Economic Effects of Hypoxia on Fisheries

Martin D. Smith
Nicholas School of the Environment
Duke University

July 15, 2014

Thanks to NOAA Grant# NA09NOS3780235

Mechanisms for Hypoxia to Affect Economic Performance in Commercial Fisheries

Slow growth

- Less abundance – lower catches
- Smaller individuals – lower prices

Mortality

- Less abundance – lower catches

Mobility

- Change spatial distribution of catches – travel costs
- Aggregation -- catchability

Approaches

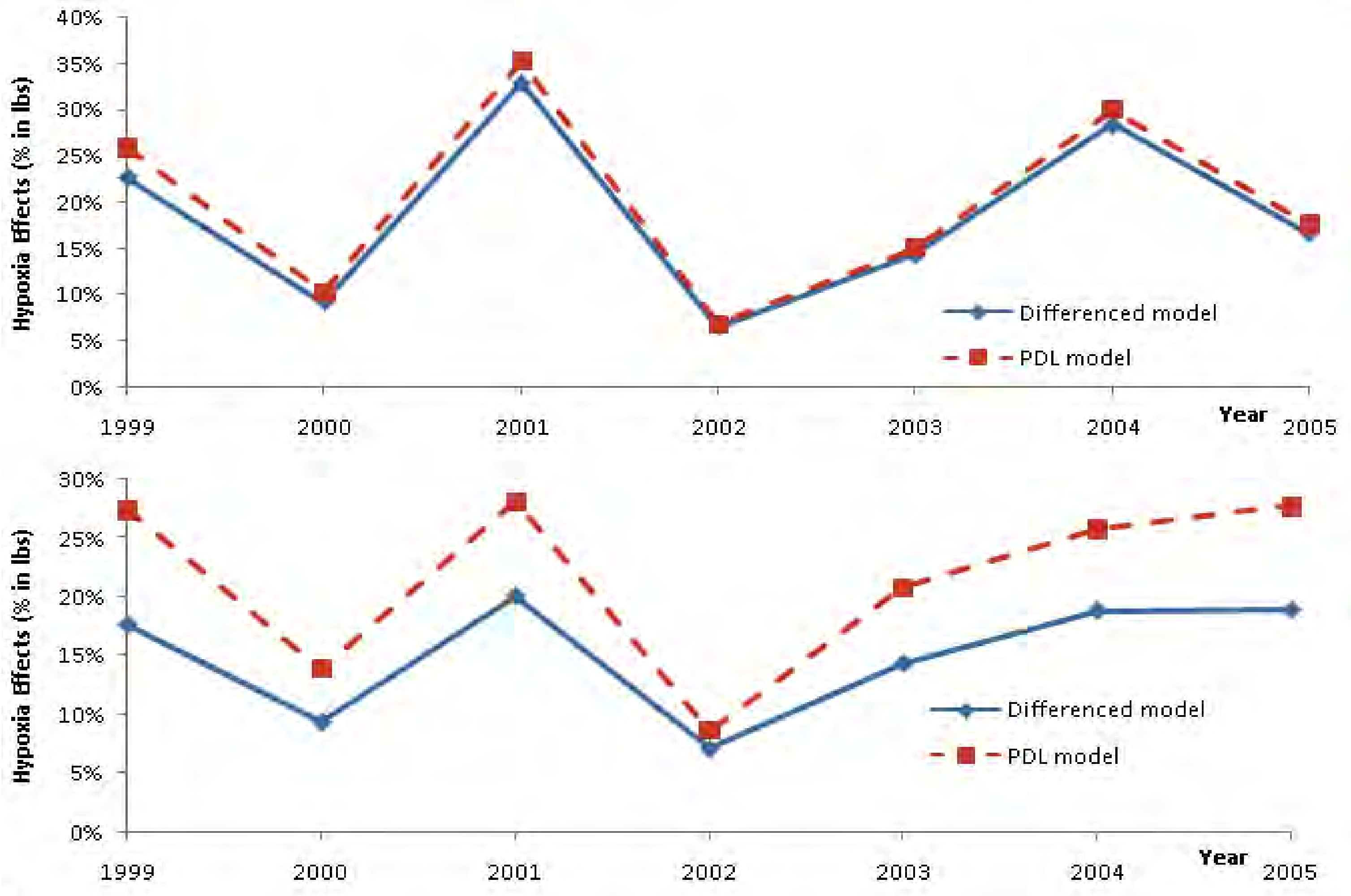
1. Empirical bioeconomic modeling
2. Treatment effects
3. Bioeconomic simulation
4. Time series analysis of prices

Future: combine 1 and 3

1. EMPIRICAL BIOECONOMIC MODELING OF HYPOXIA AND SHRIMP FISHERIES

Impact: Lost Catches From Hypoxia

Neuse R. and Pamlico Sound



Huang, Smith, and Craig (2010)
“Measuring Lagged Economic Effects of Hypoxia in a Bioeconomic Fishery Model”
Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science

From impacts to value

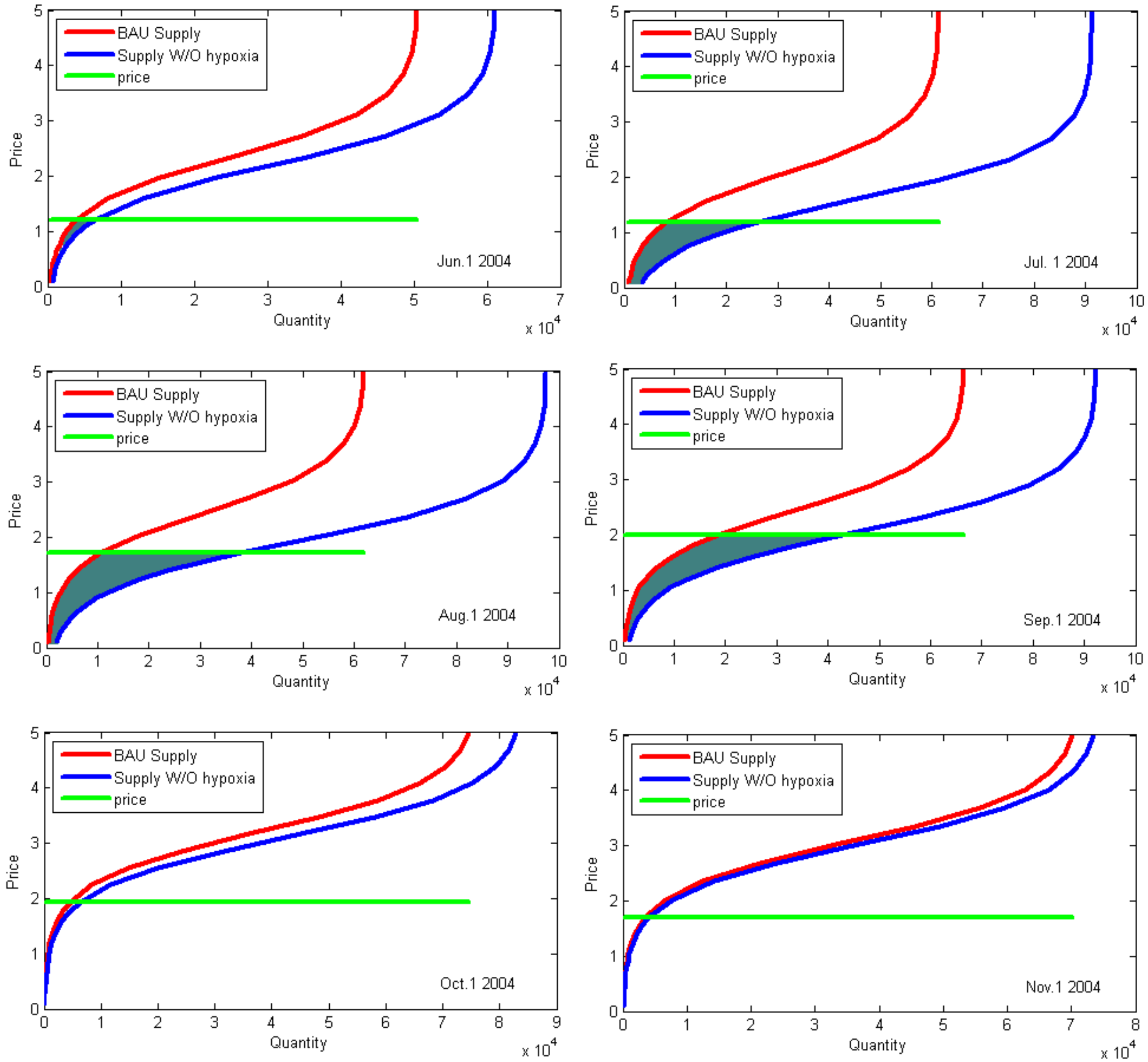
- Price for NC shrimp determined non-locally – no effects on consumers

- A hypothetical reduction in hypoxia would **increase revenues by $1.2 million annually**

- A hypothetical reduction in hypoxia would **increase value $0.3 million annually** (~25% of revenue loss)

Huang, Nichols, Craig, and Smith (2012)
"The welfare effects of hypoxia in the NC brown shrimp fishery"
Marine Resource Economics

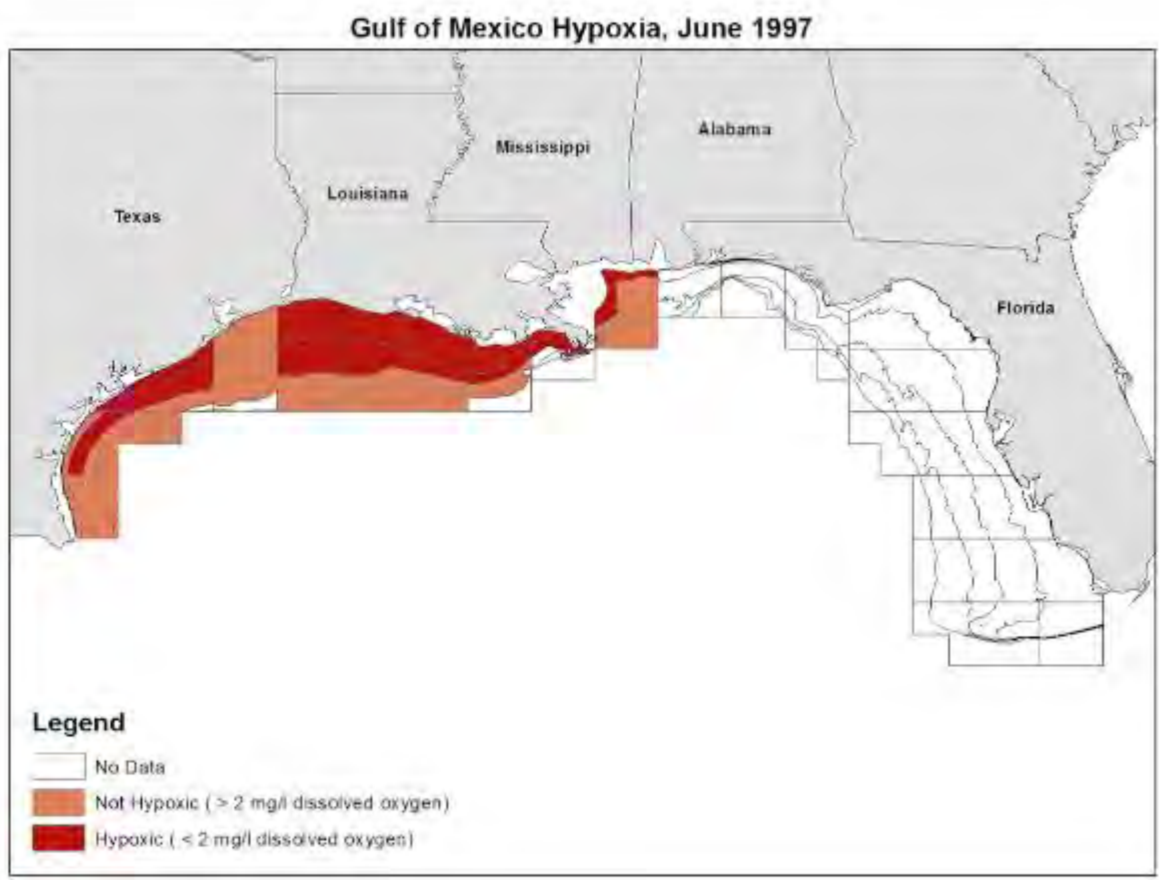
Actual economic losses are only 25% of revenue losses



3. TREATMENT EFFECTS –HYPOXIC AREAS AS “TREATMENT” AND NON-HYPOXIC AREAS AS “CONTROLS”

Subarea-Depth Zone

Snapshot of Hypoxia



Treatment Effects Models

- Triple differences – space, time, and hypoxia
- ln(Catch) dependent variable with Effort as independent variable
- 31-choice conditional logit model with BLP contraction mapping and stratified random sample of the fleet to predict Effort and purge endogeneity
- Fixed effects for year, month, zone, year-zone

Conditional Logit Restults

Variable	Estimate	std error	t-stat
Wind Speed	-2.2196	0.0423	-52.4610
Shrimp Price	8.9512	0.2109	42.4349
Diesel Price	-15.6177	0.4554	-34.2954
E(revenue)	0.2567	0.0039	66.3616
E(catch)	0.1784	0.0040	44.3949
Distance	-42.3594	0.1210	-350.1362

Treatment effects results

- No statistically significant effect on aggregate catches
- No statistically significant pattern of effects on individual size classes
- No statistically significant dynamic (lagged) effects of hypoxia
- Still exploring alternative identification strategies

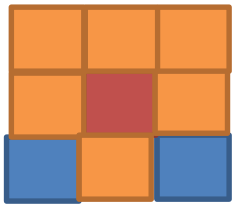
3. BIOECONOMIC SIMULATION

Results from Prior Work

- Economic benefits from reduced hypoxia are temporary increases in profits (Smith and Crowder, *Sustainability*, 2011)
- Gains from improved fisheries management of NC blue crabs far outweigh gains from eliminating hypoxia (Smith, *Land Economics*, 2007)
- Optimal fishery management response to hypoxia (in shrimp/annual species) – open season earlier, but gains are small (Huang and Smith, *Ecological Economics* 2011)
- Improved environmental quality becomes a margin for rent dissipation (Smith, *Annual Review of Resource Economics* 2012)

Gulf Shrimp Spatial-dynamic Bioeconomic Simulation

(Smith et al. *Marine Resource Economics* 2014)



Space as (3 x 3) Grid with stochastic hypoxia (worse in middle)

$$N_{0,j,y} = \widetilde{N}(1+\varepsilon_{j,y})\theta_j$$ Recruitment

$$N_{t,j,y} = N_{0,j,y}e^{\sum_s -m_s + \sum_s -f_s}$$ Survival

$$m_t = \beta(L_t)^{\rho}$$ Natural Mortality

$$f_t = qE_t$$ Fishing Mortality

$$L_t = L_{\infty}(1-e^{-\delta t})$$ Growth

$$w_t = \omega(L_t)^{\gamma}$$ Allometric (length to weight)

$$H_t = \frac{f_t}{f_t + m_t}(1-e^{-f_t})w_t N_t$$ Harvest

Hypoxia Adjustments

$$\widetilde{m_t} = (1+\Delta_m)m_t$$

$$\widetilde{q_t} = (1+\Delta_q)q$$

$$\widetilde{\delta_t} = (1-\Delta_\delta)\delta$$

$N_{a,t,j,y}$ Now adding cohorts!

Spatial-dynamic Bioeconomic Simulation

$$U_{ijt} = v_{itj} + \eta_{ijt}$$

Random Utility Maximization

$$v_{itj} = \begin{cases} \alpha, & for \;\; j = 0 \\ p_t h_{ijt} - c - \phi l_{ij}, & for \;\; j = 1, 2, 3, \ldots J \end{cases}$$

from Smith et al. *PNAS* 2010

$$p_t = \overline{p_t} + \varphi w_t$$

Weight-based Prices

$$E_{t,j} = I\left(\frac{e^{v_{i,t,j}}}{\sum_{k=0}^{J} e^{v_{i,t,k}}}\right)$$

Effort (closes the model)

Key Lesson

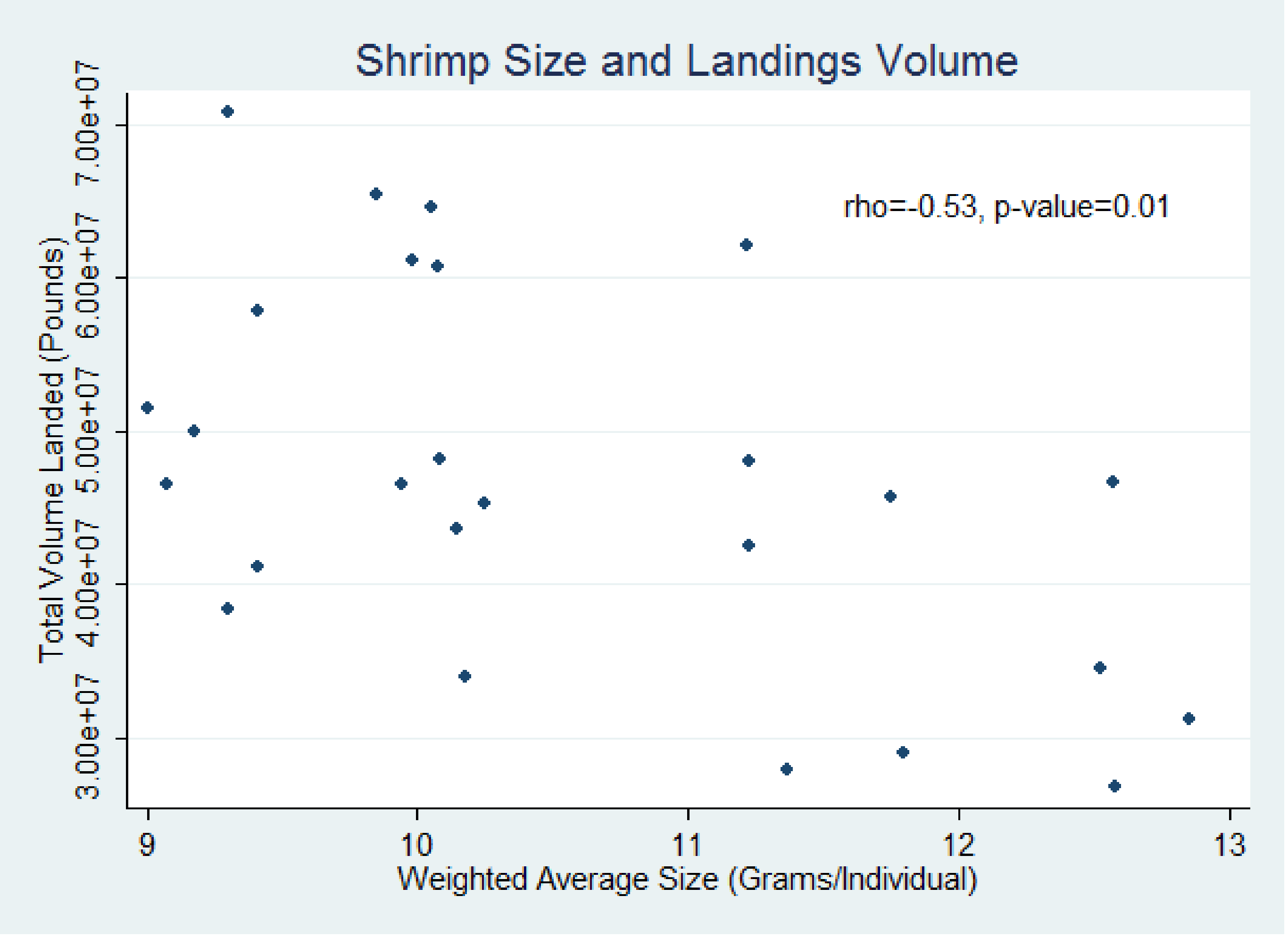
Detecting hypoxic effects from perfect data would be difficult

Simulation Outcome 1

Weighted shrimp size and total landings negatively correlated in simulations

- All correlations are negative and statistically significant (range rho = -0.31 to -0.67)
- Robust across hypoxic and counterfactual (non-hypoxic) cases
- Growth overfishing as key mechanism

Robust Relationship Between Landings and Average Shrimp Size in Simulations Appears in the Empirical Data



Simulation Outcome 2

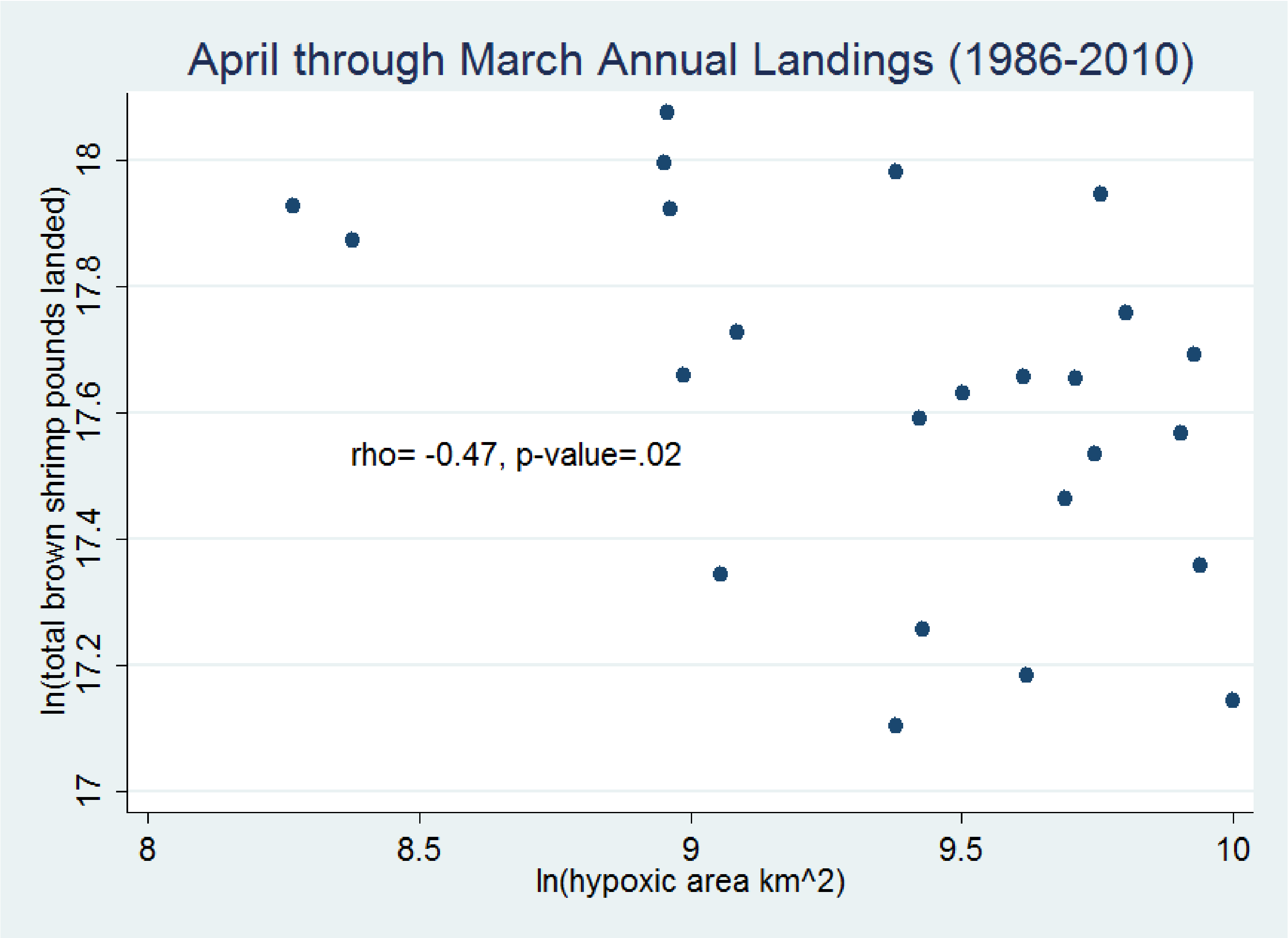
Total landings and hypoxic severity negatively correlated in simulations but weakly

(thought experiment of hypoxic extent with no counterfactual)

	Hypoxia Simulations				Counterfactual Non-Hypoxic Simulations			
Sim #	**Mortality**	**Catchability**	**Growth**	**Combined**	**Mortality**	**Catchability**	**Growth**	**Combined**
1	**-0.35**	0.01	-0.14	**-0.31**	*-0.25*	-0.05	-0.05	-0.17
2	-0.08	0.01	-0.12	-0.10	0.03	-0.05	-0.02	0.07
3	-0.14	0.17	-0.01	**-0.34**	-0.04	0.11	0.08	-0.17
4	**-0.35**	-0.16	-0.23	-0.10	-0.21	-0.21	-0.11	0.04
5	-0.09	0.16	-0.05	0.03	0.03	0.10	0.04	0.22

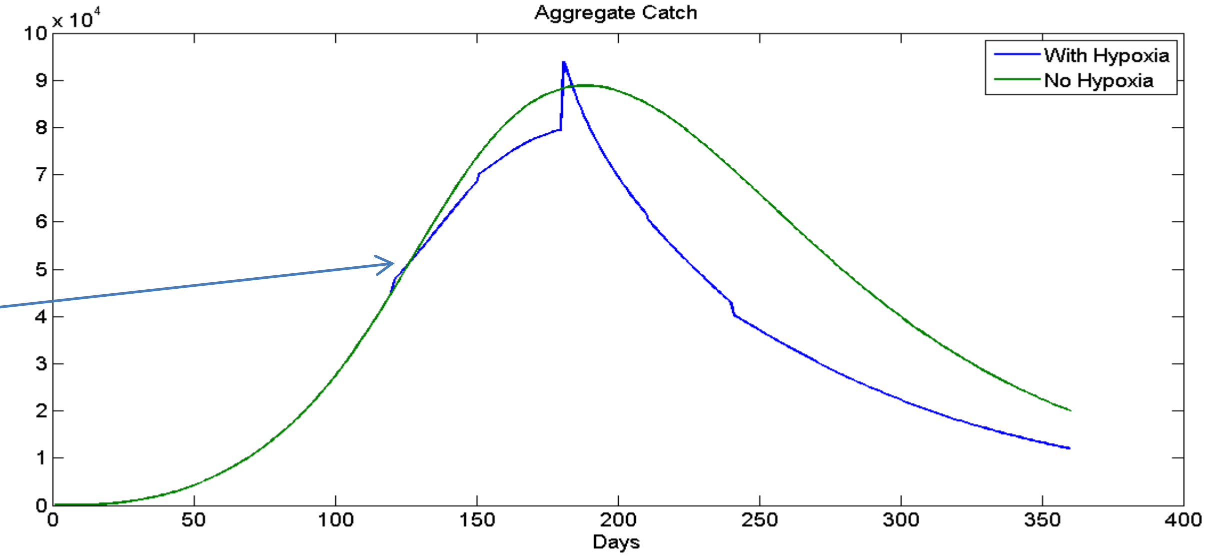
Bold means significant at 5% level, italics significant at 10% level.

Empirical annual total landings negatively correlated with hypoxia

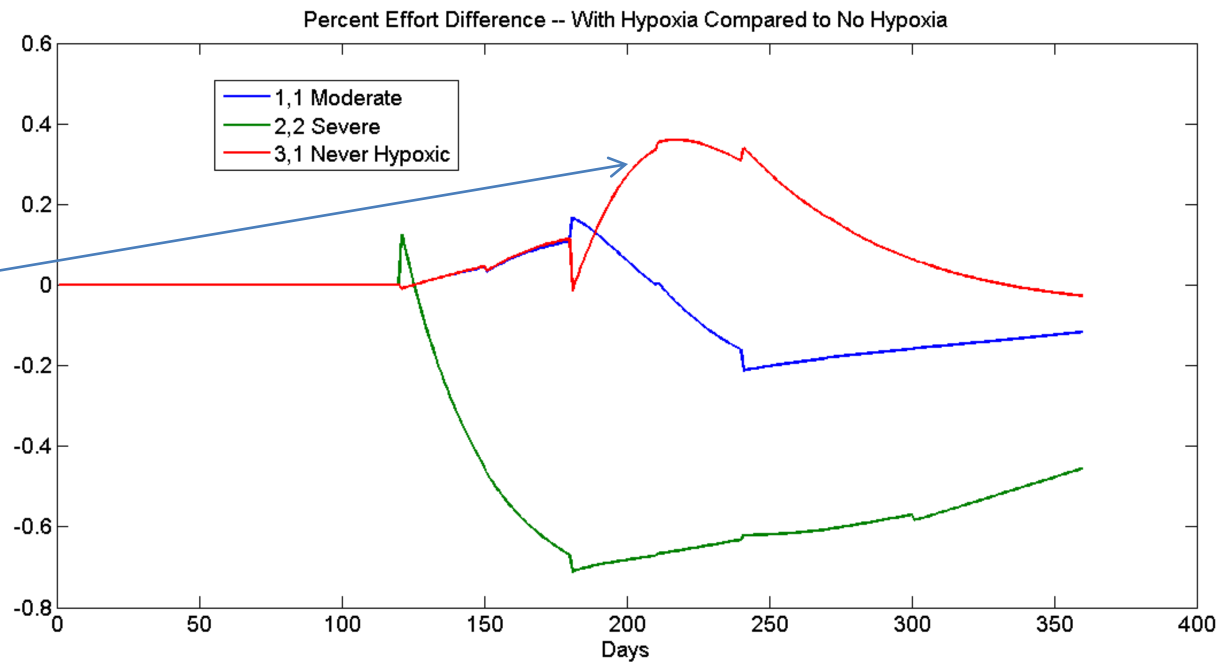


Simulation Outcome 3
Major roadblocks in detecting treatment effect!

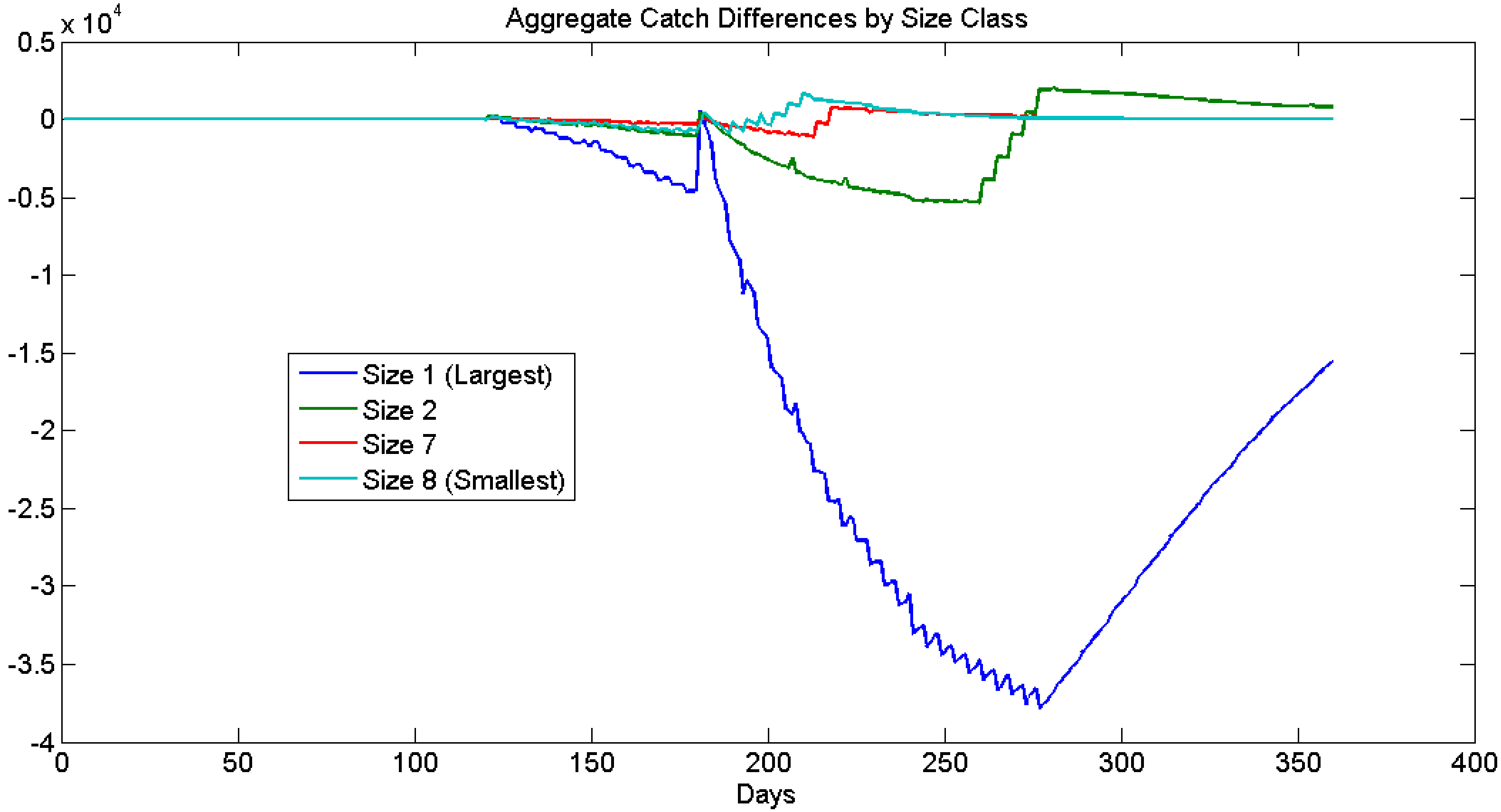
Dynamic,
Nonlinear,
and more peaked



Contamination
of the control



Simulation Outcome 4
Non-monotonic treatment effects in size-based catches



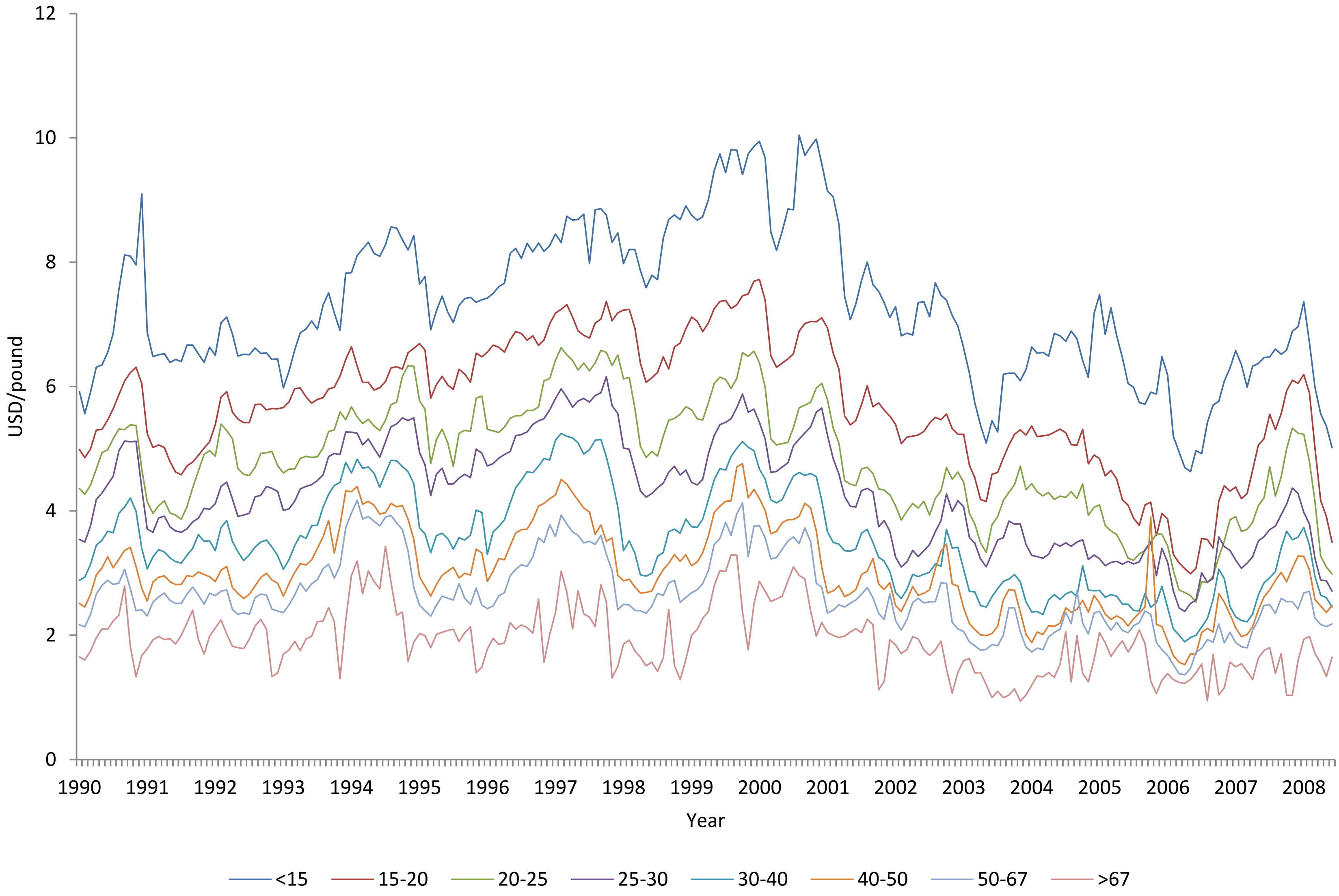
Aggregate-level data and bioeconomic simulations are generally consistent but highlight difficulty in finding effects of hypoxia on fisheries

4. TIME SERIES ANALYSIS OF SHRIMP PRICES – LET THE MARKET REVEAL THE ECOLOGICAL DISTURBANCE

Brown Shrimp Price by Size Class (#/pound)

Prices have stable long-run relationships

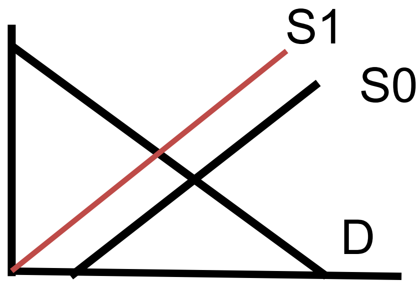
(Asche, Bennear, Oglend, and Smith, Marine Resource Econ. 2012)

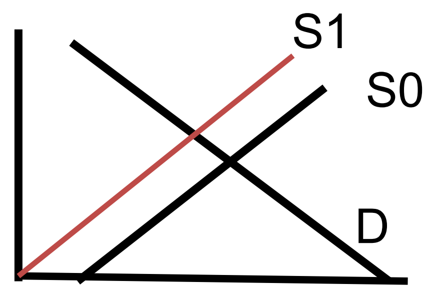


Hypothesis: Hypoxic mechanisms change relative prices (deviate from long-run relationships)

Small Shrimp | **Large Shrimp**

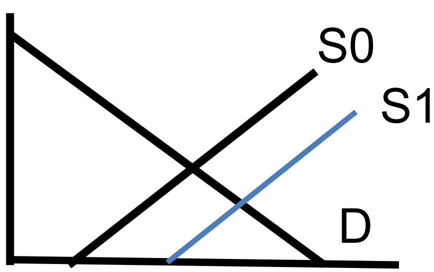
Ordinary Recruitment Shock

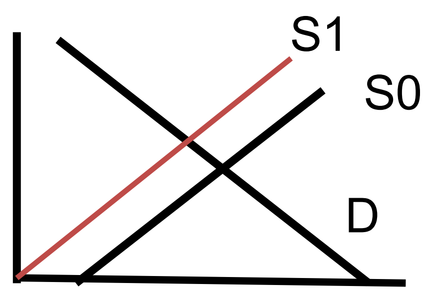




P_S	+
P_L	+
P_S/P_L	?

Hypoxia Shock





P_S	-
P_L	+
P_S/P_L	-

Key assumption: markets determine what a meaningful supply shift is

Hypoxia “causes” increase in relative price of large to small shrimp

B15-B3040		COEF	STD	T-VAL
Interpolation 1		0.054	0.026	2.038
Interpolation 2		0.014	0.018	0.824
B1520-B3040				
Interpolation 1		0.073	0.026	2.765
Interpolation 2		0.037	0.015	2.441
B2025-B3040				
Interpolation 1		0.047	0.019	2.482
Interpolation 2		0.046	0.011	4.355
B15-B4050				
Interpolation 1		0.067	0.031	2.159
Interpolation 2		0.036	0.022	1.682
B1520-B4050				
Interpolation 1		0.085	0.031	2.713
Interpolation 2		0.058	0.020	2.901
B2025-B4050				
Interpolation 1		0.058	0.026	2.194
Interpolation 2		0.068	0.016	4.130
B15-B5060				
Interpolation 1		0.089	0.032	2.756
Interpolation 2		0.088	0.021	4.233
B1520-B5060				
Interpolation 1		0.105	0.037	2.849
Interpolation 2		0.110	0.021	5.315
B2025-B5060				
Interpolation 1		0.078	0.033	2.374
Interpolation 2		0.119	0.019	6.251

Results robust to including fuel prices, sea surface temperature, and seasonal dummies!

Future Work

- Refine spatial-dynamic bioeconomic simulation
- Build structural econometric model forced by simulation model (using Method of Moments) to estimate deep parameters
- Run parameterized structural model with hypoxia turned on/off to trace out economic effects