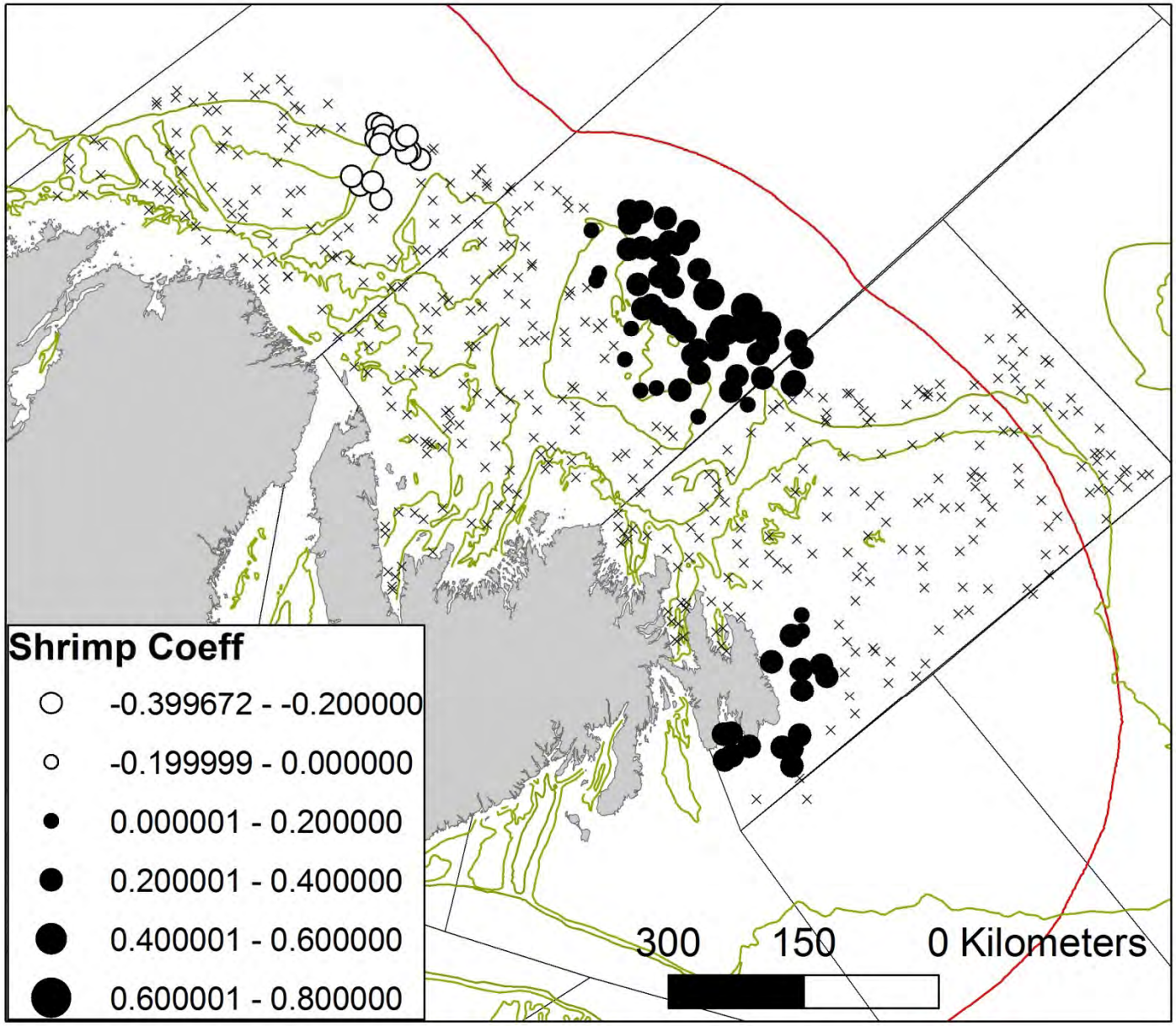
2001

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



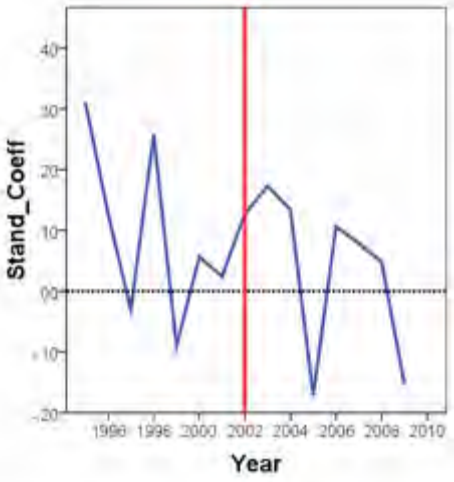
GWR – Shrimp Coefficients



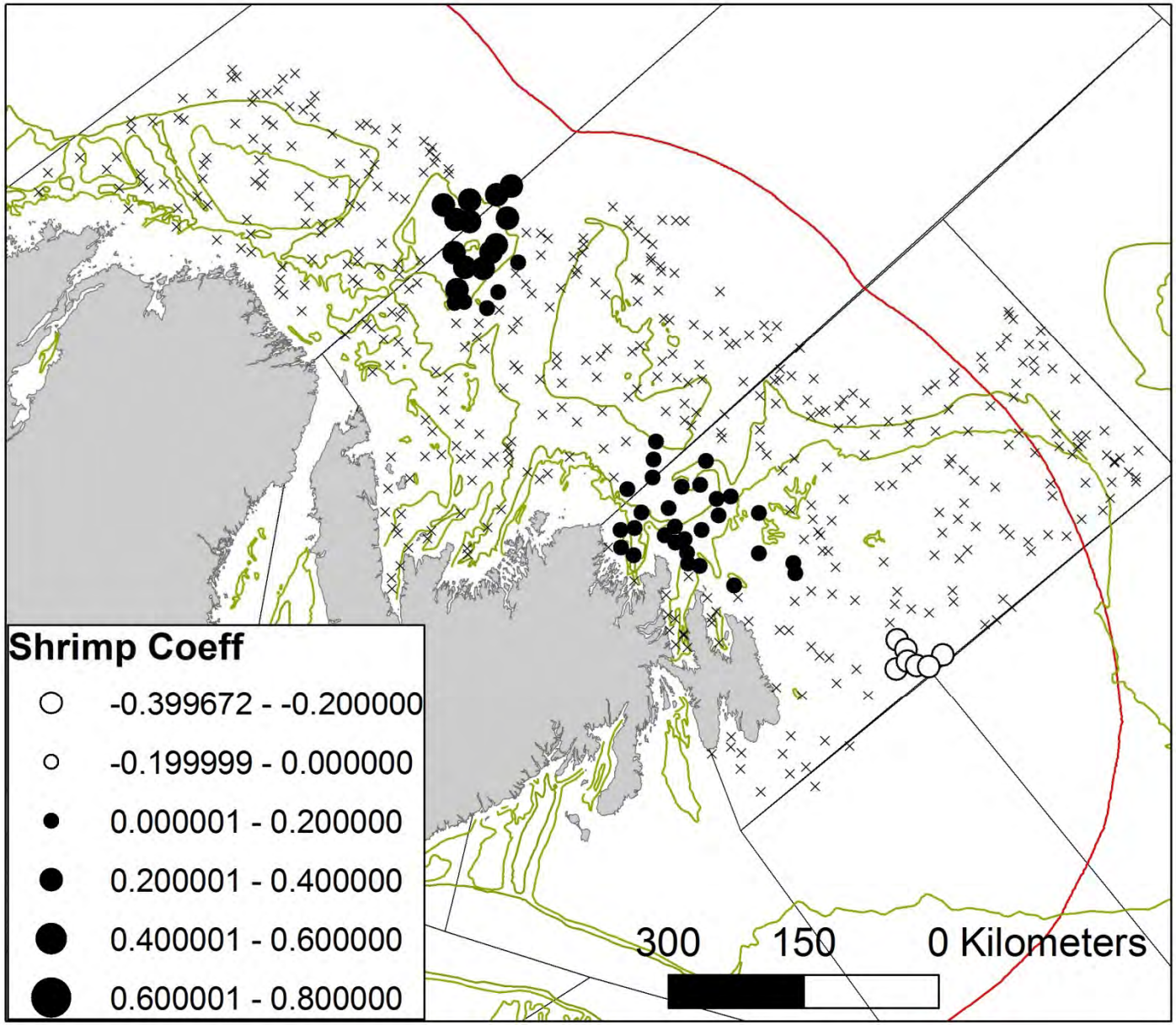
2002

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



GWR – Shrimp Coefficients



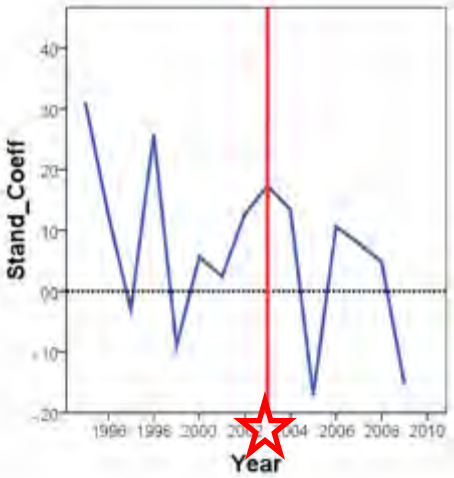
2003

Positive

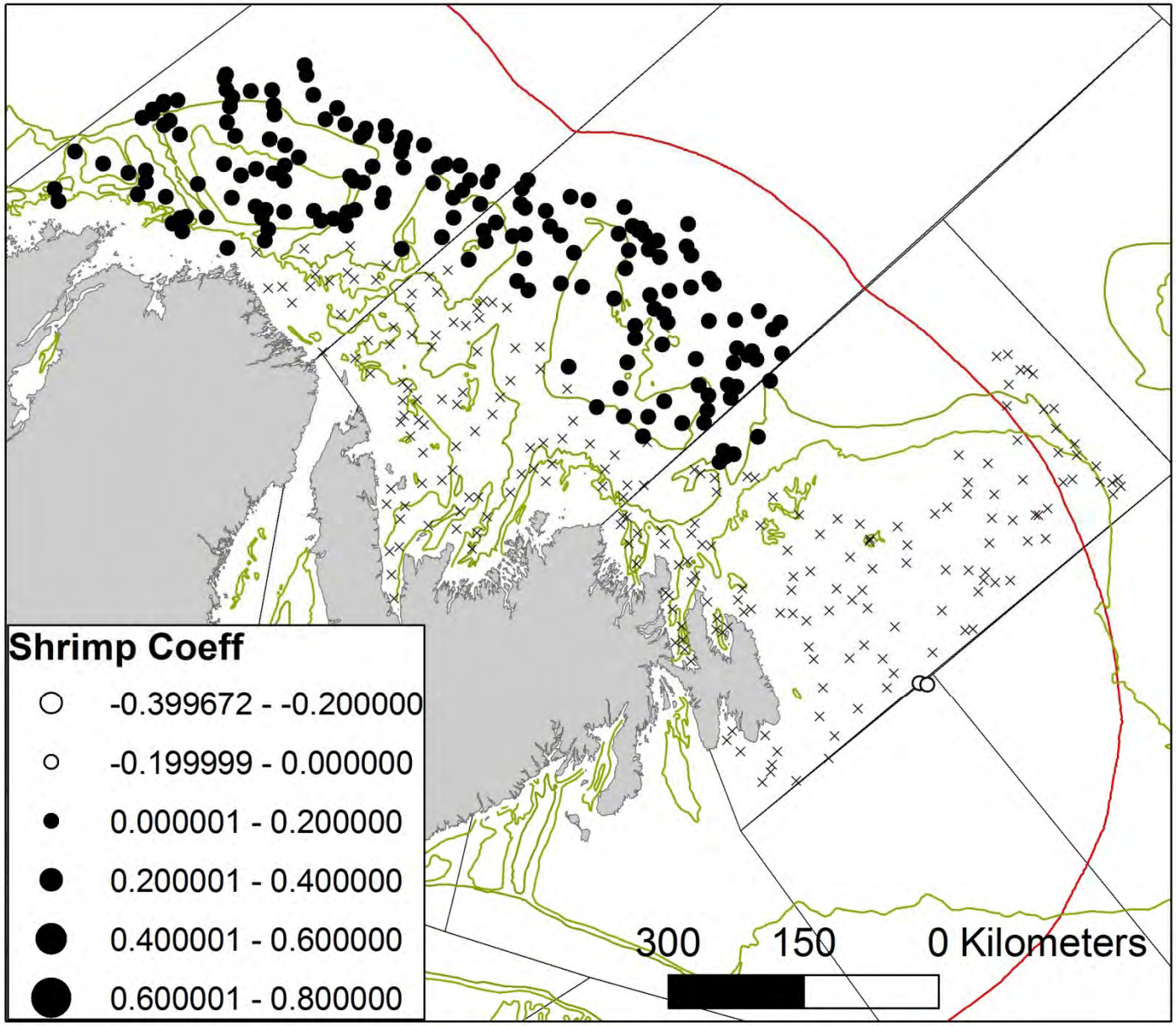
Negative

x Not Significant

OLS Stand. Coeff



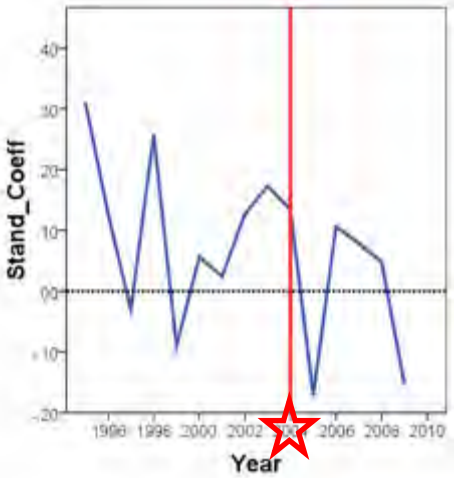
GWR – Shrimp Coefficients



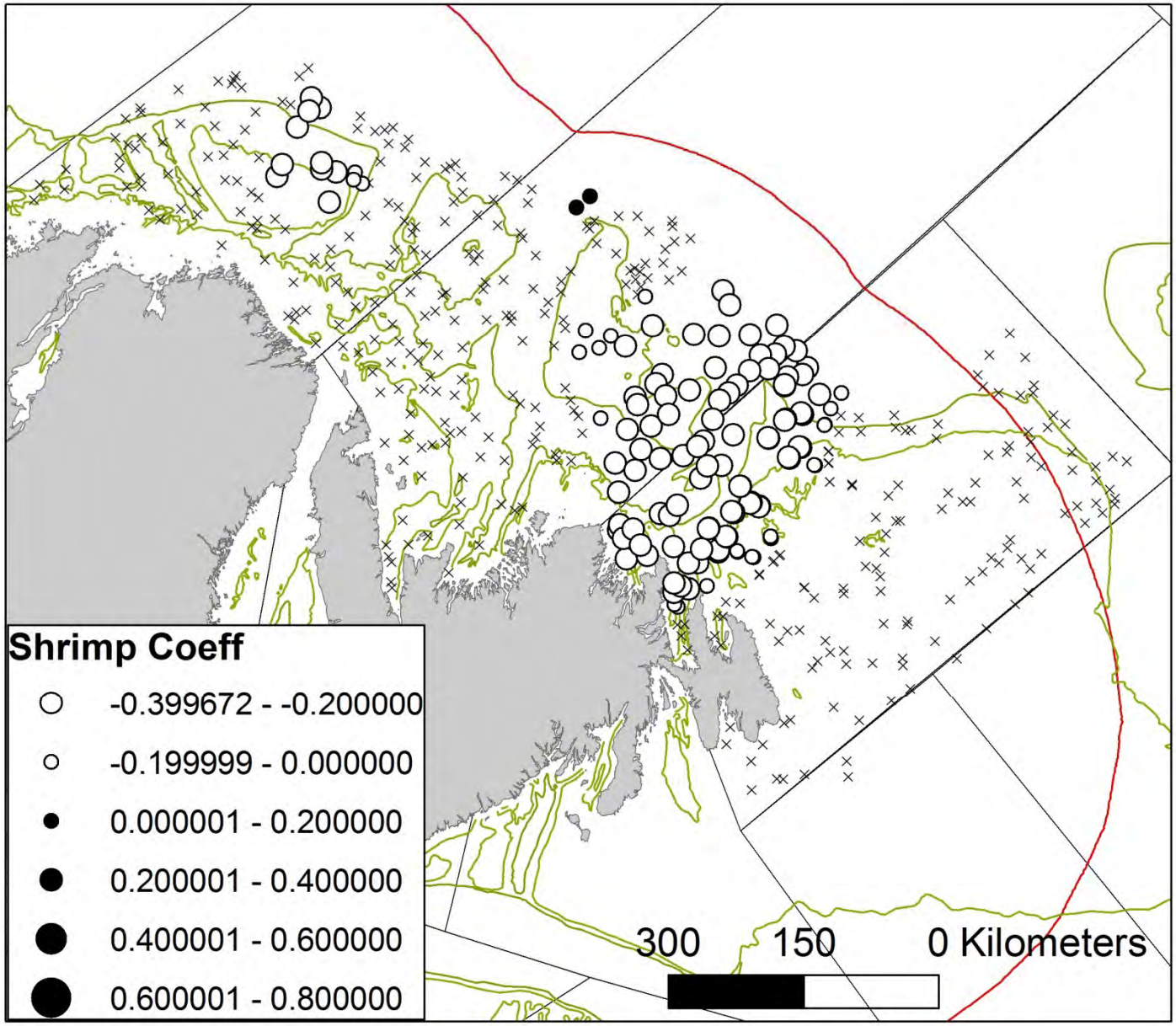
2004

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



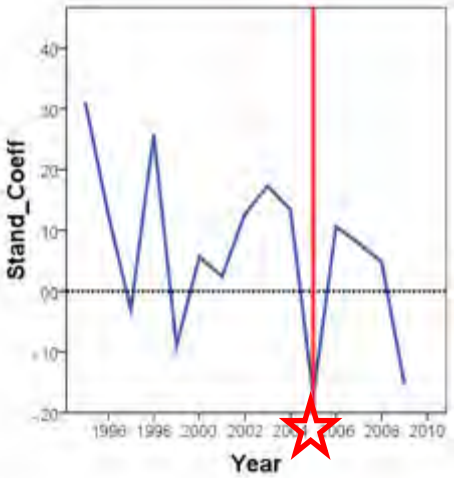
GWR – Shrimp Coefficients



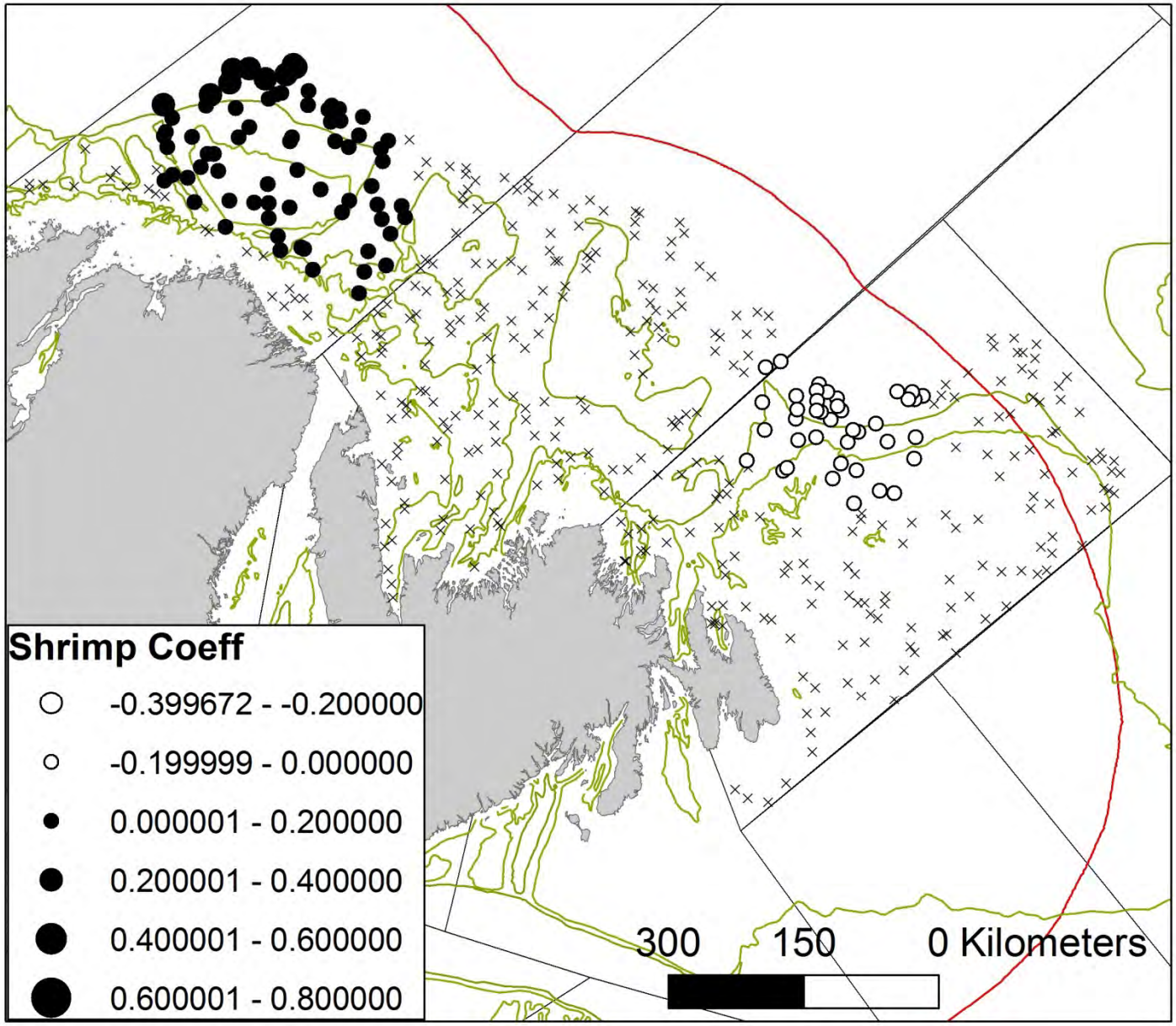
2005

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



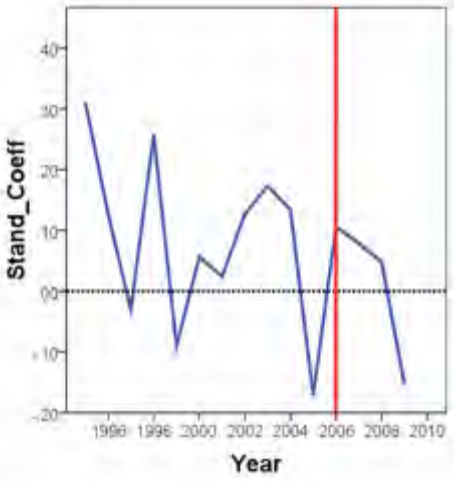
GWR – Shrimp Coefficients



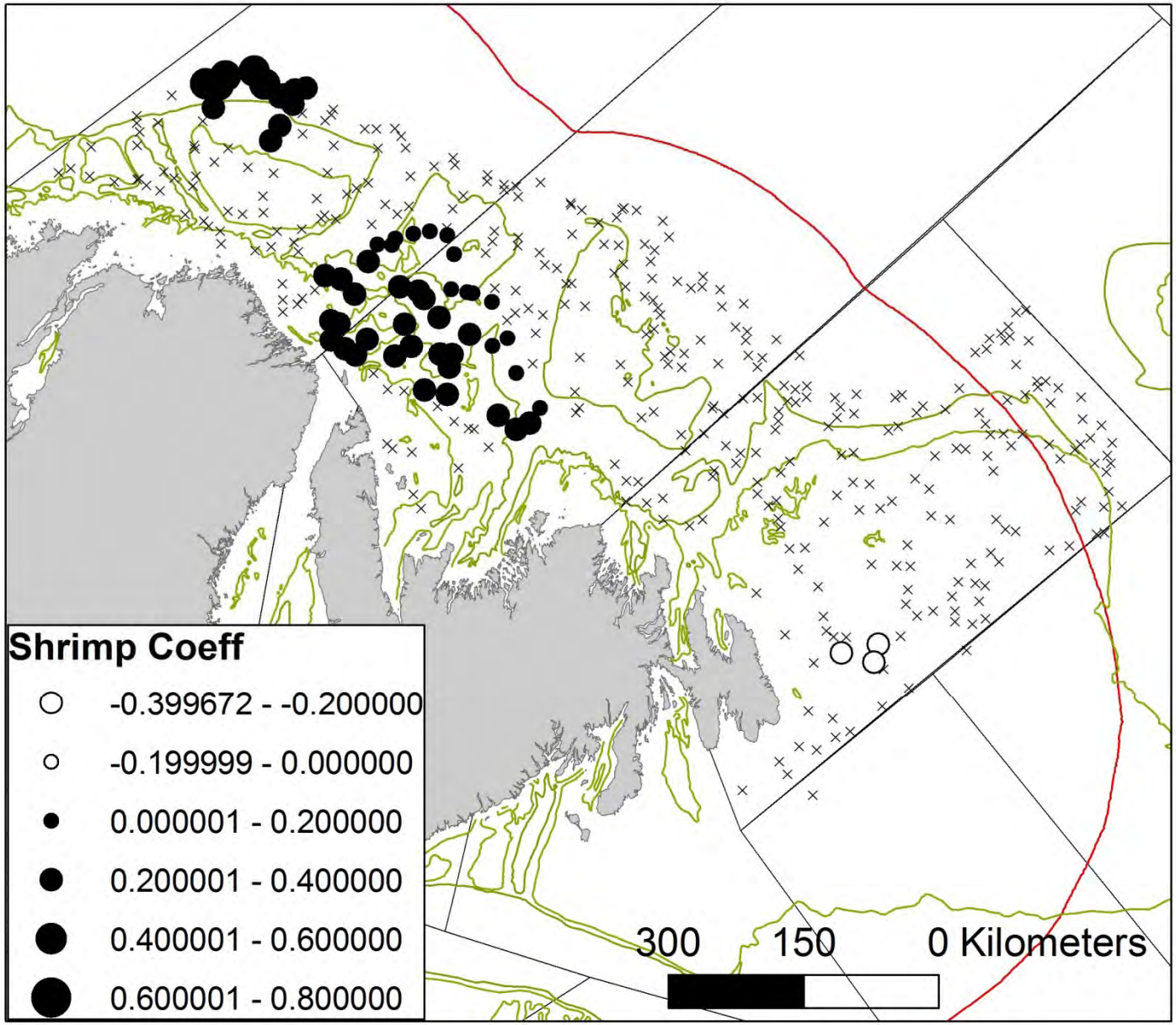
2006

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



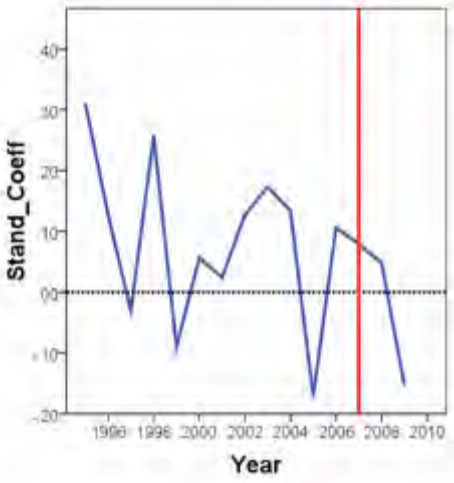
GWR – Shrimp Coefficients



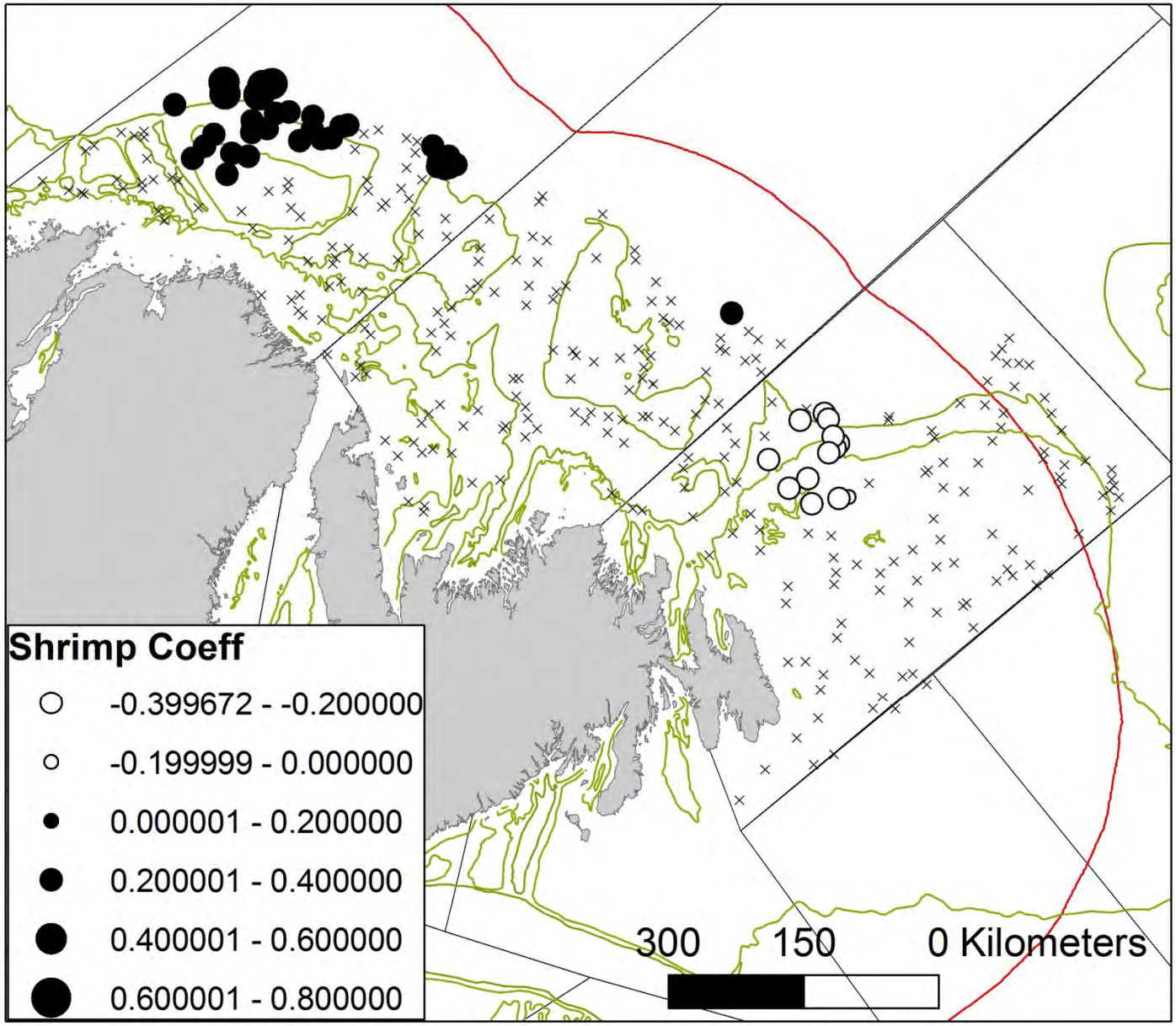
2007

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



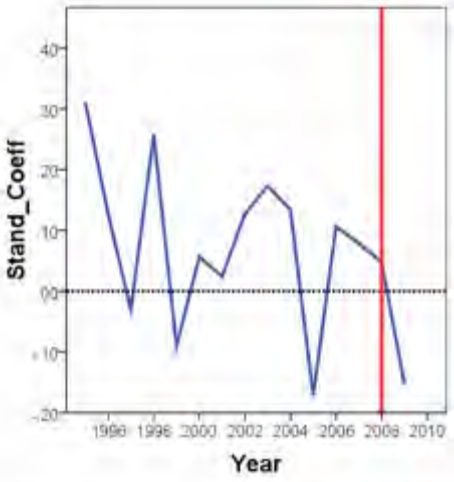
GWR – Shrimp Coefficients



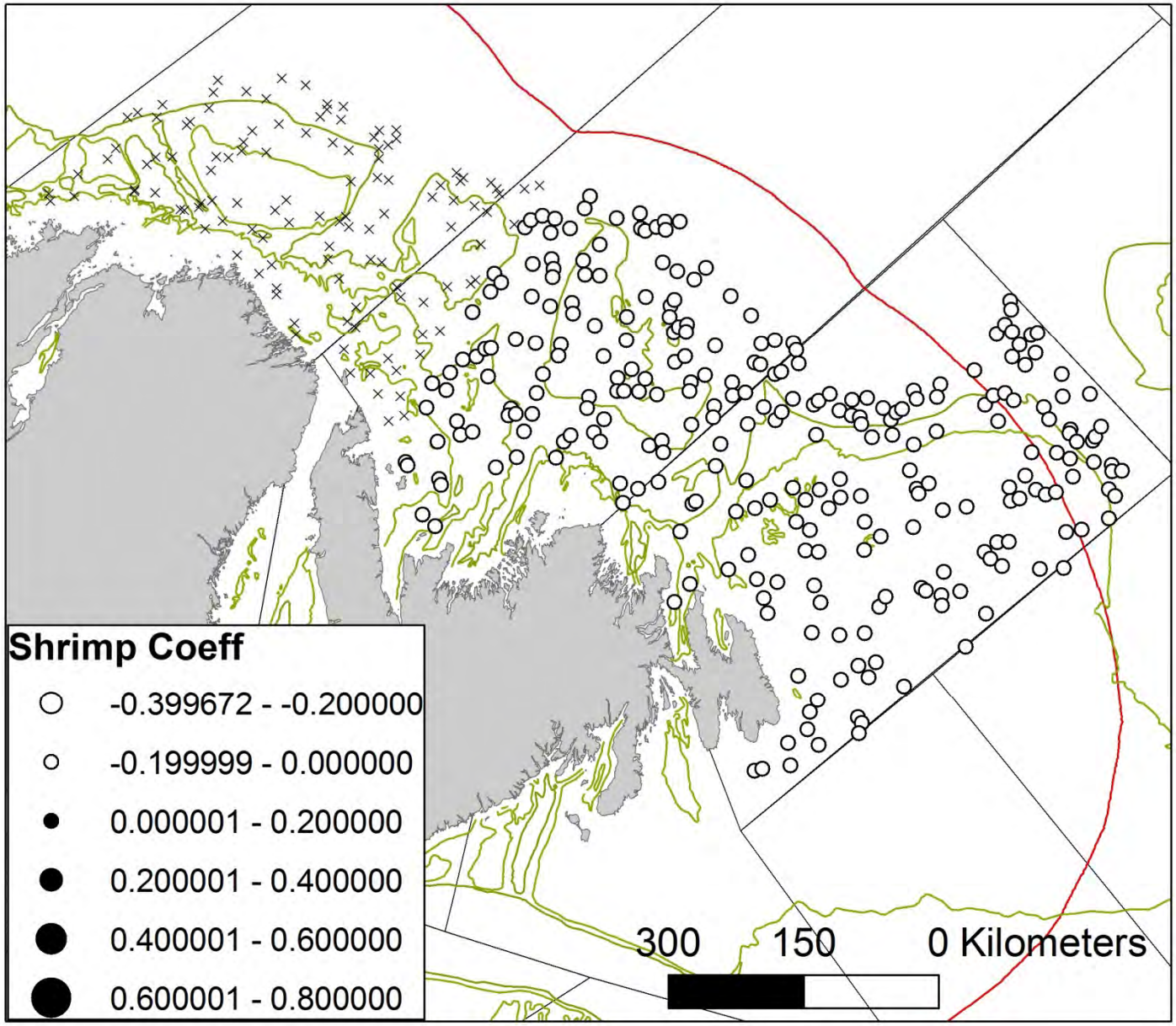
2008

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



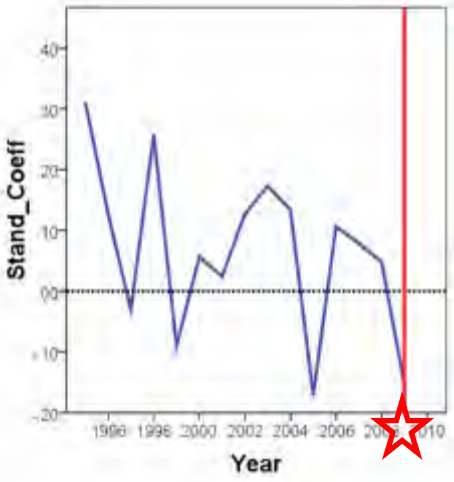
GWR – Shrimp Coefficients



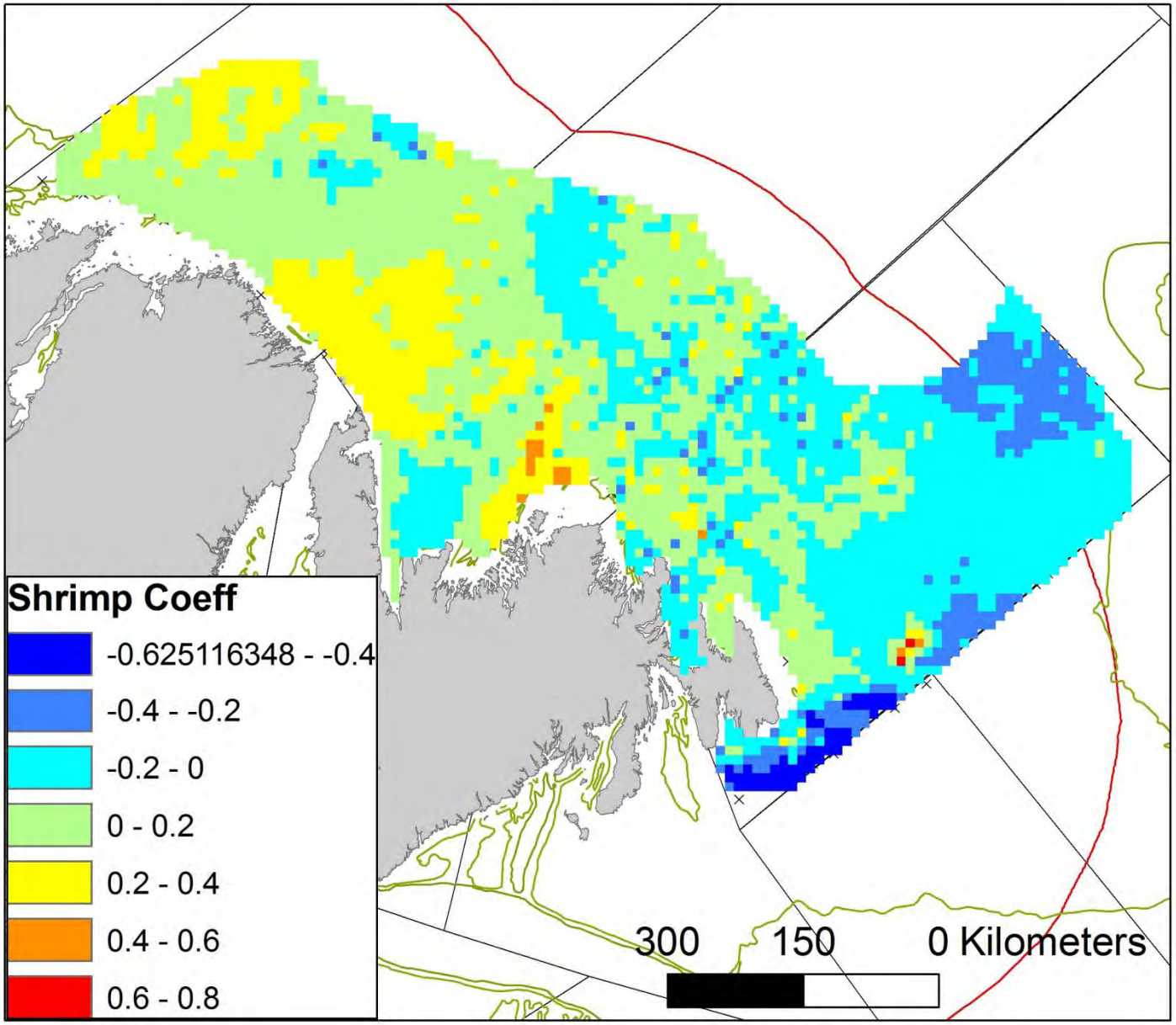
2009

- Positive
- Negative
- x Not Significant

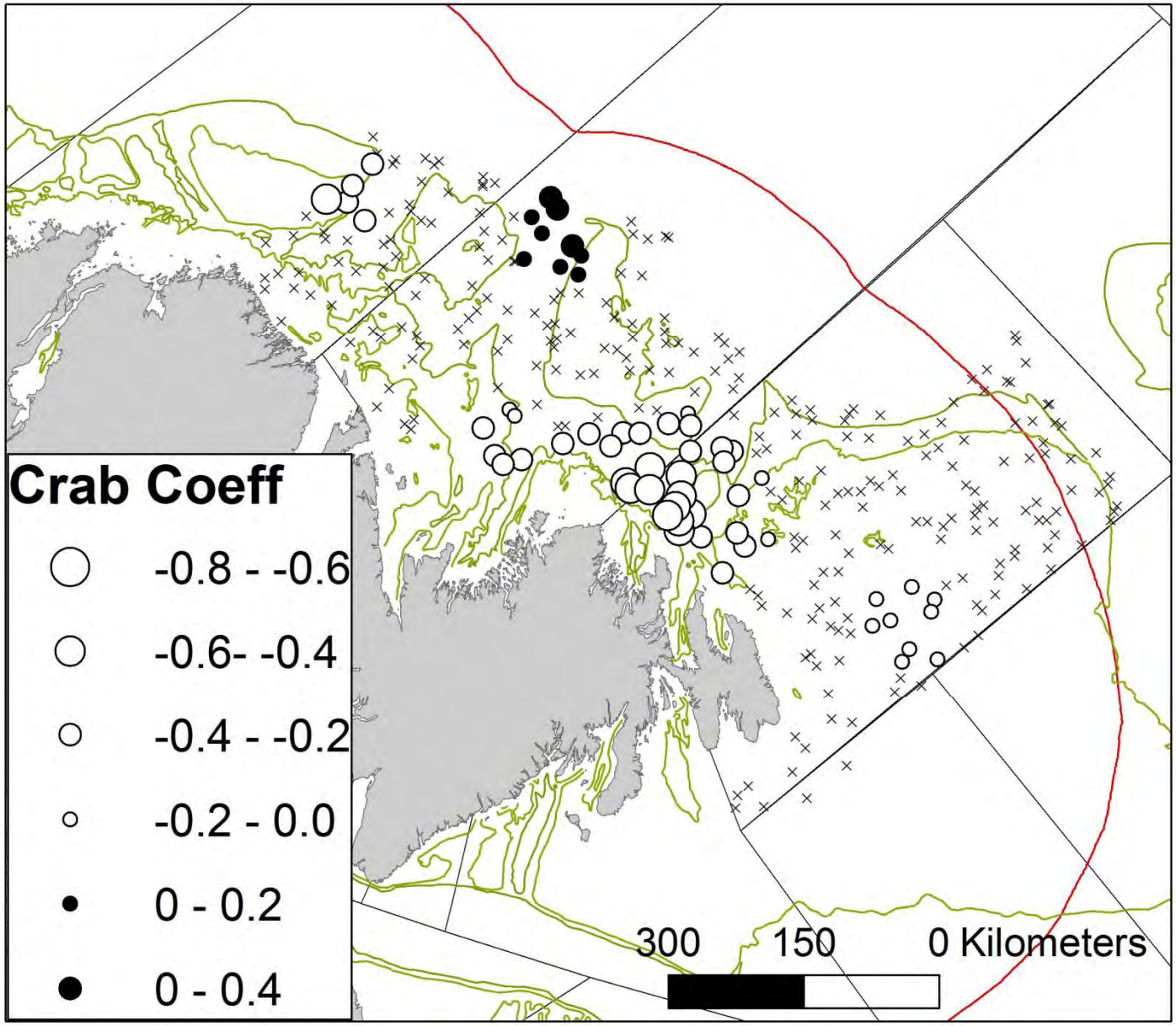
OLS Stand. Coeff



Ave. Significant Shrimp Coeff.



GWR – Crab Coefficients



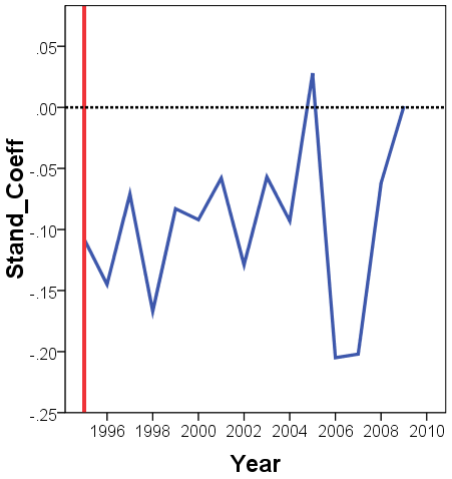
1995

Positive

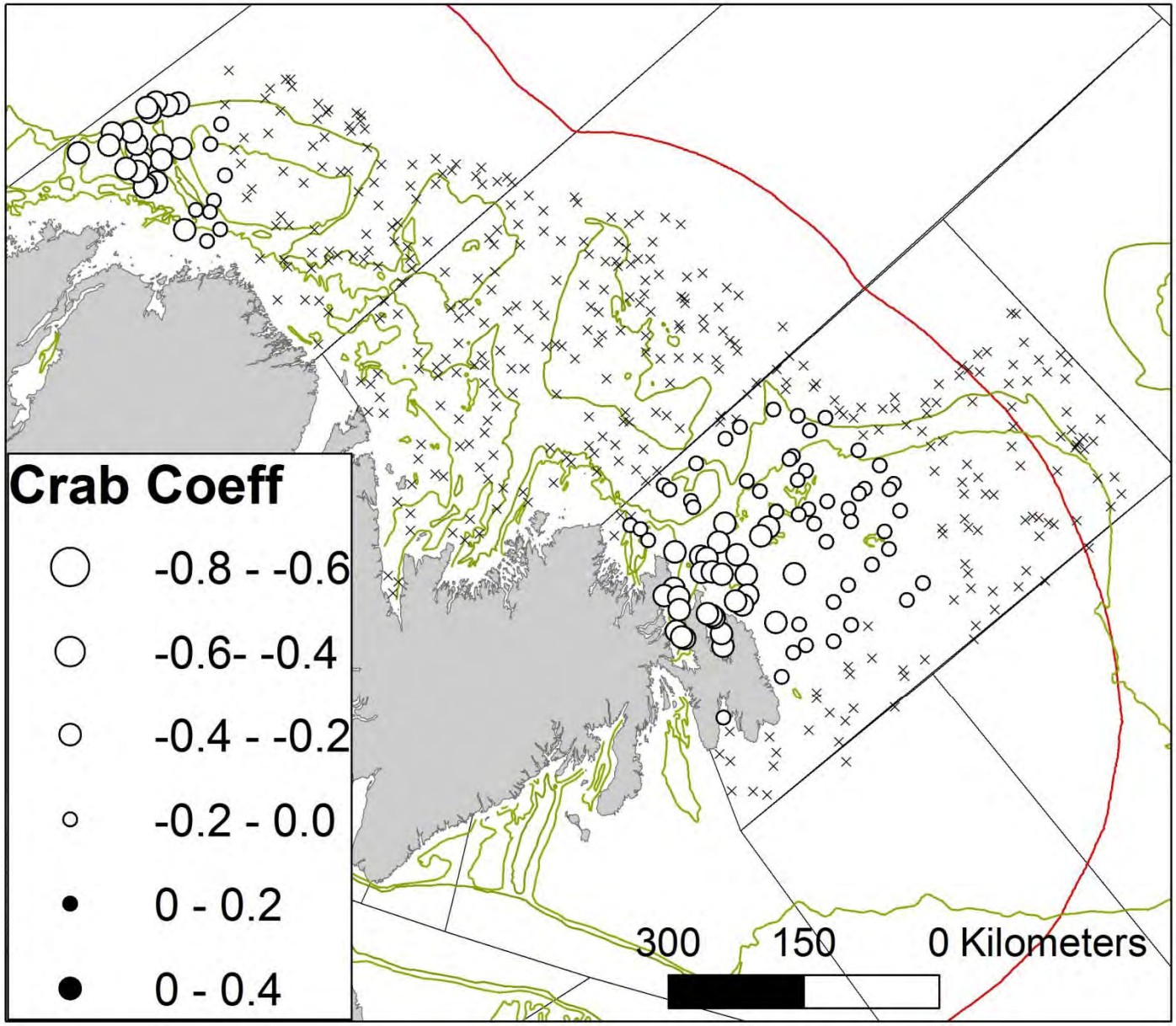
Negative

x Not Significant

OLS Stand. Coeff



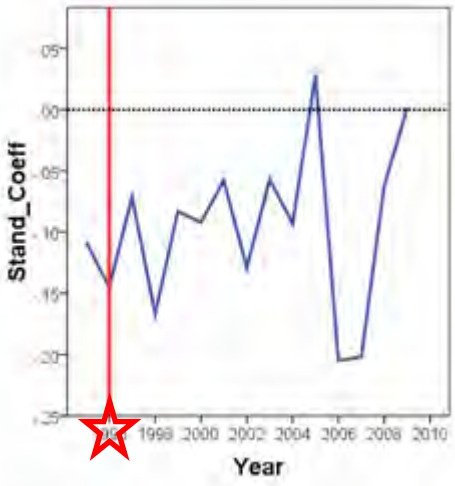
GWR – Crab Coefficients



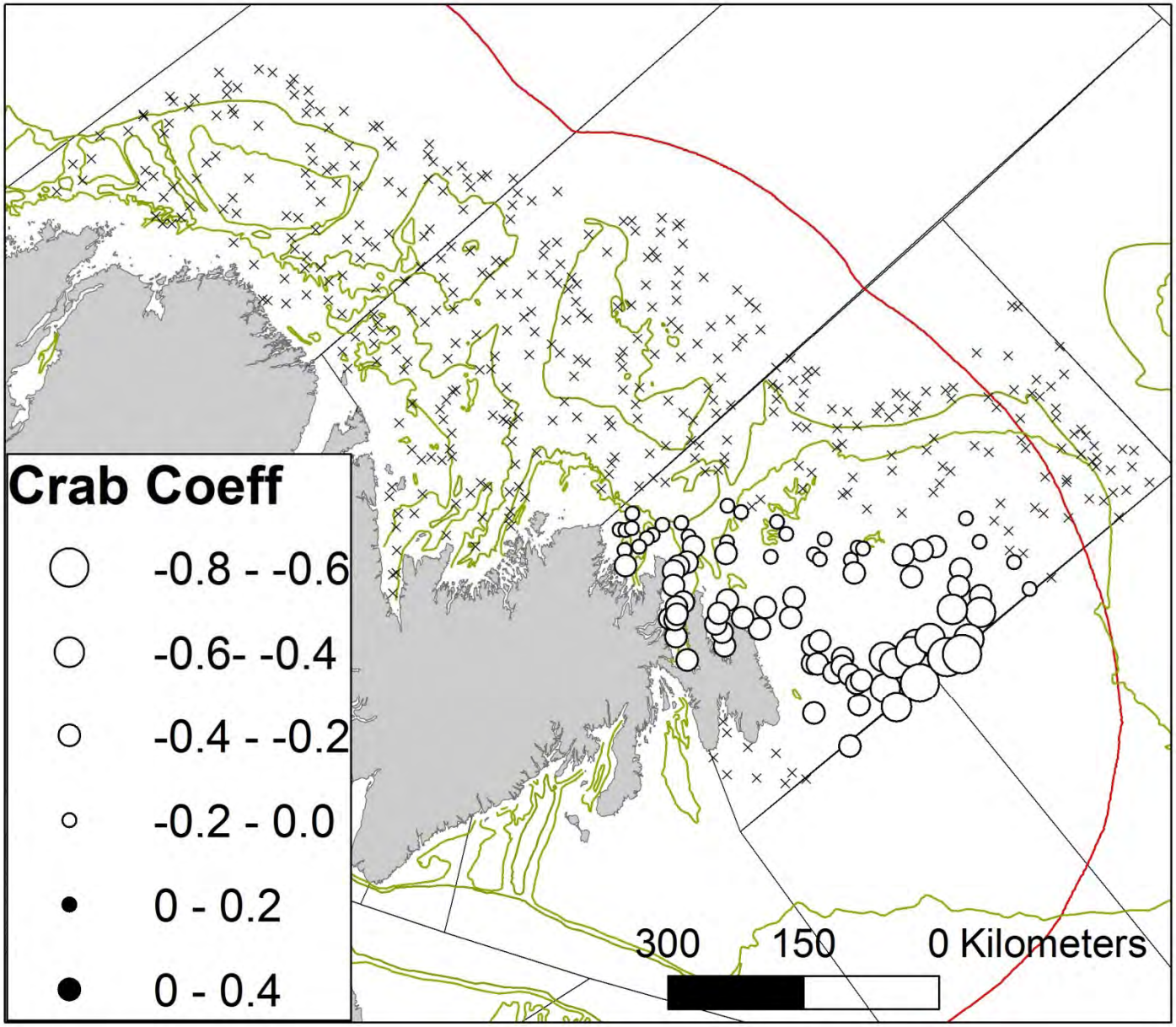
1996

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



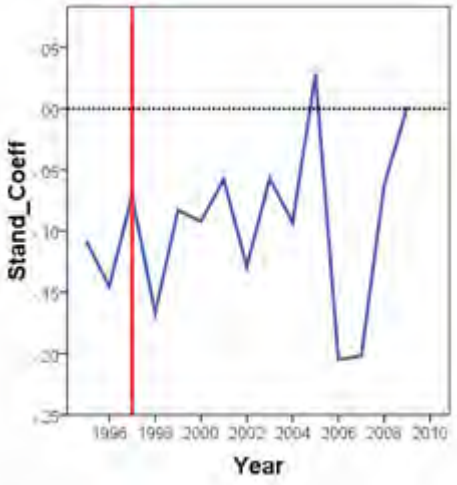
GWR – Crab Coefficients



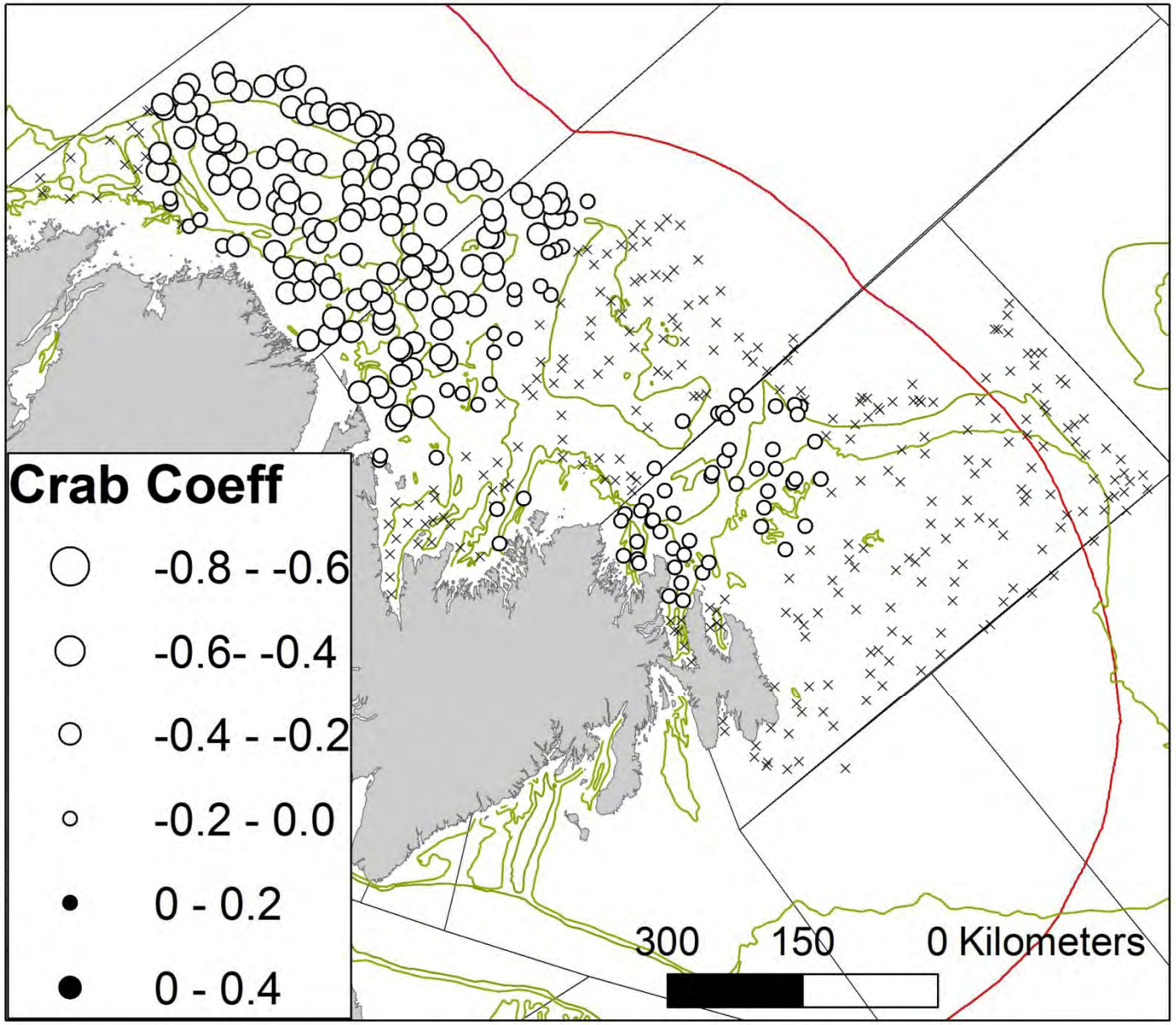
1997

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



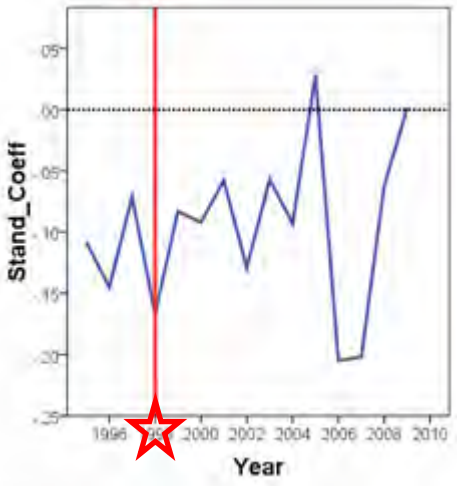
1998

Positive

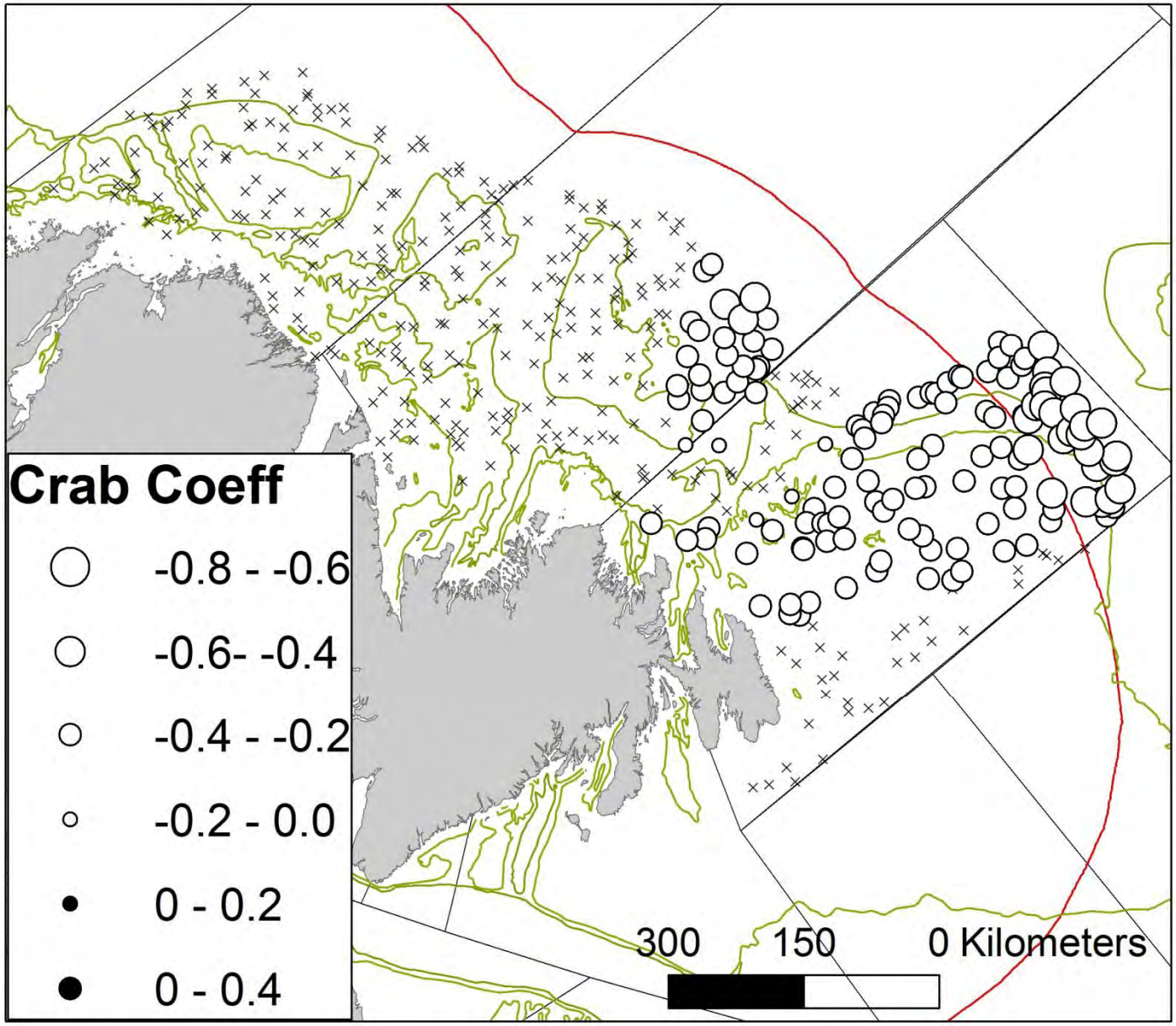
Negative

x Not Significant

OLS Stand. Coeff



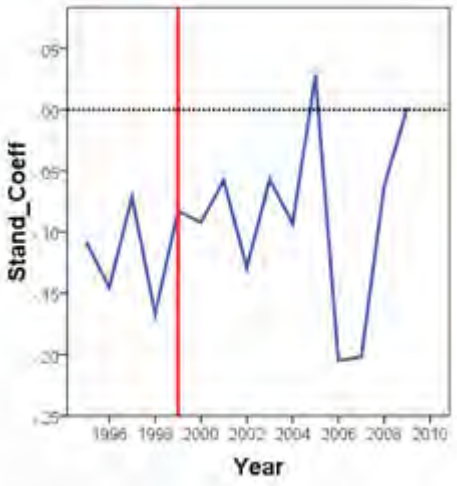
GWR – Crab Coefficients



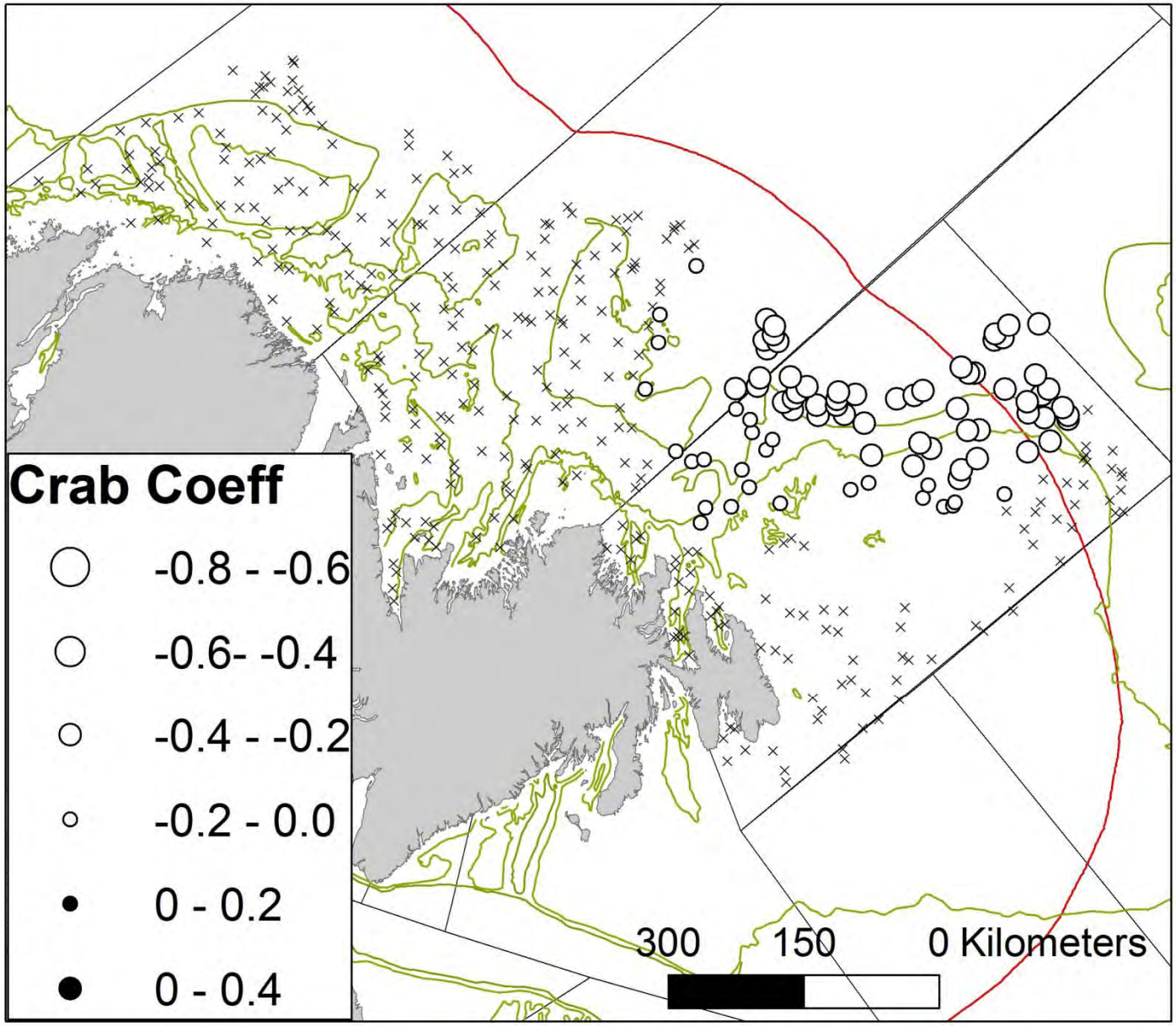
1999

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



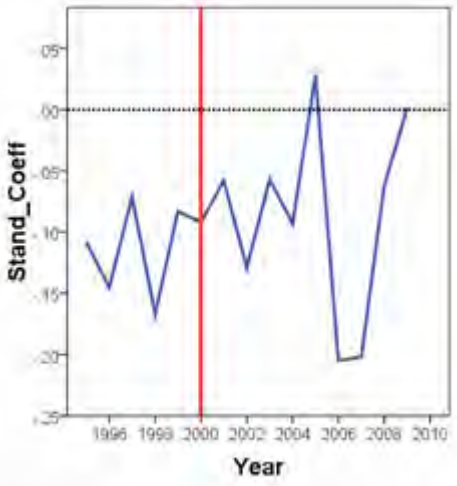
2000

Positive

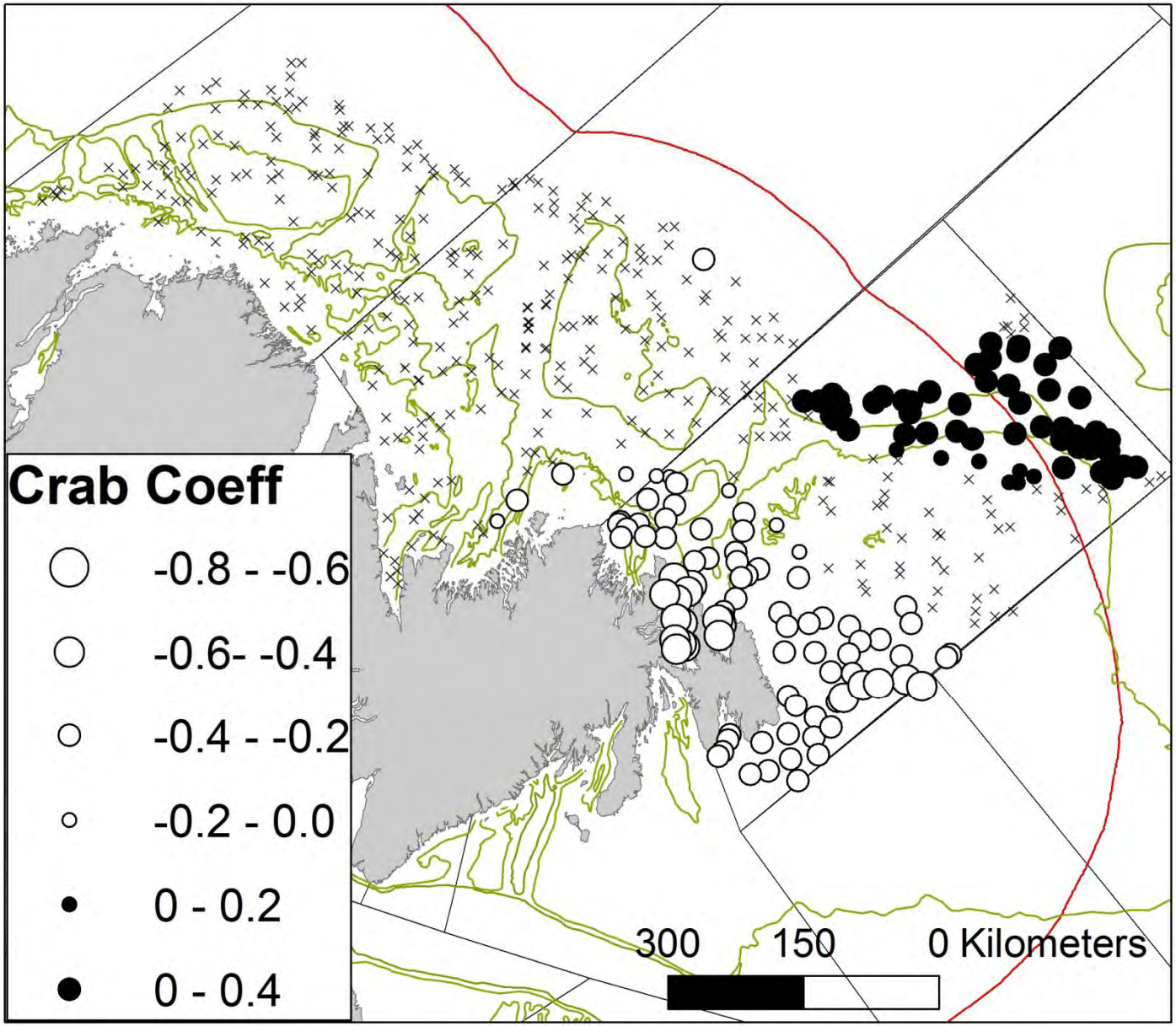
Negative

x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



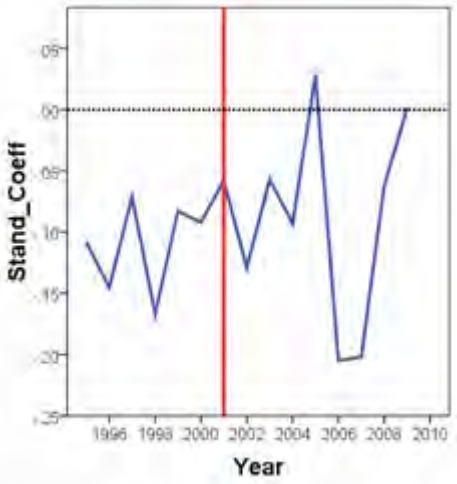
2001

Positive

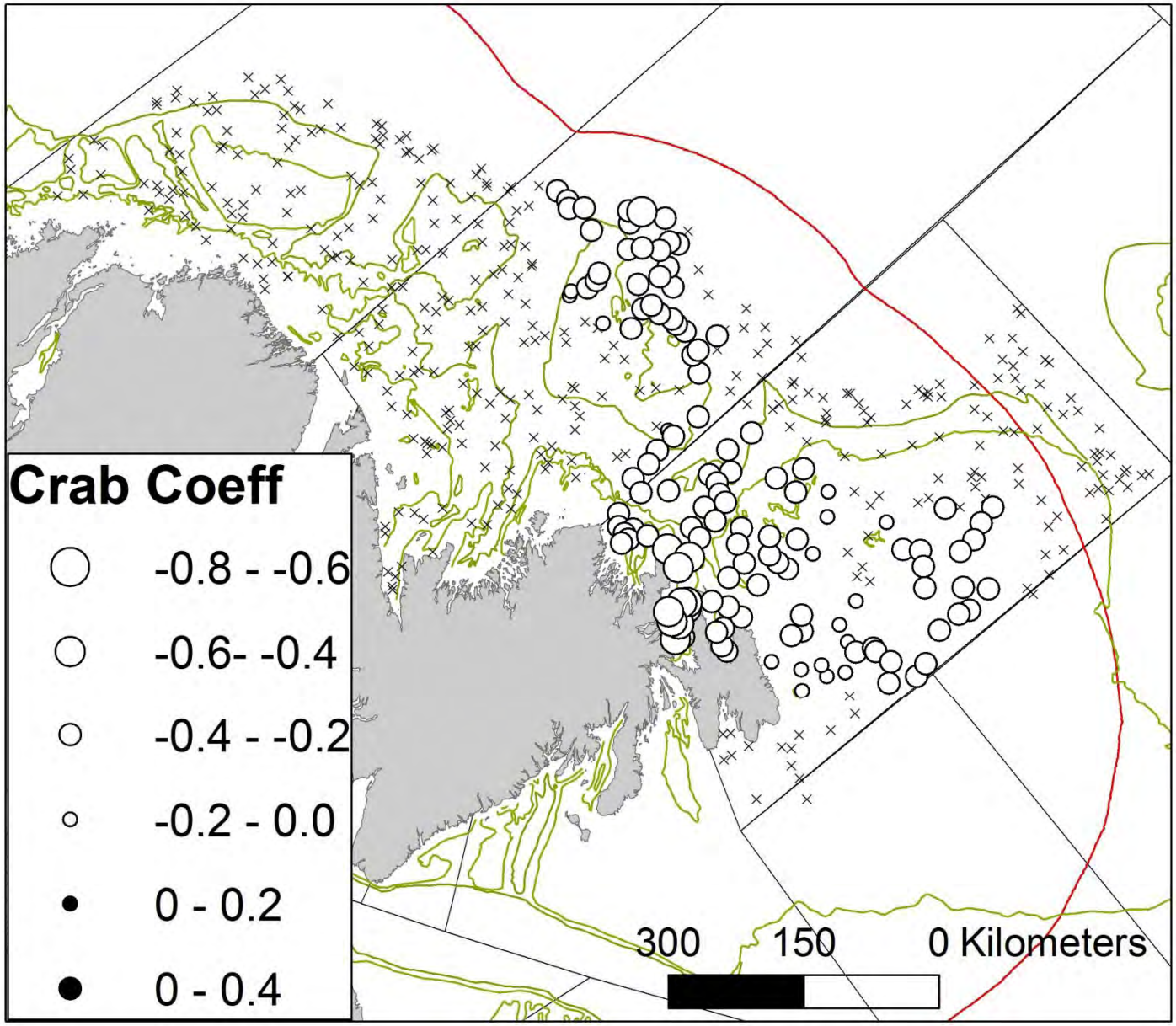
Negative

x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



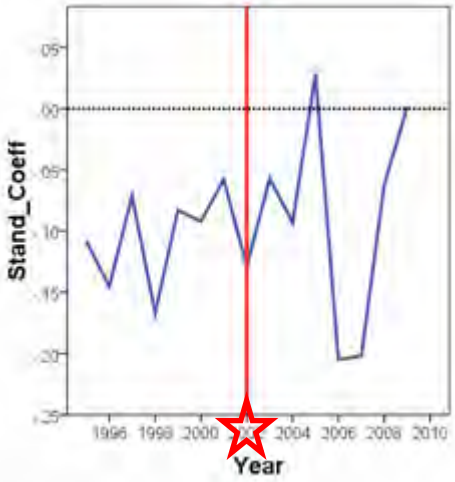
2002

Positive

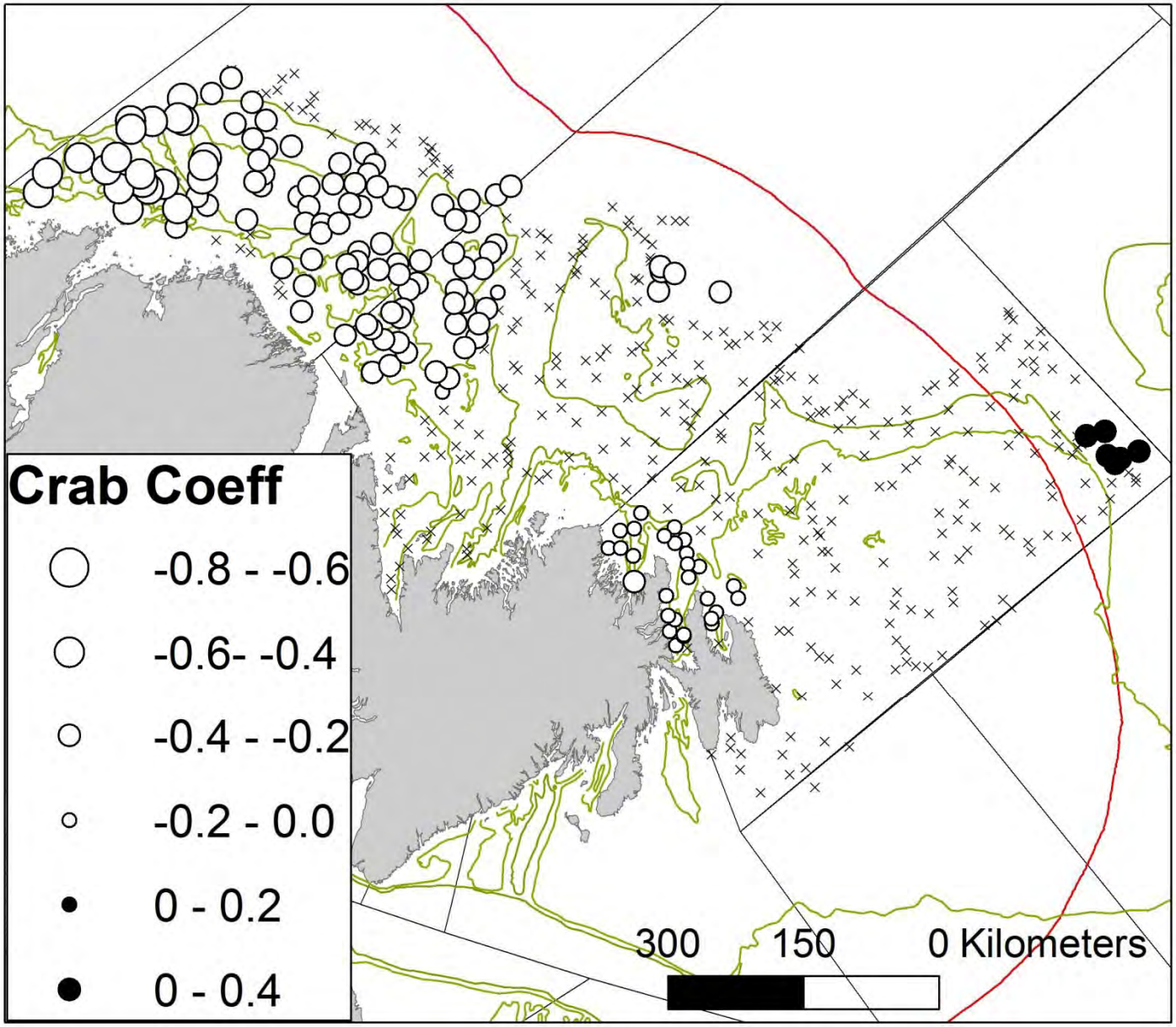
Negative

x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



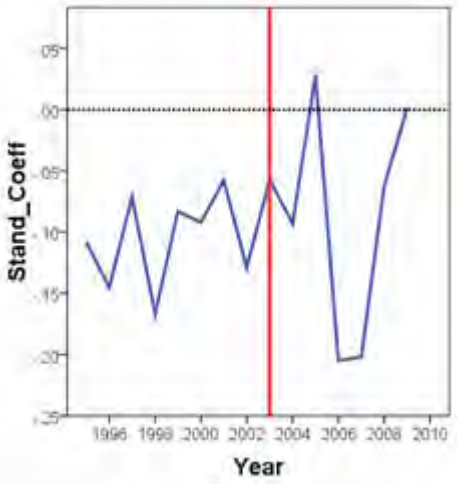
2003

Positive

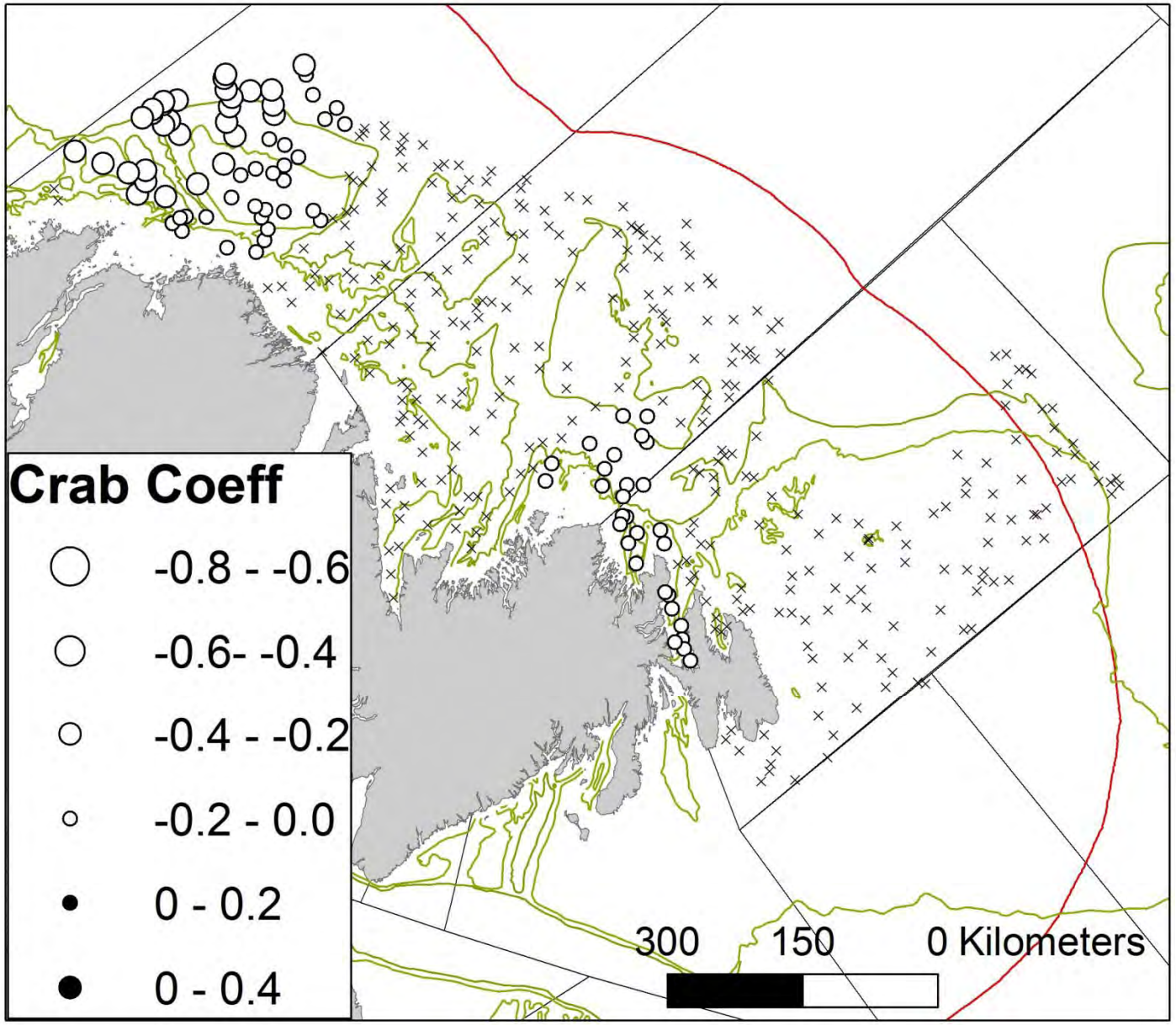
Negative

x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



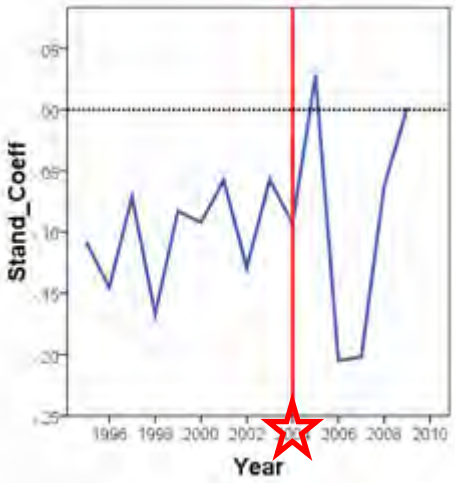
2004

Positive

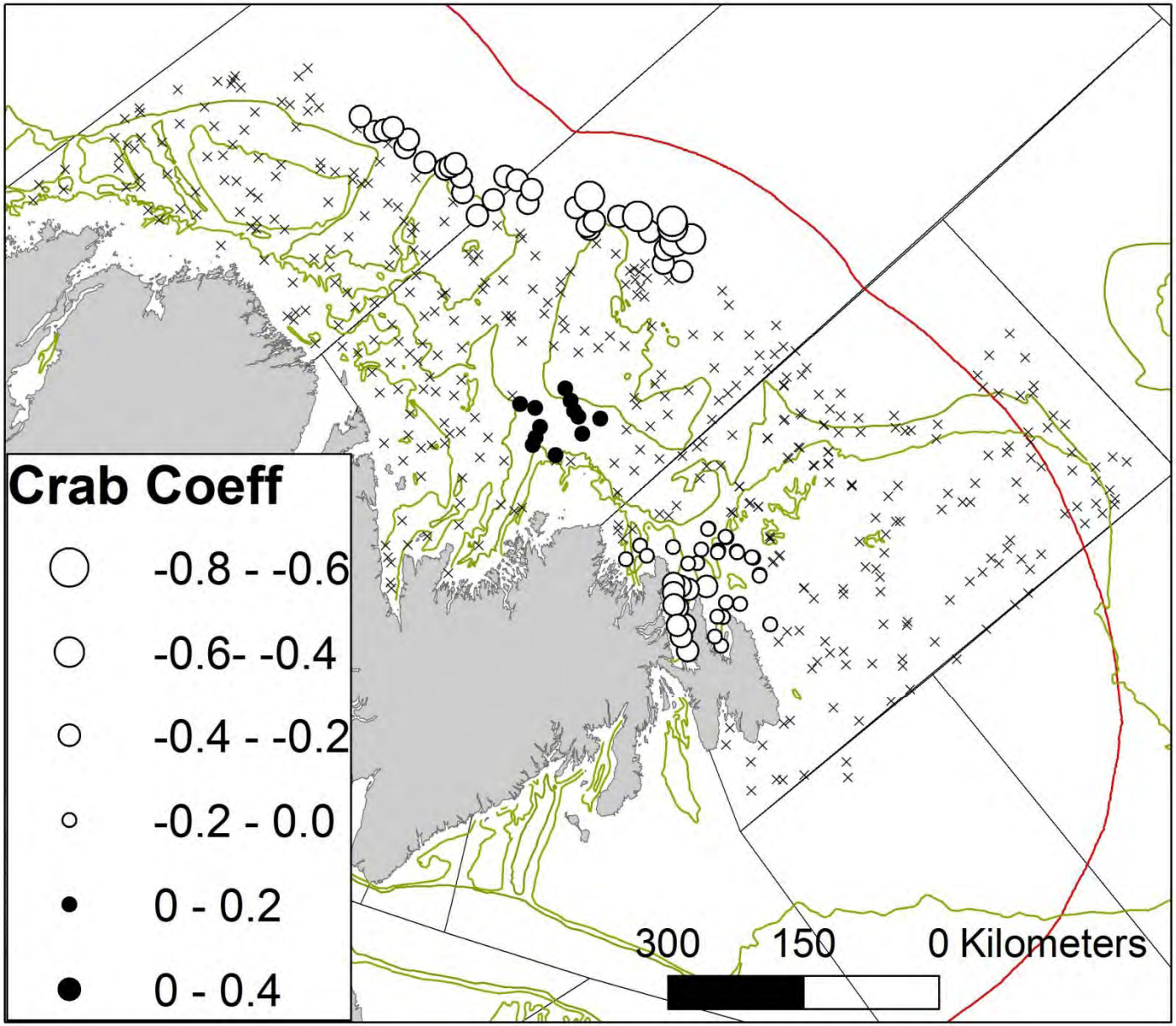
Negative

x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



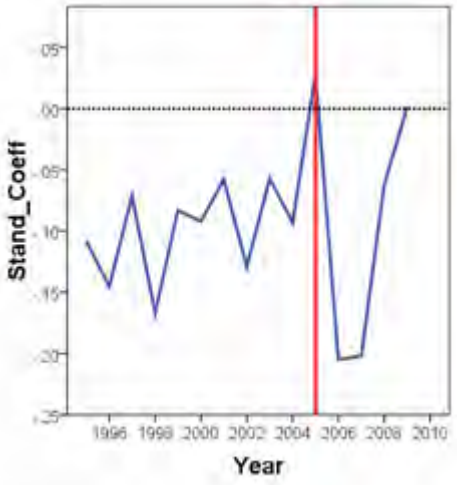
2005

Positive

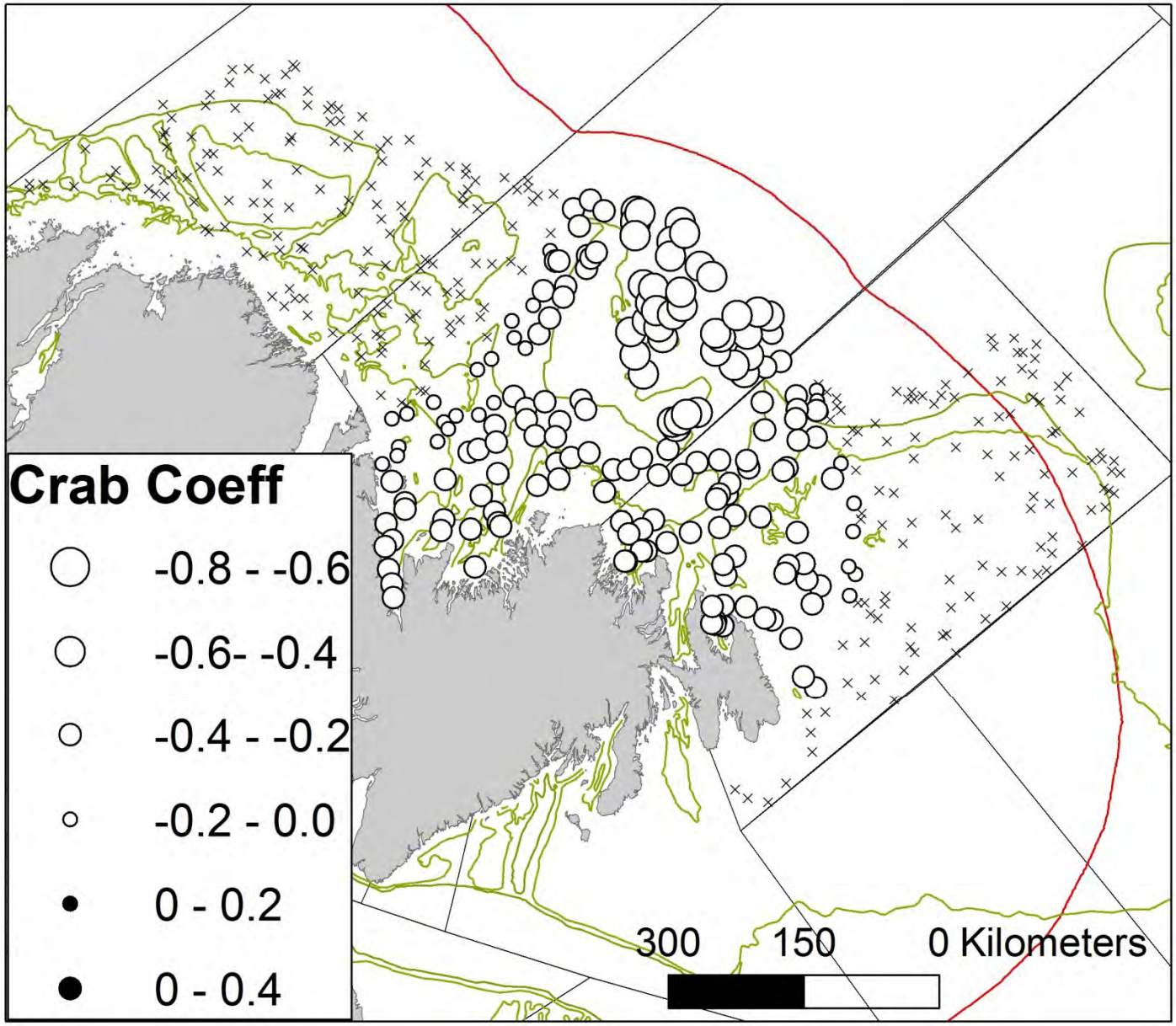
Negative

x Not Significant

OLS Stand. Coeff



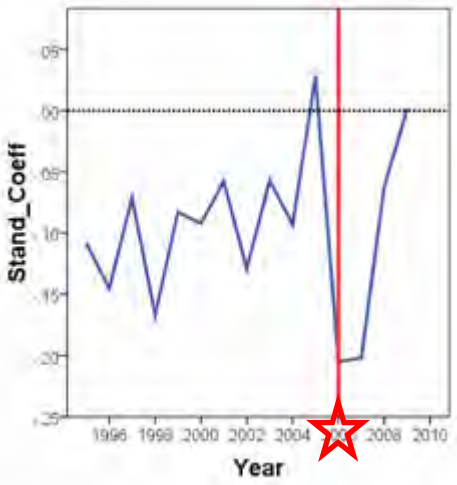
GWR – Crab Coefficients



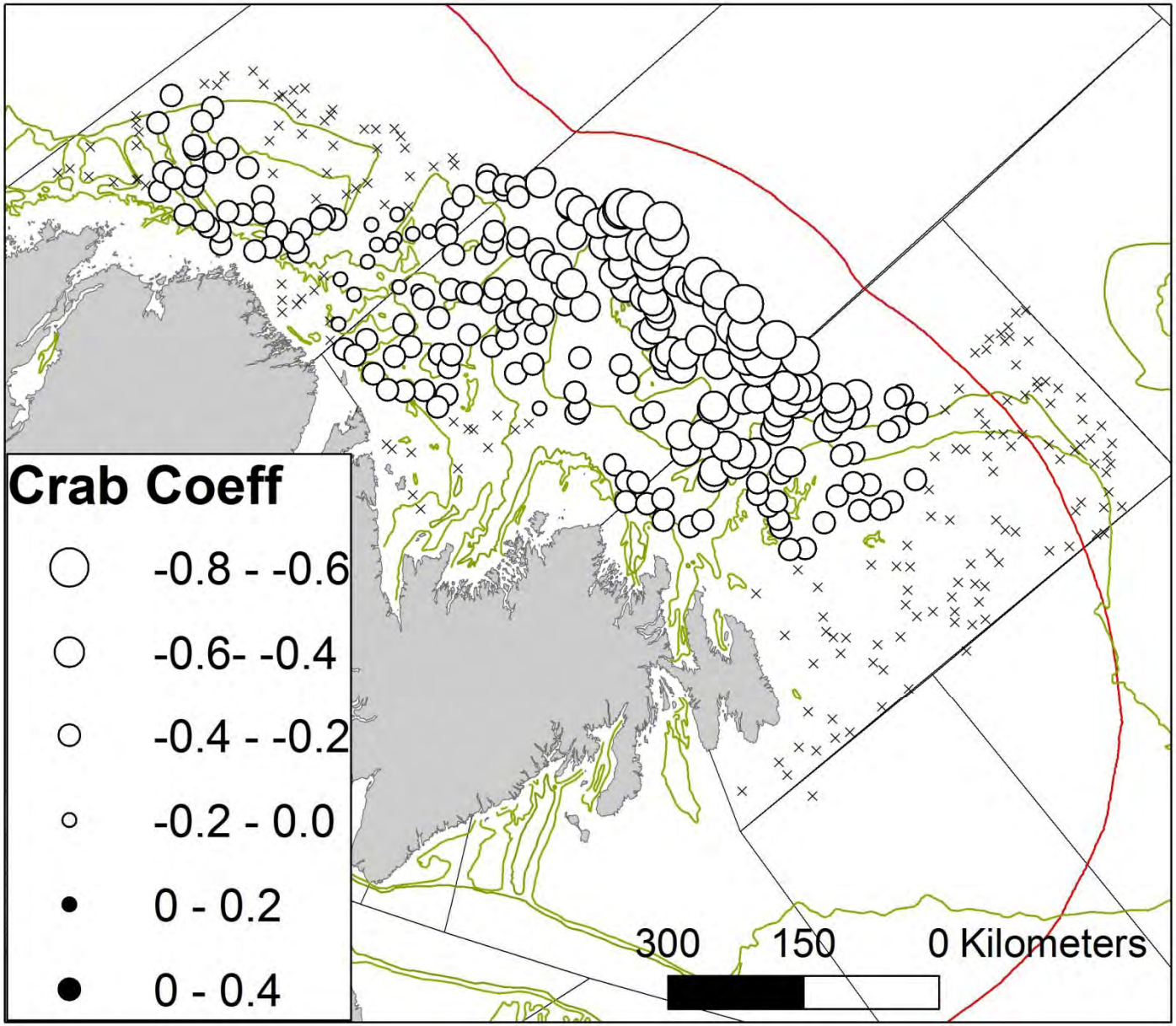
2006

- Positive
- Negative
- x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



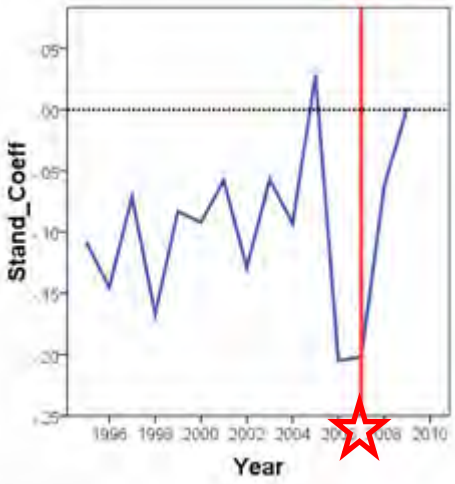
2007

Positive

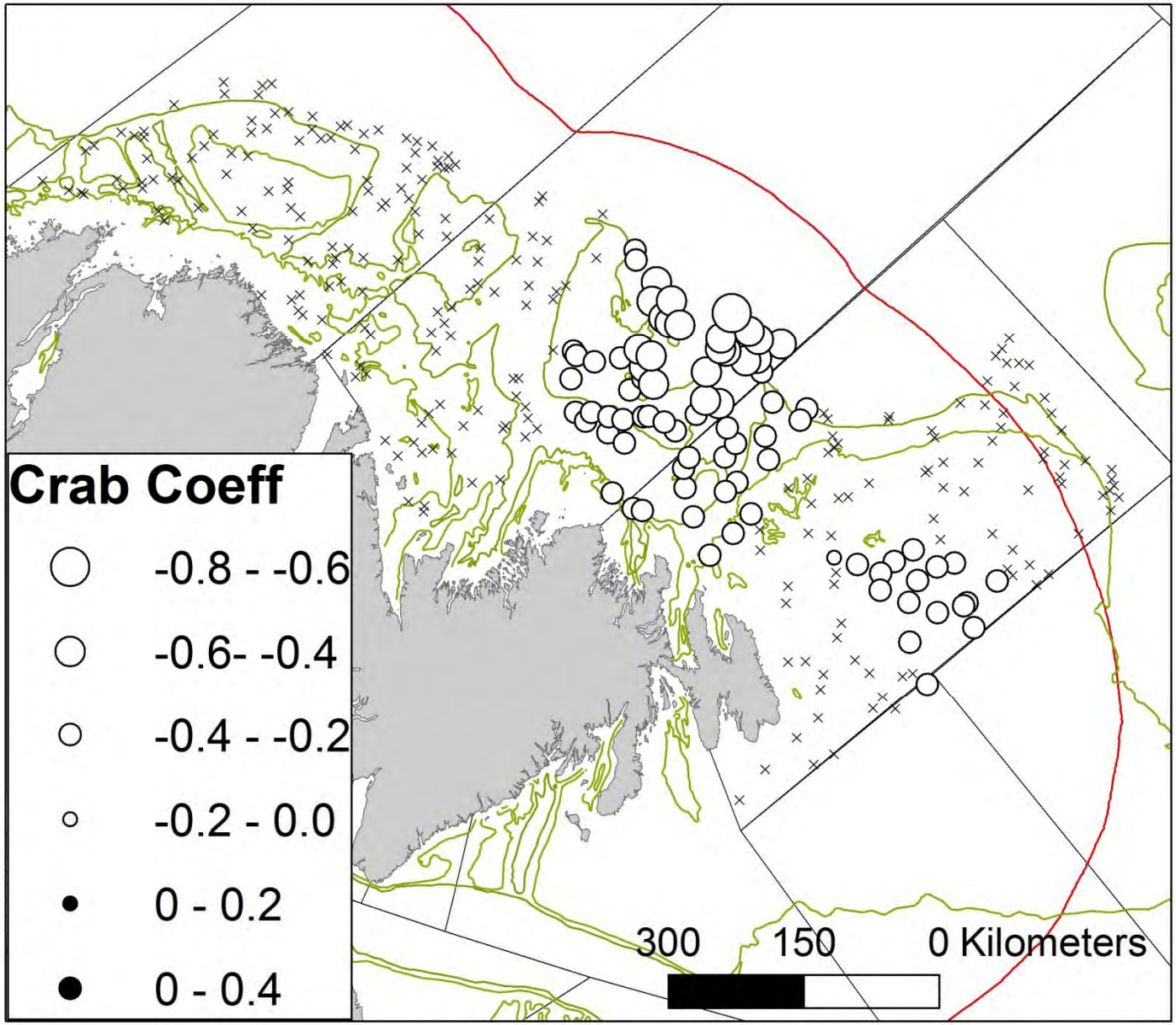
Negative

x Not Significant

OLS Stand. Coeff



GWR – Crab Coefficients



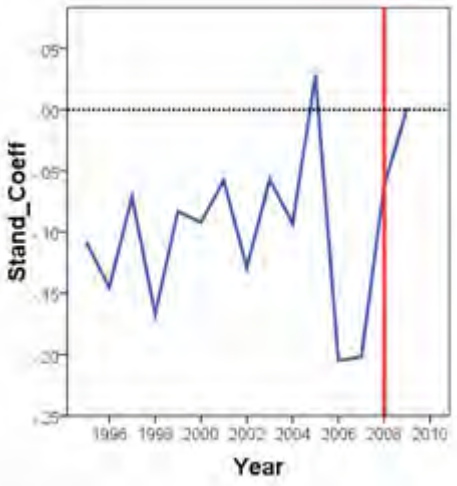
2008

Positive

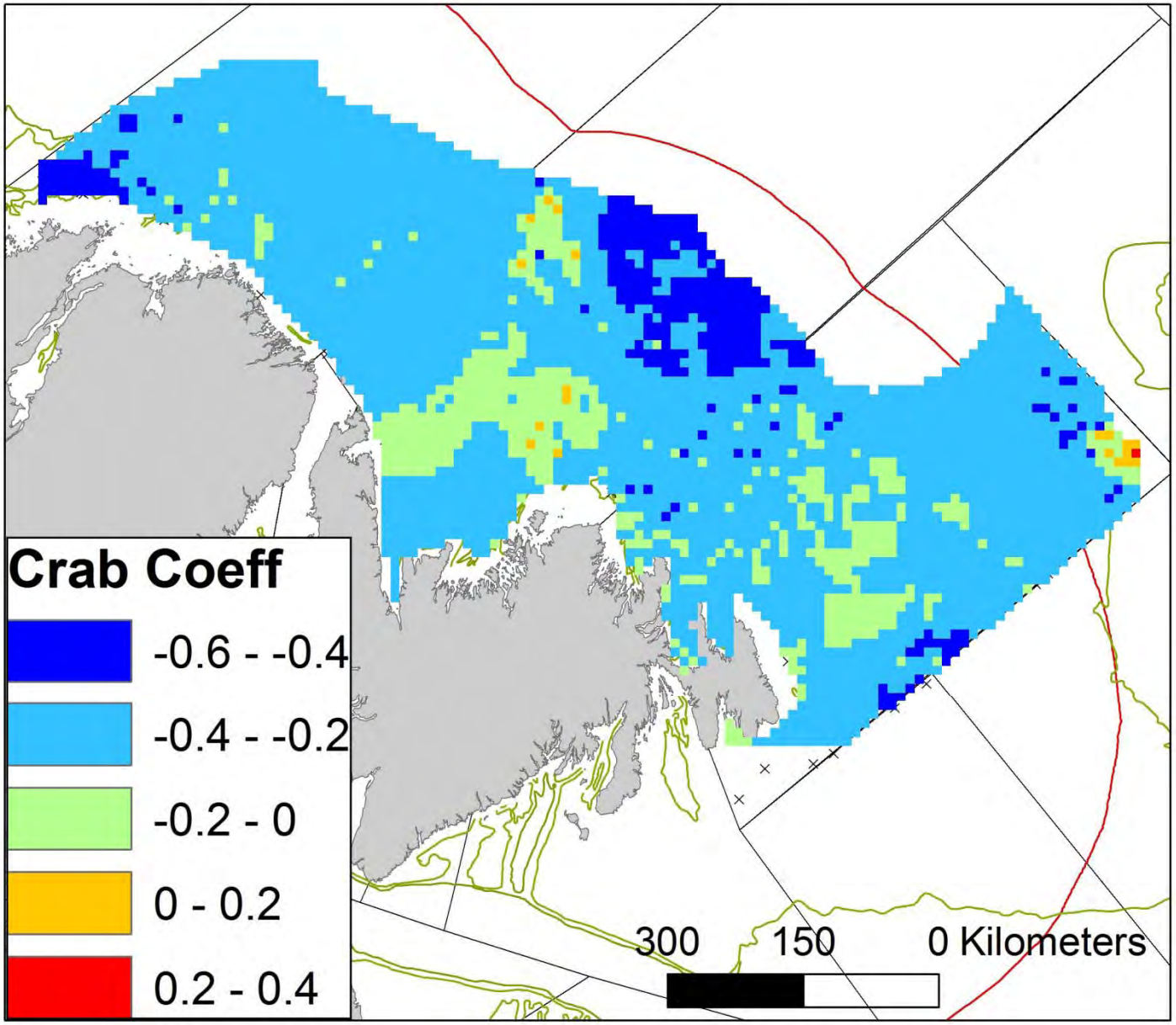
Negative

x Not Significant

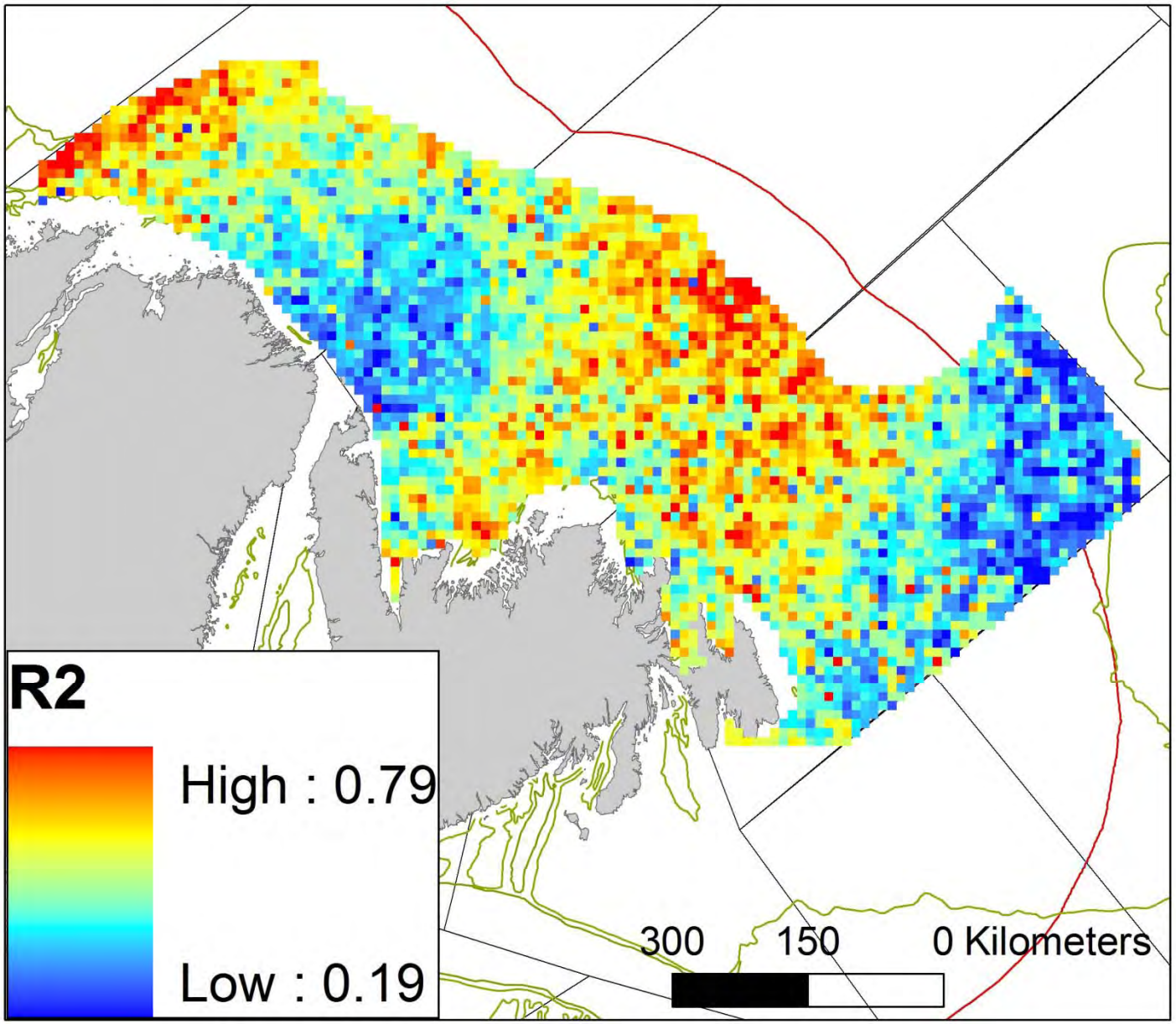
OLS Stand. Coeff



Ave. Significant Crab Coeff.



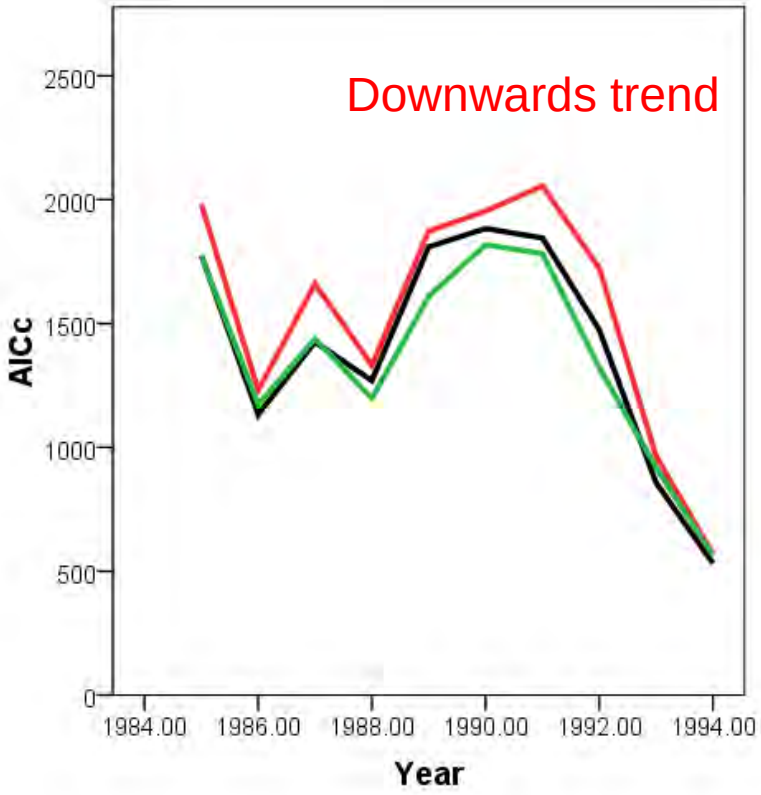
Summary of GWR Local R2

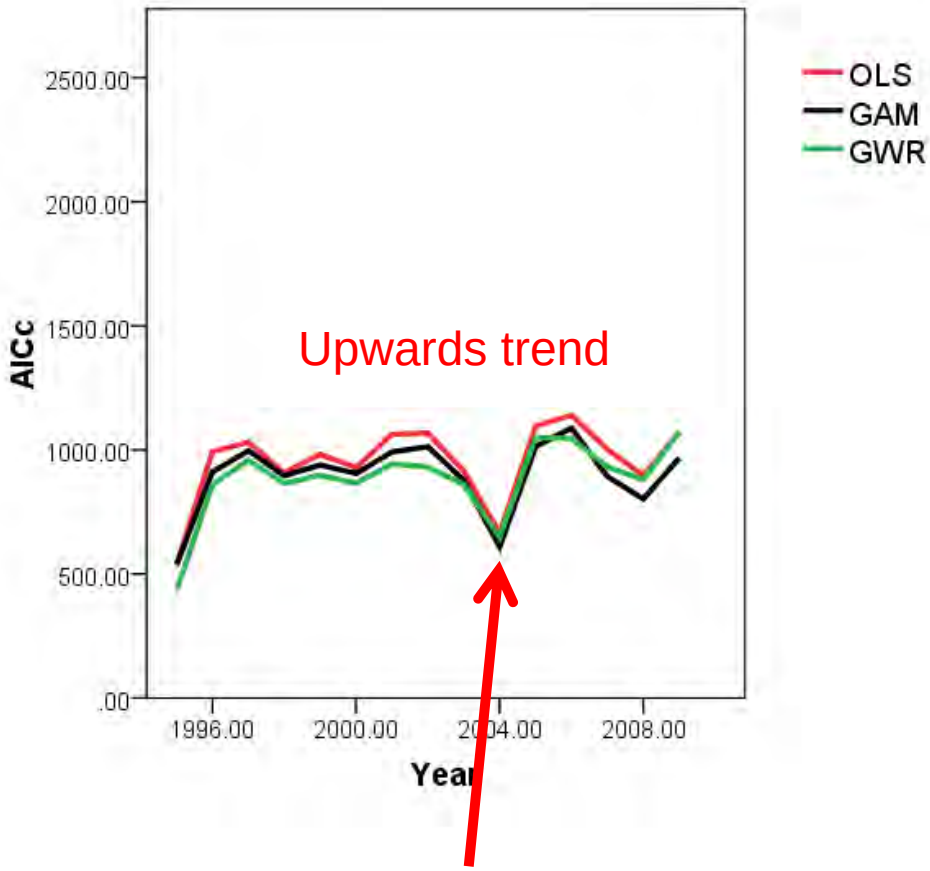


Comparison of Model Performance

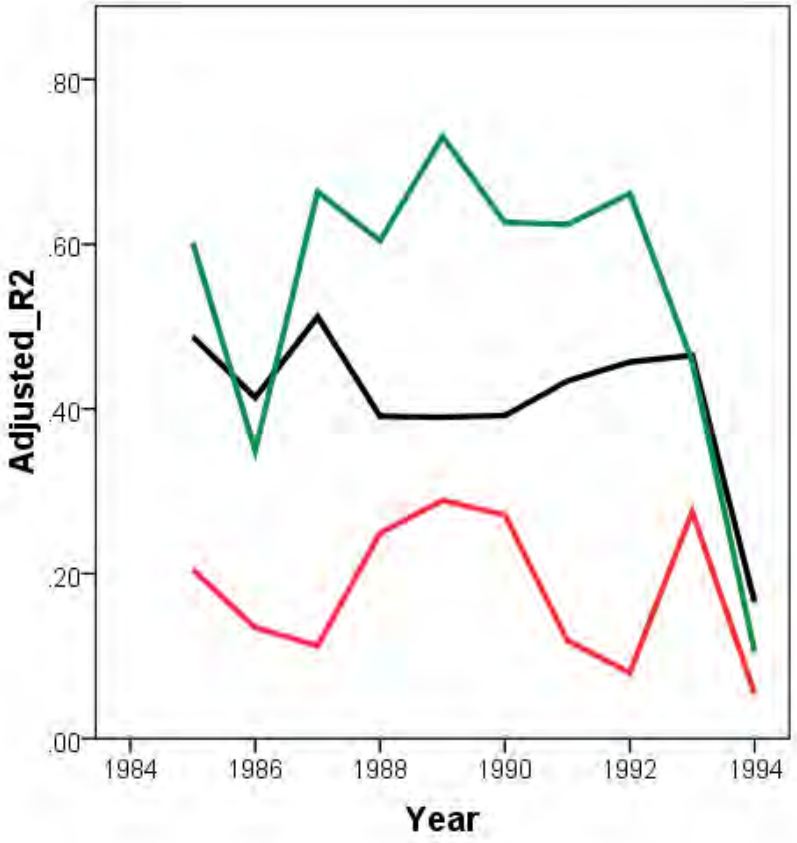
- Akaike Information Criterion (AIC) Scores
  - The lower the AIC, the closer the approximation of the model to reality
  - AIC values that differ by more than 3 units considered significantly different
- Coefficient of variation (R^2)

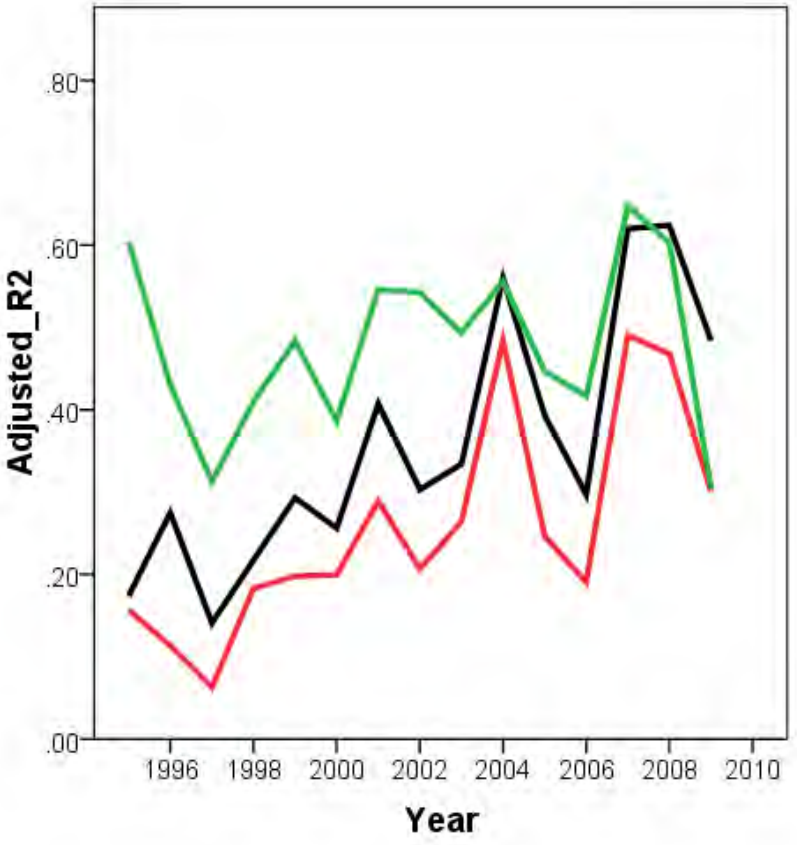
Model Performance Comparison





Model Performance Comparison





R2 higher when cod stock is healthy → cod distribution more predictable

Gradual increase in R2 over time → cod distribution becoming more predictable

Conclusions

- Local spatial regression models have potential to outperform global analyses and can better explore spatial variability of fisheries data
  - Increase/decrease of explanatory variable in one location can predict cod in current/future year for same location
- Cod from previous year best predictor of cod distribution
- GWR coefficients reveal spatial patterns in locations of significant relationships between cod and crustaceans
  - Spatial pattern of significance – temporally variable
  - Spatial pattern of direction – temporally stable
- GWR outperformed OLS and GAM regressions, complimentary to global analyses

Acknowledgements

- GEOIDE Network
- Canadian Center for Fisheries Innovations
- Fisheries and Oceans Canada
- Fisheries and Aquaculture Newfoundland
- World Wildlife Fund
- CIDCO
- St. Lawrence Observatory
- IFREMER

For more information visit the GeoCod website:

http://www.ucs.mun.ca/~rdeville/geocod