Spatial Fisheries Values in the North Pacific

Matthew Berman

Institute of Social and Economic Research
University of Alaska Anchorage

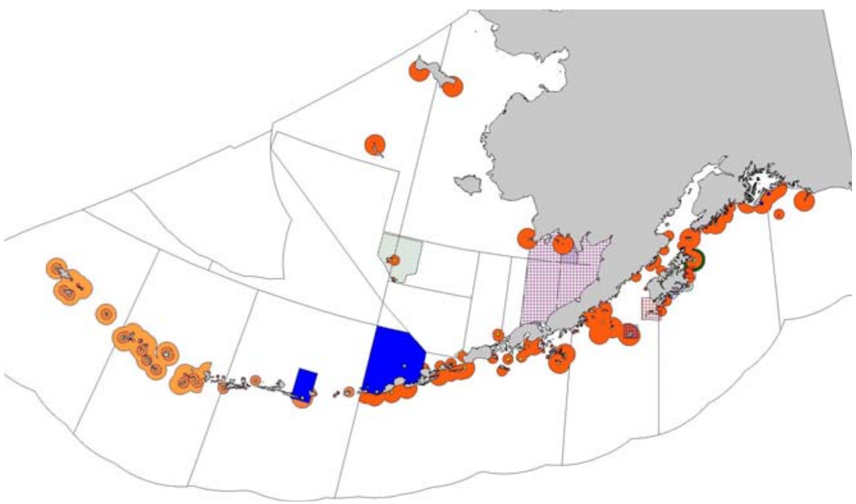
Ed Gregr
Ryan Coatta
Gaku Ishimura
Rashid Sumaila
Rowenna Flinn
Andrew Trites
Ryan Coatta

Fisheries Centre
The University of British Columbia

Research problem:

- New marine protected areas impose costly restrictions on commercial fishing.
- Methods lacking to estimate costs of fishery time and area closures at scales relevant to decisions
- Estimates of fisheries impacts lacking connection to ecological variables – might change over time

Spatial scale of protected areas:
Steller sea lion critical habitat



Spatial scale of available methods
Haynie and Layton (2004)

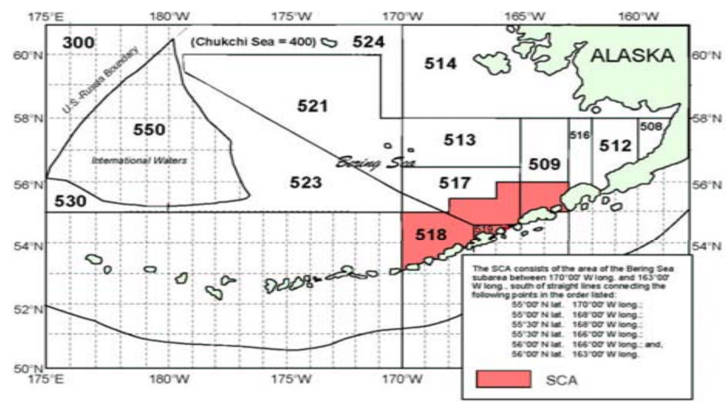
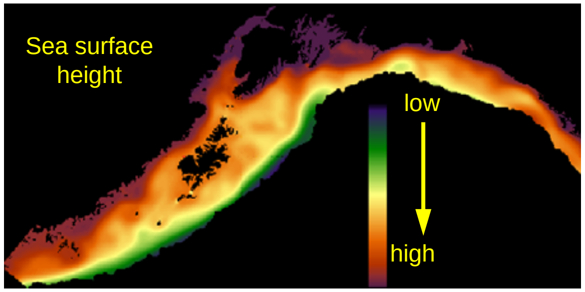


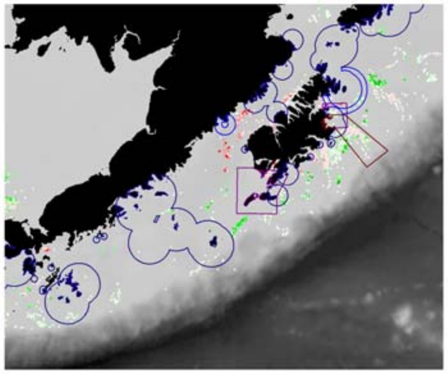
Figure 28 to Part 679. Steller sea lion conservation area (SCA) of the Bering Sea

Study Objectives

1. Link spatial variability of fisheries catch per unit of effort (CPUE) and profitability over the season to environmental variables;



2. Develop methods to estimate opportunity costs to the fishing industry of habitat closures, at time and area scales relevant to management decisions.



Application to Gulf of Alaska and Bering Sea groundfish fisheries

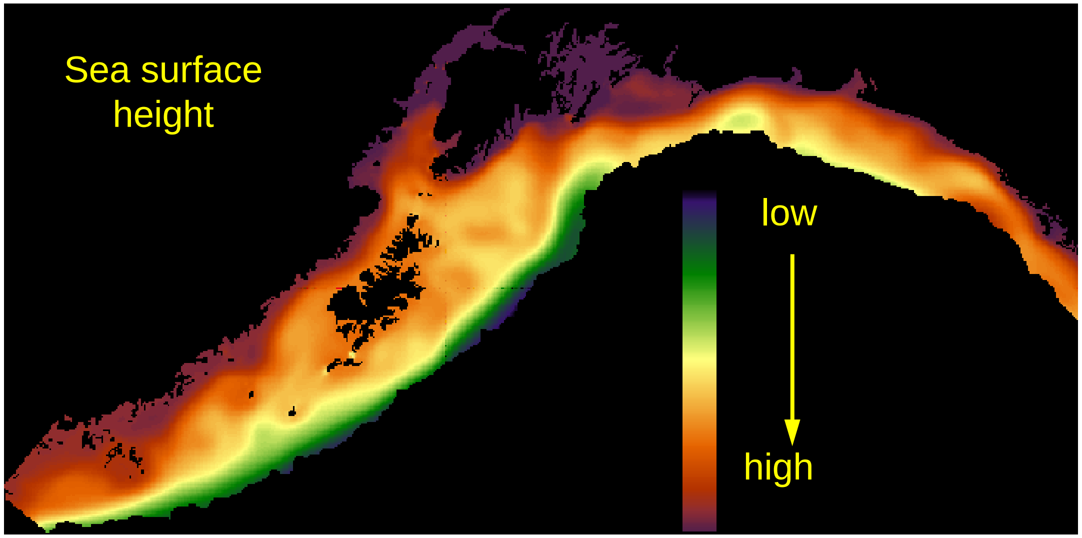
What do we mean by costs of habitat protection?


Photo ©American Seafoods Group LLC

Opportunity costs, or profits foregone from time and area closures and gear restrictions

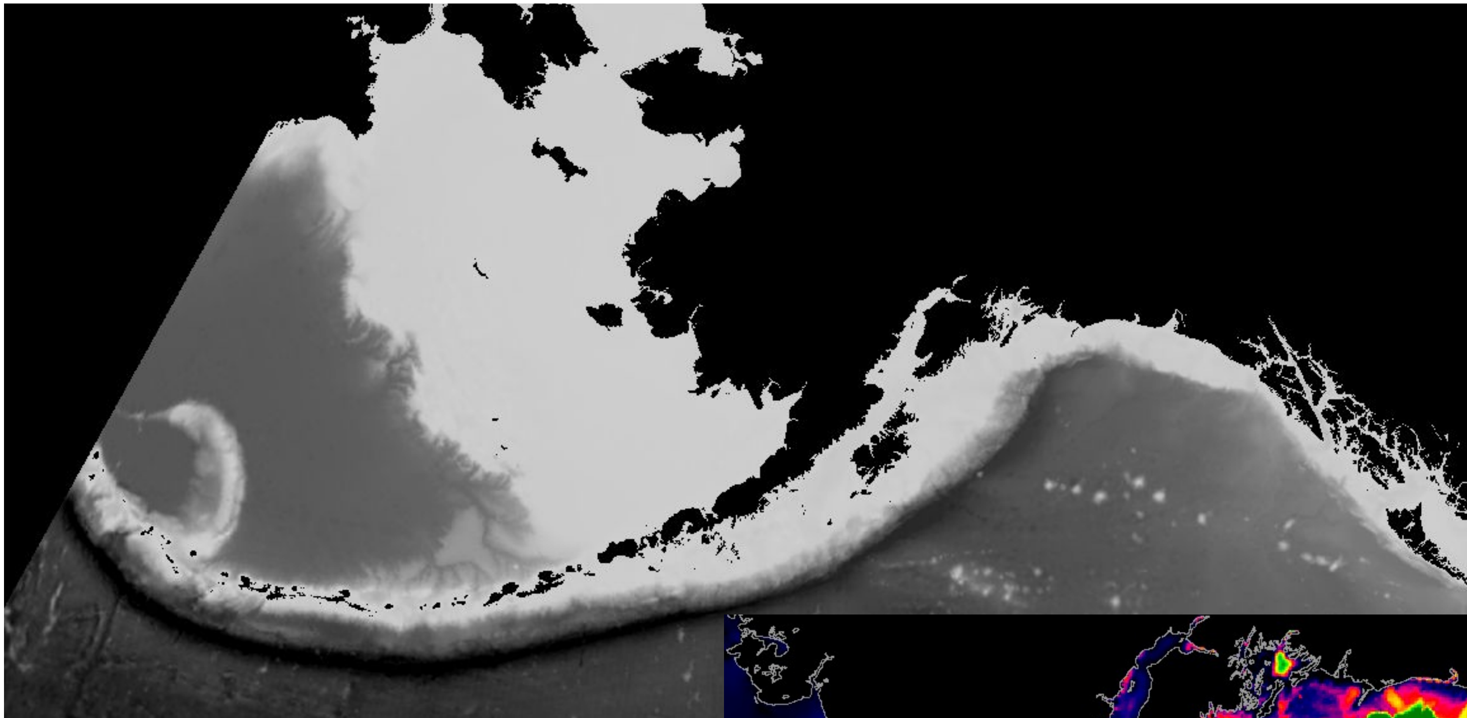
Objective 1: Link Spatial Variability of Fisheries CPUE and Values to Environmental Variables

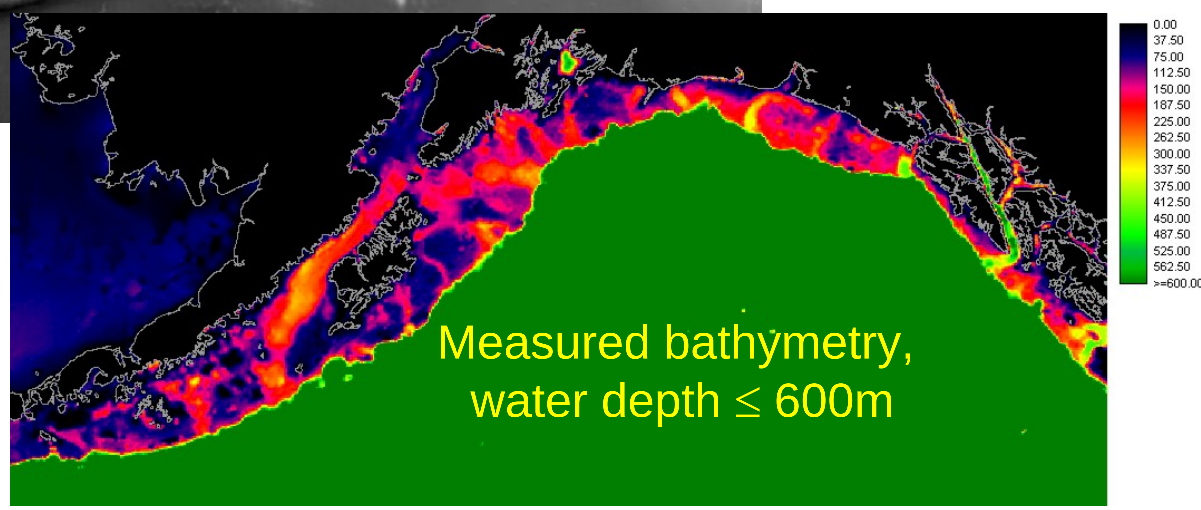
Hypothesis 1: Spatial anomalies in environmental conditions predict spatial variation in fish densities.



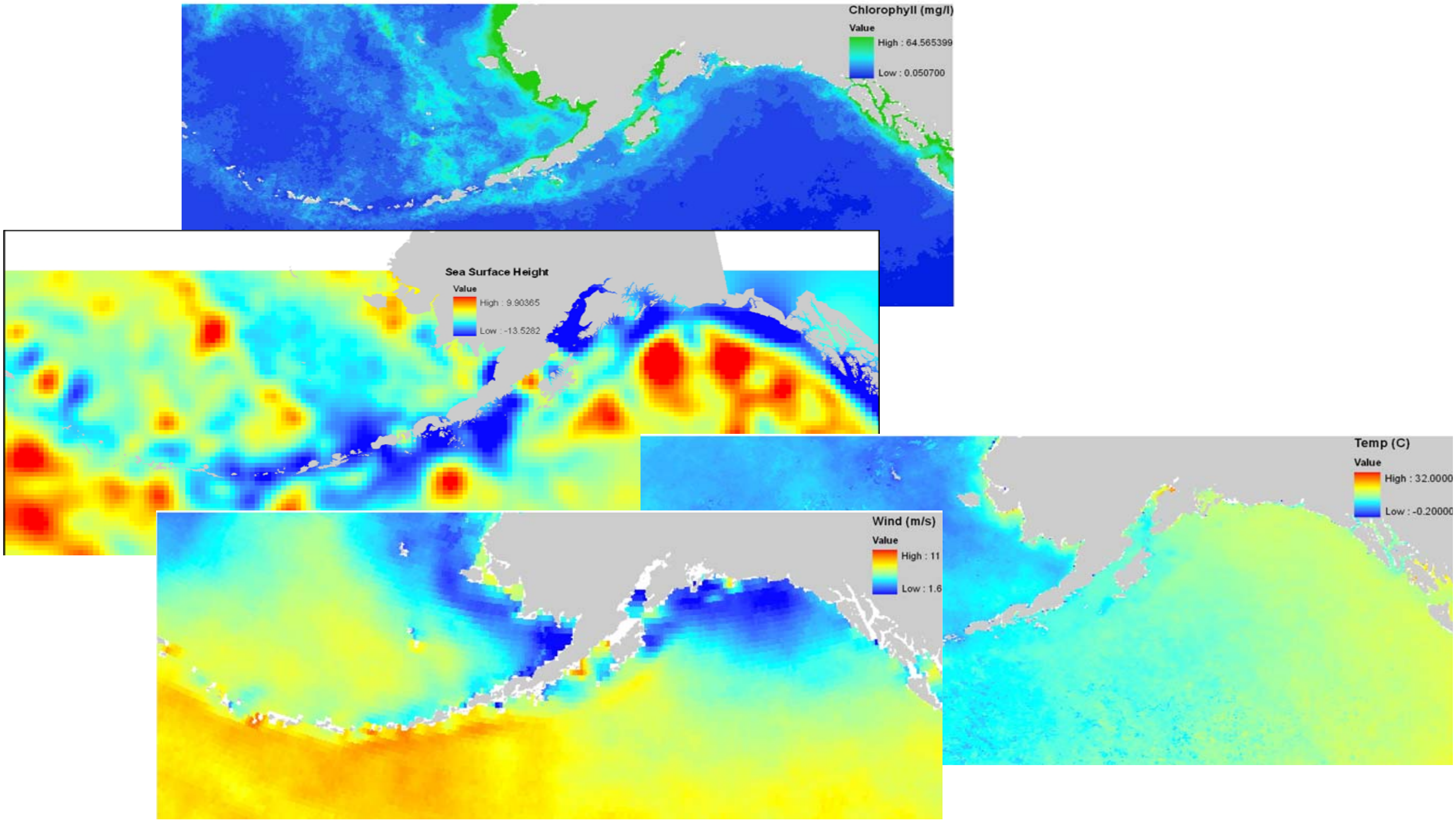
Environmental Data:

Measured Bottom Depth and Slope





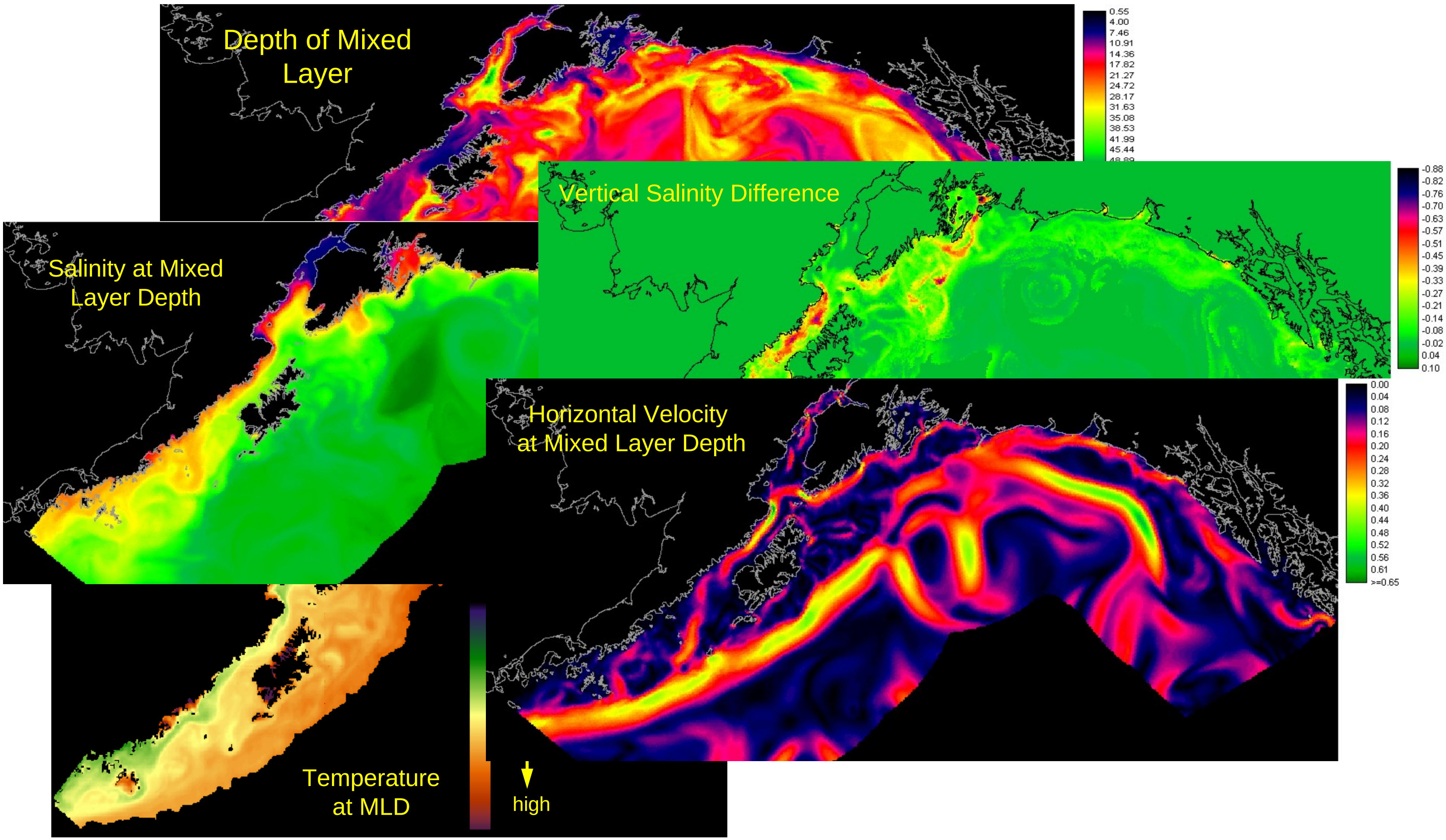
Environmental Data:
Remote-Sensed Physical Environment



Environmental Data:

Regional Ocean Modeling System (ROMS) Output

(Hermann et al.)



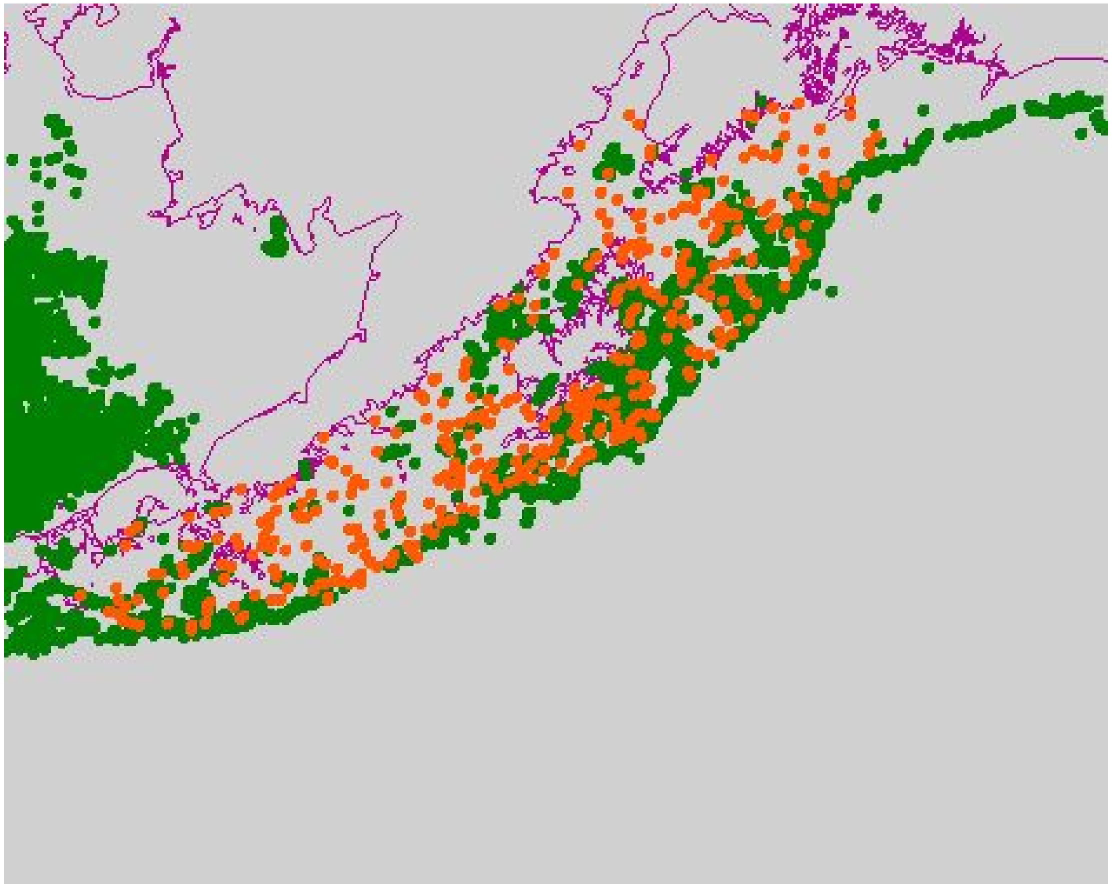
Data on CPUE

NMFS fisheries observer data

- Limited spatial and temporal coverage
- Random sample

NMFS trawl biomass survey data

- Many data points, wide geographic coverage
- Not a random sample



2001 observer haul locations (green)

vs.

2001 trawl survey locations (orange)

Results of Equations to Predict Spatial Variation in Fish Biomass:
CPUE Data from 2001 NMFS Gulf of Alaska Bottom Trawl Survey

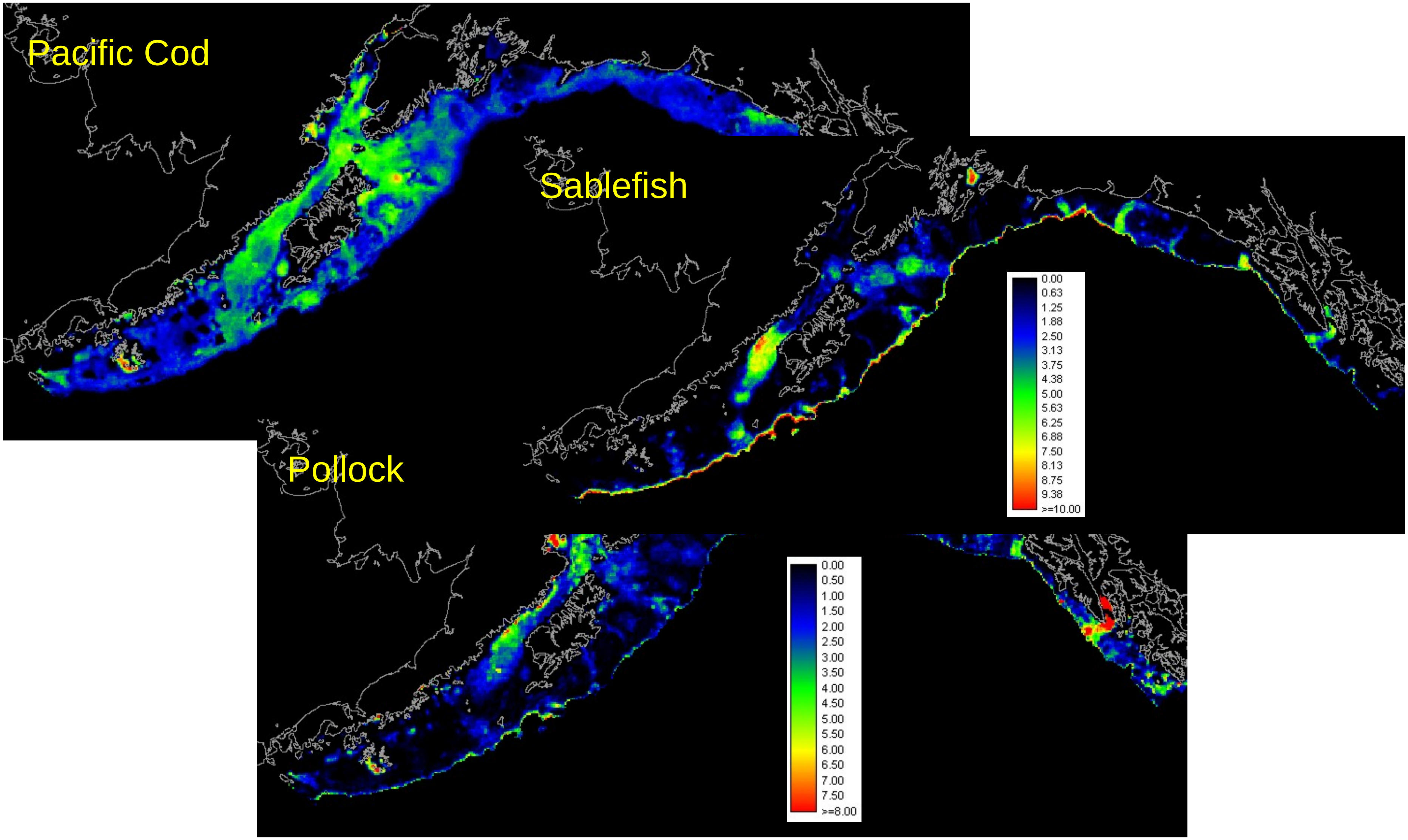
Variable	*P. cod*	*pollock*	*black cod*	*halibut*	*flatfish*	*rockfish*
Modeled environment						
Bottom depth	22	++	22	--	22	22
Bottom slope			+	+	++	
Mixed layer depth		++		--		
Bottom temp.	22	22		-	+	
Temp. gradient	+	++	++		+	-
Salinity at mld	22	2	++		-	+
Salinity gradient	-	--	+		++	
Vertical velocity			-			
Vert. vel. gradient			+			
Horiz. velocity				++	--	
Hor. vel. gradient			-	+	--	
Sea surface height	+					
Remote sensed environment						
Sea surface temp.	--				-	
Sea surface height			++	+	-	
Chlorophyll		++	++			++
Lagged chlor.	+		+	--		
Wind	+		-			-
R sq. OLS	0.28	0.33	0.63	0.35	0.30	0.45
Significant positive association		+	Positive association < .01			++
Significant negative association		-	Positive association < .01			--
Significant quadratic association		2	Quadratic association < .01			22

Results of Equations to Predict Spatial Variation in Fish Biomass:
CPUE Data from 2001 NMFS Gulf of Alaska Summer Bottom Trawl Survey

Variable	*P. cod*	*pollock*	*black cod*	*halibut*	*flatfish*	*rockfish*
Modeled environment						
Bottom depth	22	++	+	--	22	2
Bottom slope	2		+	+	++	
Mixed layer depth		++		--		
Bottom temp.	22	22	22	-	+	
Temp. gradient	+	++	++		+	--
Salinity at mld	22	2	2		-	2
Salinity gradient	-	--			++	++
Vertical velocity						
Vert. vel. gradient			++			-
Horiz. velocity			--	++	--	
Hor. vel. gradient			--	+	--	
Sea surface height	+					
Remote sensed environment						
Sea surface temp.	--				-	
Sea surface height				+	-	
Chlorophyll	++	++	++			++
Lagged chlor.	+		--	--		
R sq. OLS	0.27	0.33	0.58	0.35	0.30	0.48
Significant positive association		+	Positive association < .01			++
Significant negative association		-	Positive association < .01			--
Significant quadratic association		2	Quadratic association < .01			22

Average predicted CPUE, mid June

Estimated with data from 2001 NMFS Gulf of Alaska Bottom Trawl Survey



Results of Equations to Predict Spatial Variation in Fish Biomass:
CPUE Data from 2001 NMFS Gulf of Alaska Summer Bottom Trawl Fisheries

Variable	*P. cod*	*pollock*	*black cod*	*halibut*	*flatfish*	*rockfish*
Modeled environment						
Bottom depth	22	22	22	22	22	22
Bottom slope		++				2
Mixed layer depth	+	+		--	++	--
Temp. at MLD	--	-	--	--	22	22
Temp. gradient	+	-				--
Salinity at mld	22	--	2			
Salinity gradient		--	-			++
Vertical velocity						
Vert. vel. gradient	++				+	
Horiz. velocity			-		--	
Hor. vel. gradient		-	+	-	-	
Sea surface height			+			
Remote sensed environment						
Sea surface temp.	--	++			--	++
Sea surface height		--	++	++	++	
Chlorophyll		++				+
Lagged chlor.	-	++	-			--
R sq. OLS	0.41	0.34	0.43	0.16	0.40	0.64
Selection bias		--		++	+	++
Significant positive association		+	Positive association < .01			++
Significant negative association		-	Positive association < .01			--
Significant quadratic association		2	Quadratic association < .01			22

Results of Equations to Predict Spatial Variation in Fish Biomass:

CPUE Data from 2001 NMFS Gulf of Alaska Winter Bottom Trawl Fisheries

Variable	*P. cod*	*pollock*	*black cod*	*halibut*	*flatfish*	*rockfish*
Modeled environment						
Bottom depth	2	+	22		2	2
Bottom slope	2	++				2
Mixed layer depth		++	--	-	--	--
Temp. at MLD	++	++	2	++		2
Temp. gradient	++	--	++		+	--
Salinity at mld	22	22	++	2	++	22
Salinity gradient	--	--	++		--	++
Vertical velocity			+			
Vert. vel. gradient						-
Horiz. velocity						
Hor. vel. gradient						
Sea surface height	--	--				++
Remote sensed environment						
Sea surface temp.	-			--		
Sea surface height	+					
Chlorophyll	--				++	++
Lagged chlor.						
R sq. OLS	0.30	0.34	0.31	0.16	0.27	0.42
Selection bias		++	-		--	
Significant positive association		+	Positive association < .01			++
Significant negative association		-	Positive association < .01			--
Significant quadratic association		2	Quadratic association < .01			22

Comparison of Equation Results for Pollock and Pacific Cod Estimated with Different Data Sources

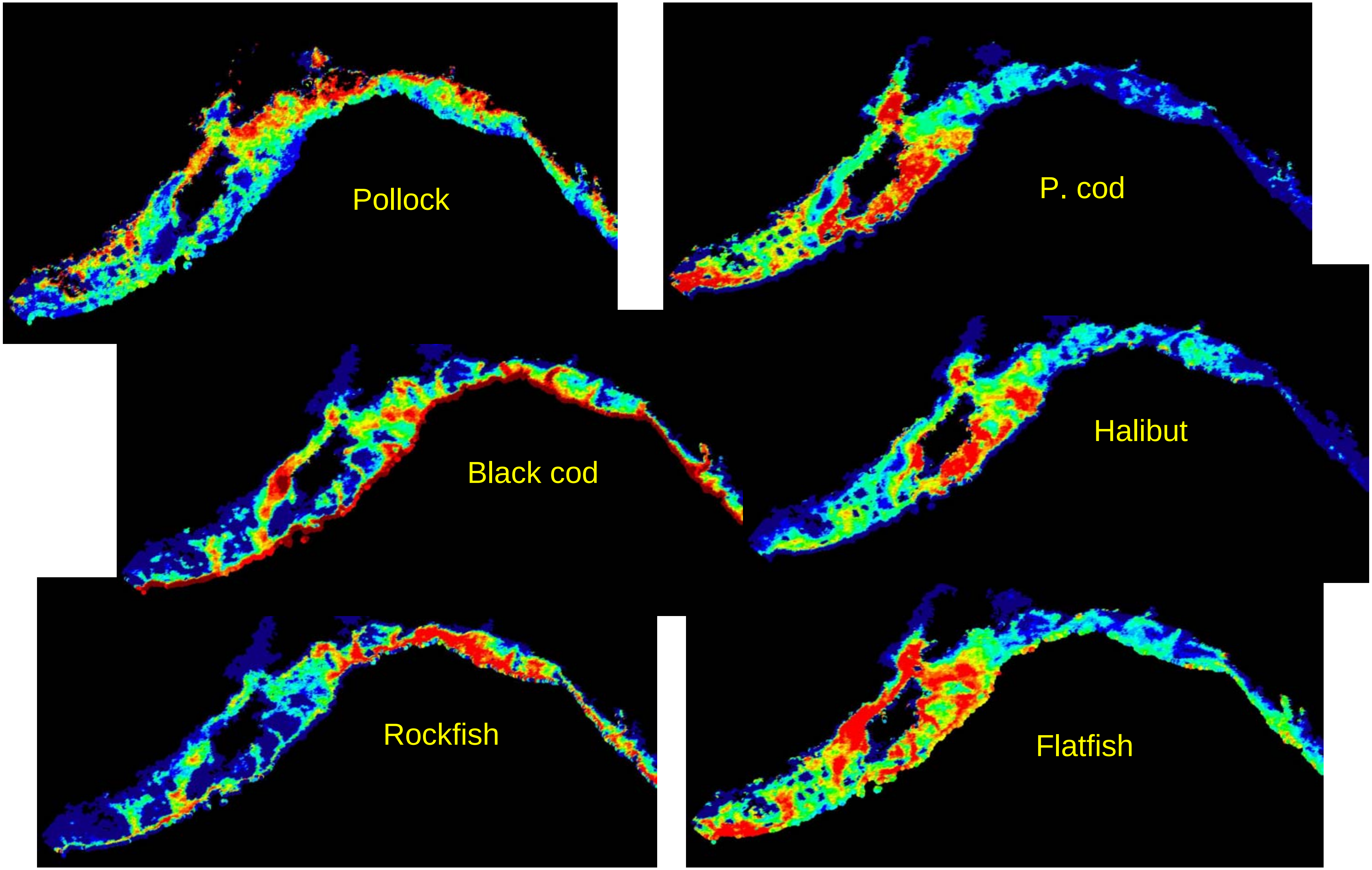
	Pollock				Pacific cod		
Variable	*Summer survey*	*Summer fishery*	*Winter fishery*		*Summer survey*	*Summer fishery*	*Winter fishery*
Modeled environment							
Bottom depth	++	22	+		22	22	2
Bottom slope		++	++		2		2
Mixed layer depth	++	+	++			+	
Bottom temp.	22	-	++		22	--	++
Temp. gradient	++	-	--		+	+	++
Salinity at mld	2	--	22		22	22	22
Salinity gradient	--	--	--		-		--
Vertical velocity							
Vert. vel. gradient						++	
Horiz. velocity							
Hor. vel. gradient		-					
Sea surface height			--		+		--
Remote sensed environment							
Sea surface temp.		++			--	--	-
Sea surface height		--					+
Chlorophyll	++	++			++		--
Lagged chlor.		++			+	-	
R sq. OLS	0.33	0.34	0.34		0.27	0.41	0.30
Significant positive association		+	Positive association < .01				++
Significant negative association		-	Positive association < .01				--
Significant quadratic association		2	Quadratic association < .01				22

Comparison of Equation Results for Flatfish and Rockfish Species Estimated with Different Data Sources

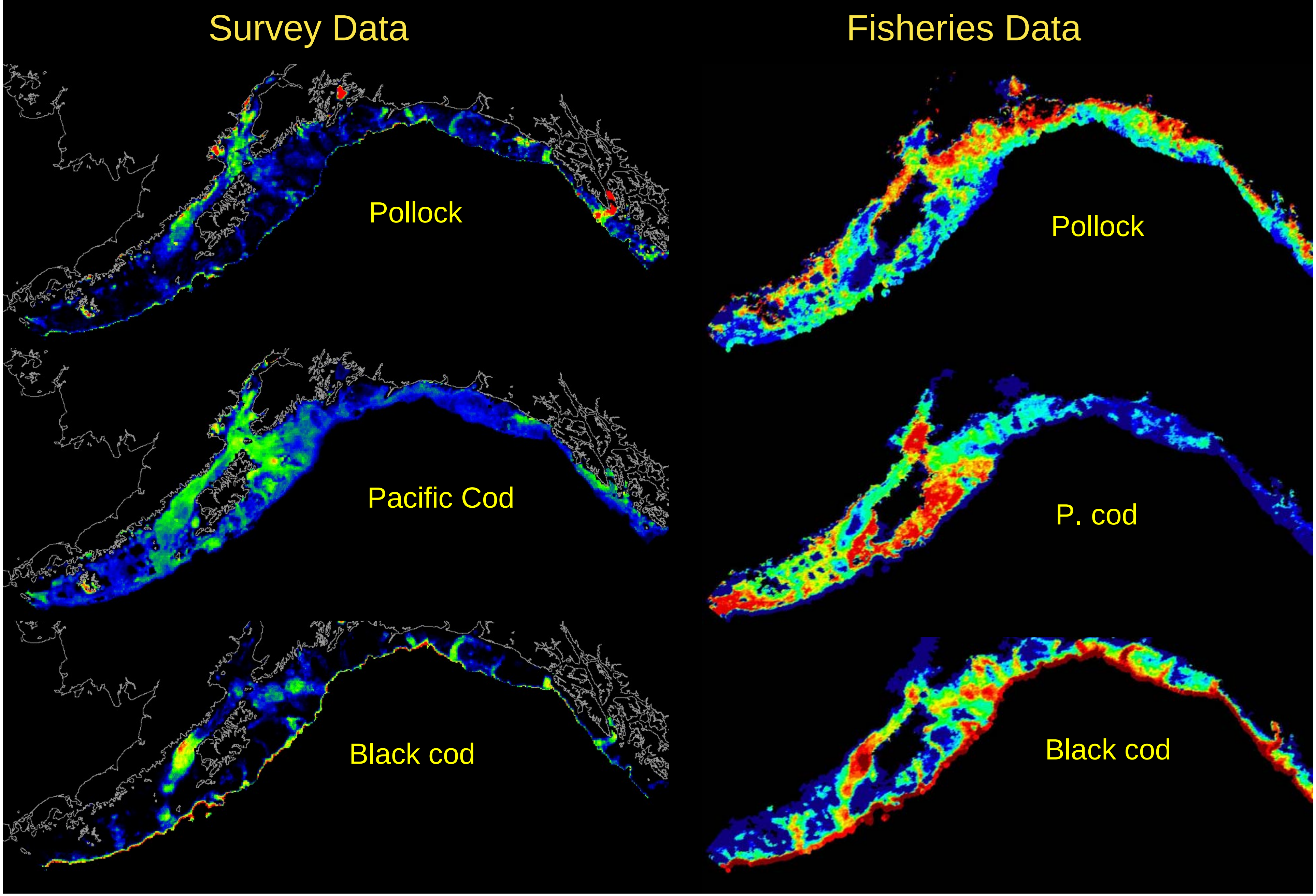
		Flatfish				**Rockfish**	
					Summer	*Summer*	*Winter*
Variable	*flatfish*	*flatfish*	*flatfish*		*survey*	*fishery*	*fishery*
Modeled environment							
Bottom depth	22	22	2		2	22	2
Bottom slope	++					2	2
Mixed layer depth		++	--			--	--
Bottom temp.	+	22				22	2
Temp. gradient	+		+		--	--	--
Salinity at mld	-		++		2		22
Salinity gradient	++		--		++	++	++
Vertical velocity							
Vert. vel. gradient		+			-		-
Horiz. velocity	--	--					
Hor. vel. gradient	--	-					
Sea surface height							++
Remote sensed environment							
Sea surface temp.	-	--				++	
Sea surface height	-	++					
Chlorophyll			++		++	+	++
Lagged chlor.						--	
R sq. OLS	0.30	0.40	0.27		0.48	0.64	0.42
Significant positive association		+	Positive association < .01				++
Significant negative association		-	Positive association < .01				--
Significant quadratic association		2	Quadratic association < .01				22

Average predicted CPUE, mid June

Estimated from 2001 Gulf of Alaska Bottom Trawl Fisheries
(NMFS Observer Data)



Comparison of Predictions for mid June Estimated with Different Data Sources



Results of Equations to Predict Spatial Variation in Fish Biomass:

CPUE Data from 2001 NMFS Observer Data, Bering Sea and Gulf of Alaska

	Catch per unit of effort (tons/hr): summer bottom trawl fisheries					
Variable	*pollock*	*P. cod*	*A. mackere*	*black cod*	*rockfish*	*flatfish*
Measured environment						
Bottom depth	22	22	22	+	22	22
Depth over time	+					+
Bottom slope	--	--	++	--	++	--
Remote sensed environment						
Sea surface temp.		+	22	22		
SST slope			++		+	
Sea surface height			++	-	++	++
SSH slope				++		
Wind speed	++			-	--	+
Chlorophyll	++	--		-	++	
Lagged chlor.	++	-	--	-	--	
R sq. OLS	0.24	0.23	0.40	0.36	0.50	0.27
Selection bias	-	--		--	++	-
Significant positive association	+	Positive association < .01				++
Significant negative association	-	Positive association < .01				--
Significant quadratic associatio	2	Quadratic association < .01				22

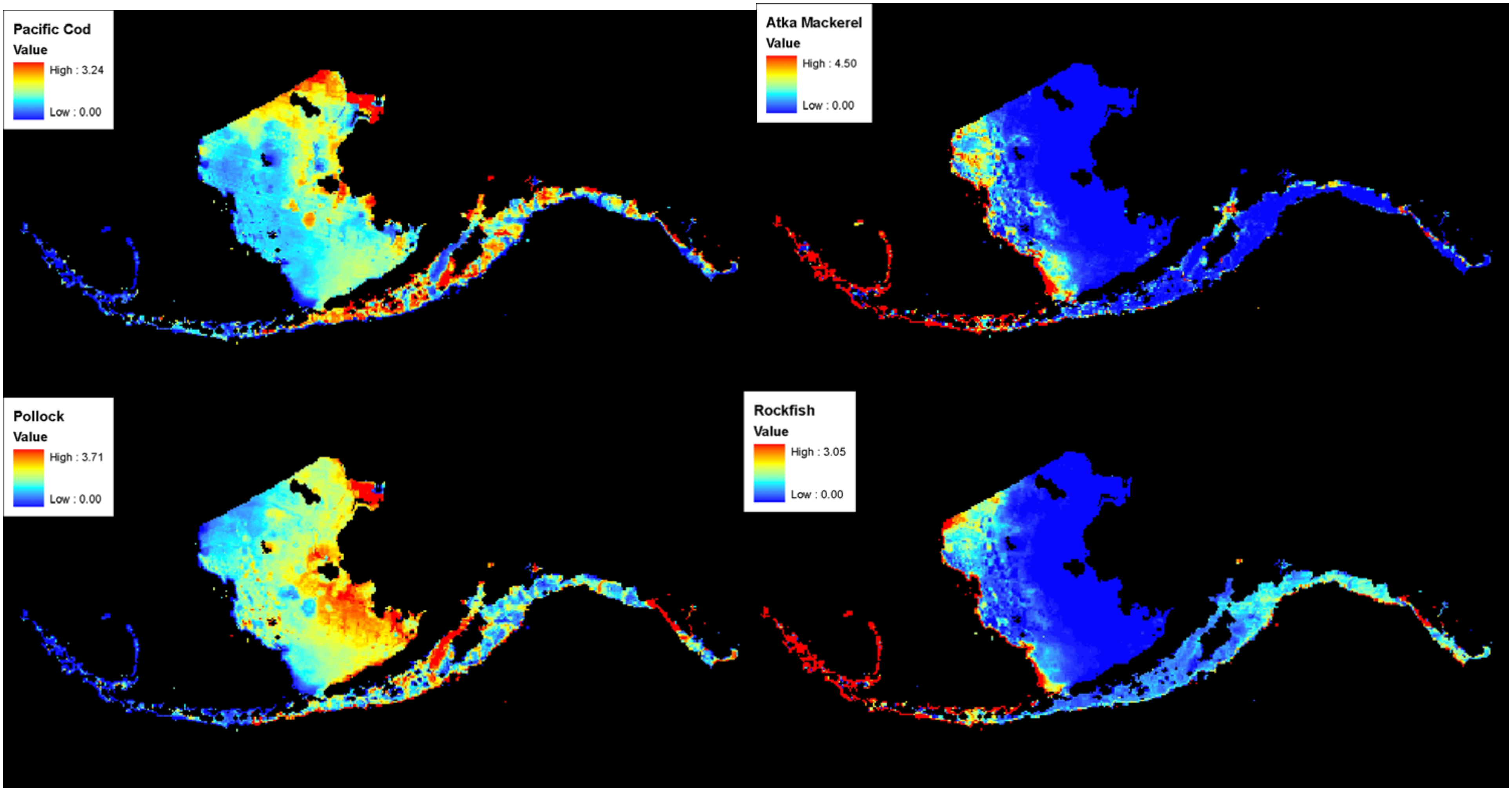
Results of Equations to Predict Spatial Variation in Fish Biomass:

Standardized CPUE Data from 2001 NMFS Observer Data, Bering Sea and Gulf of Alaska

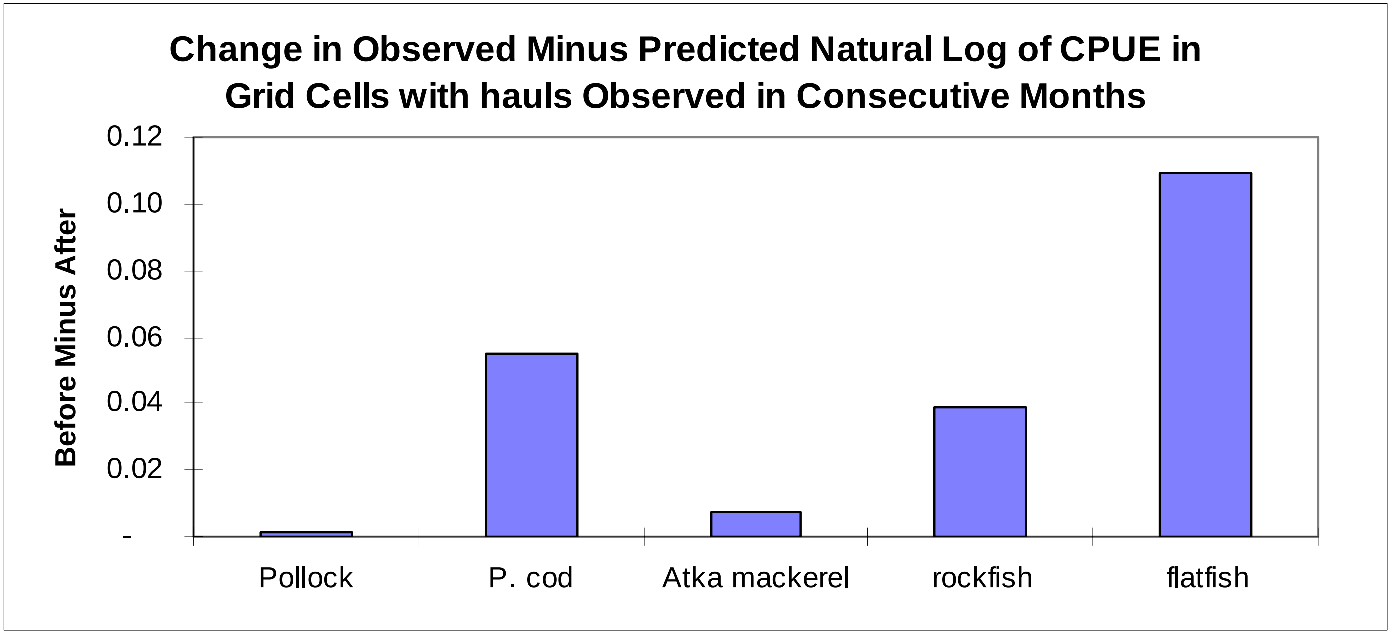
	Catch per unit of effort (tons/hr): winter bottom trawl fisheries						
Variable		*pollock*	*P. cod*	*A. mackere*	*black cod*	*rockfish*	*flatfish*
Measured environment							
	Bottom depth		22	22	22	22	22
	Depth over time	+		--			++
	Bottom slope	--	++	++		++	--
Remote sensed environment							
	Sea surface ter	22	22		2	22	22
	SST slope	--		++			-
	Sea surface he	++	++	--	++	--	++
	SSH slope		++	+	++		
	Wind speed	+		--		--	
	Chlorophyll		--				++
	Lagged chlor.		-			-	
R sq. OLS		0.20	0.38	0.47	0.34	0.28	0.28
Selection bias			+	+	--		--
Significant positive association			+	Positive association < .01			++
Significant negative association			-	Positive association < .01			--
Significant quadratic associatio			2	Quadratic association < .01			22

Average predicted Standardized CPUE, January

Estimated from 2001 North Pacific Trawl Fisheries
(NMFS Observer Data)



Evidence of Local Depletion in CPUE Residuals Estimated from NMFS Observer Data

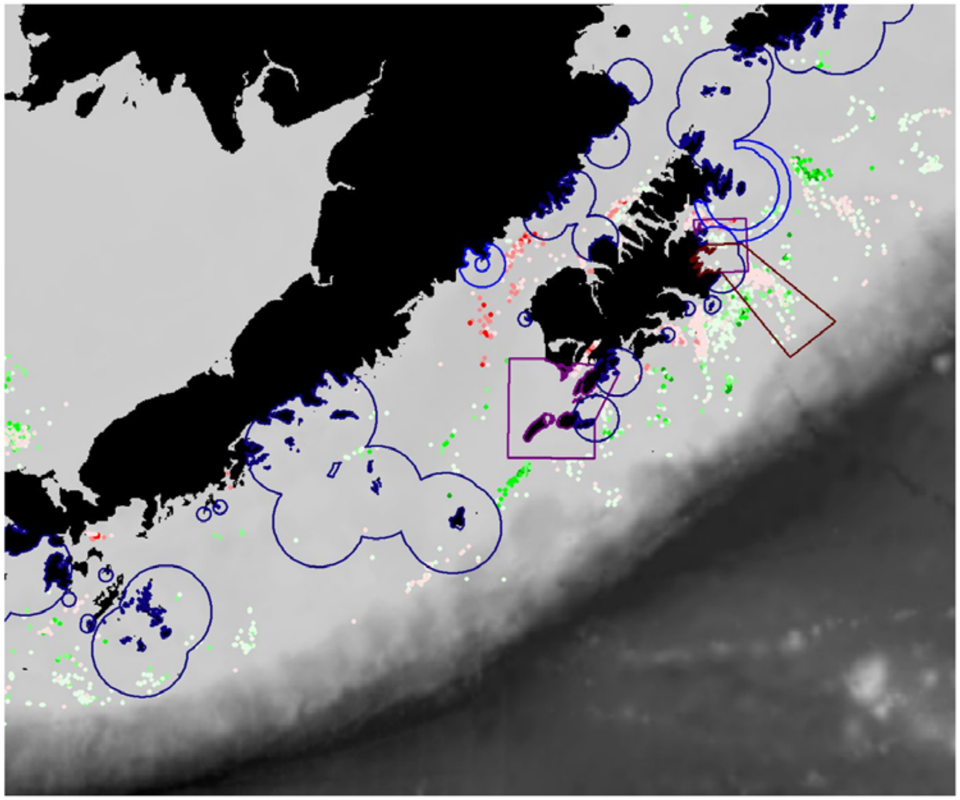


Significance tests for CPUE residuals (prob. Different from zero

	Pollock	P. cod	Atka mackerel	rockfish	flatfish
Raw residual		0.1		0.01	0.01
Res. with lag catch		0.05		0.01	0.01
laghauls			0.01	0.01	0.01
lag catch				0.01	
lag hauls with lag catch			0.01	0.01	0.01
Number significant	0	2	2	5	4

Objective 2: Estimate Values at Scales Relevant to Management Decisions to Protect Habitat

Hypothesis 2: Predicted spatial variation in fish density predicts spatial distribution of fishing effort at detailed spatial scales (3km grid).



Different aspects of opportunity costs

- Short-term effects
  - Direct losses of profits that could have been earned from closed areas
  - Effects of reallocation of effort to other areas, times, fisheries
- Long-term effects
  - Entry, exit, relocation of fishing vessels
  - Ecological feedbacks

This project focuses just on the short-term opportunity costs, acknowledging the potential importance of longer-term effects.

Fisheries Values: Turning Harvest into Money

- Prices of landed catch
- Fishing costs
  - Focus on costs that vary spatially (cost of moving around the ocean)
  - Distance to port (shore-based fleet)
  - Distance between good fishing sites (offshore fleet)

Approach to measuring profitability

- Industry fishes where the profits are highest
- Use Random Utility Model to predict spatial distribution of effort
  - Scale down to level appropriate to data and choice set (3km grid)
  - Approximate RUM using econometric models of count data
- Assume potential heterogeneity of fleet
- Focus on relative rather than absolute spatial and temporal values

Components of fishing costs modeled

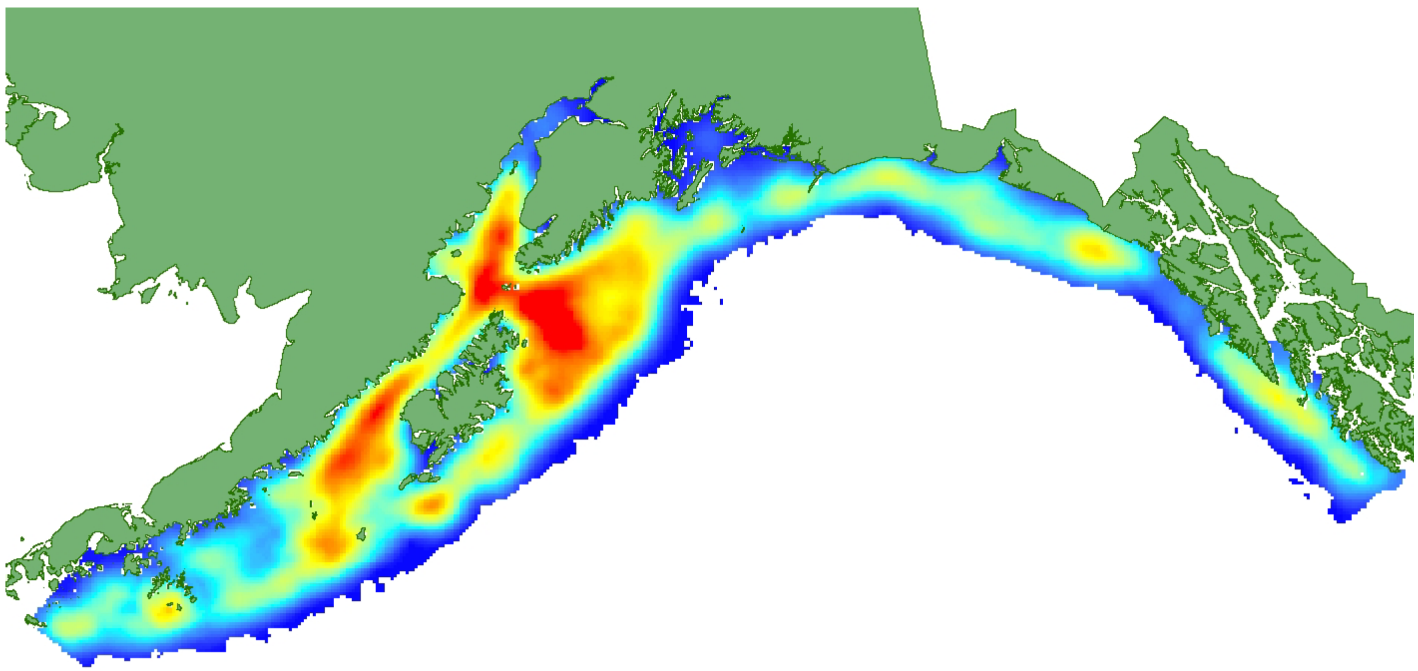
- Cost of fishing effort
  - Inverse of CPUE; (i.e., Effort per Unit of Catch)
- Travel cost
  - Distance to port
  - Distance from other fishing sites

Measuring Effects of Travel Costs for Offshore Fleet:

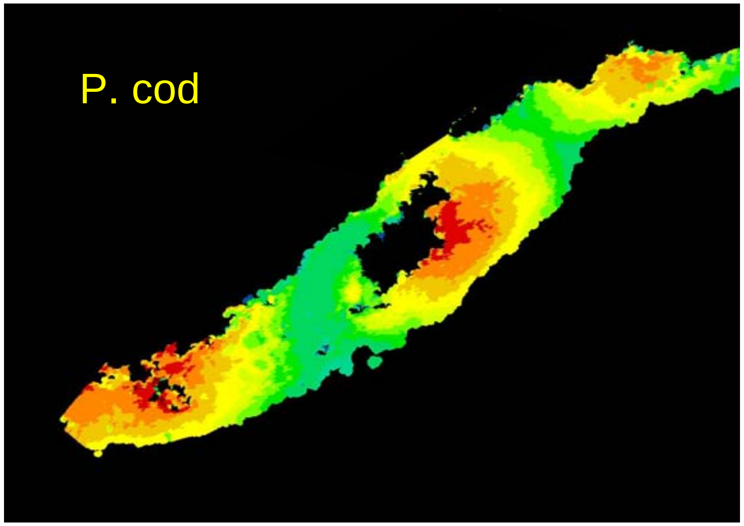
Spatial Density of Good Fishing Sites

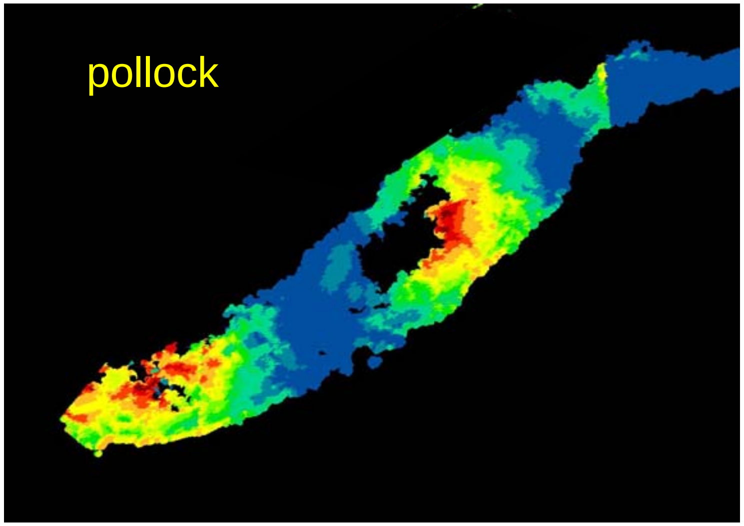
Average predicted CPUE of Pacific cod > 0. 5 kg
within a 30km radius of the fishing site

Estimated with data from 2001 NMFS Gulf of Alaska Bottom Trawl Survey



Results for shore-based trawl fleet
Summer-fall Pacific cod and pollock, 2001



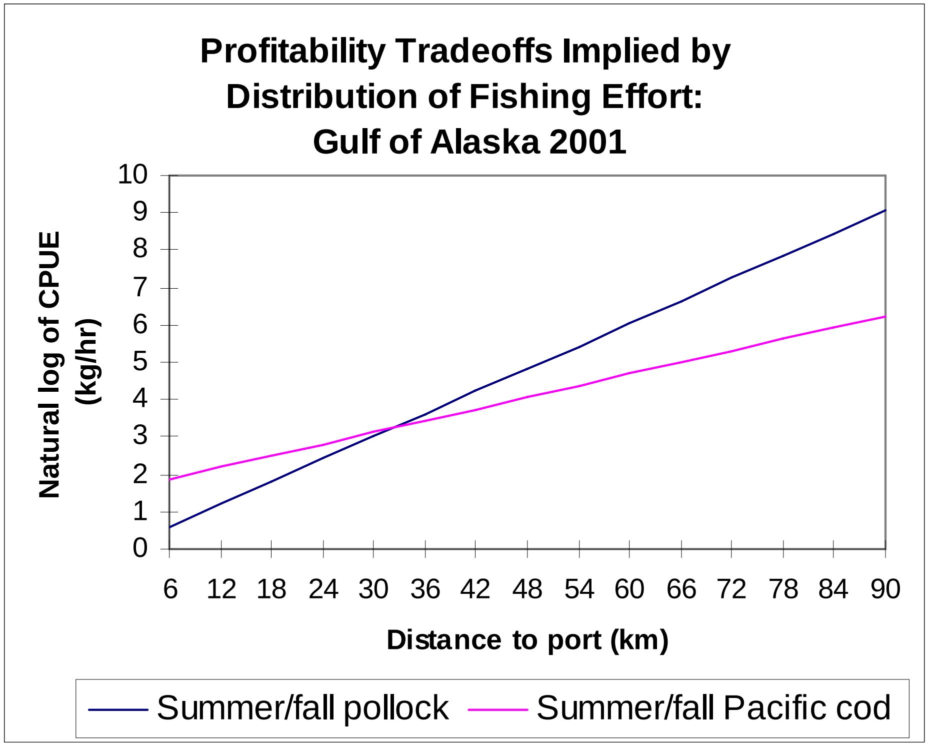


Pacific cod: ($p<.01$)

$$\pi = \alpha + 0.25*\log(cpue) - 0.013*portdistance$$

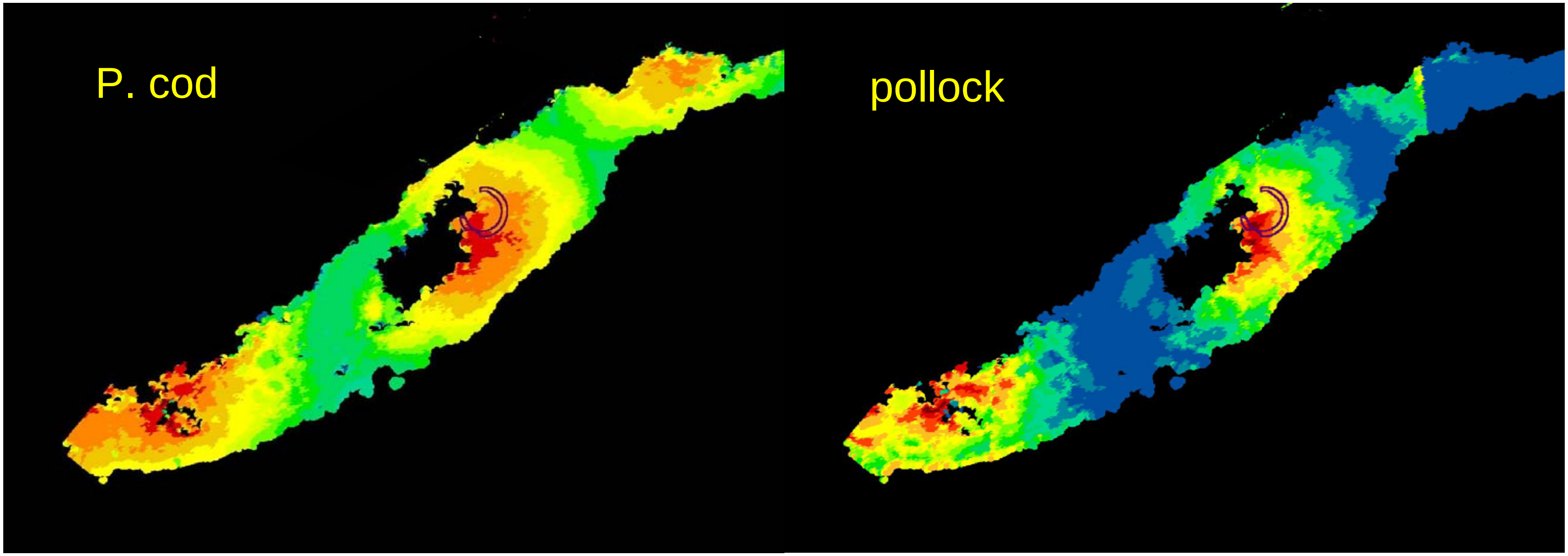
Pollock: ($p<.01$)

$$\pi = \alpha + 0.28*\log(cpue) - 0.028*portdistance$$



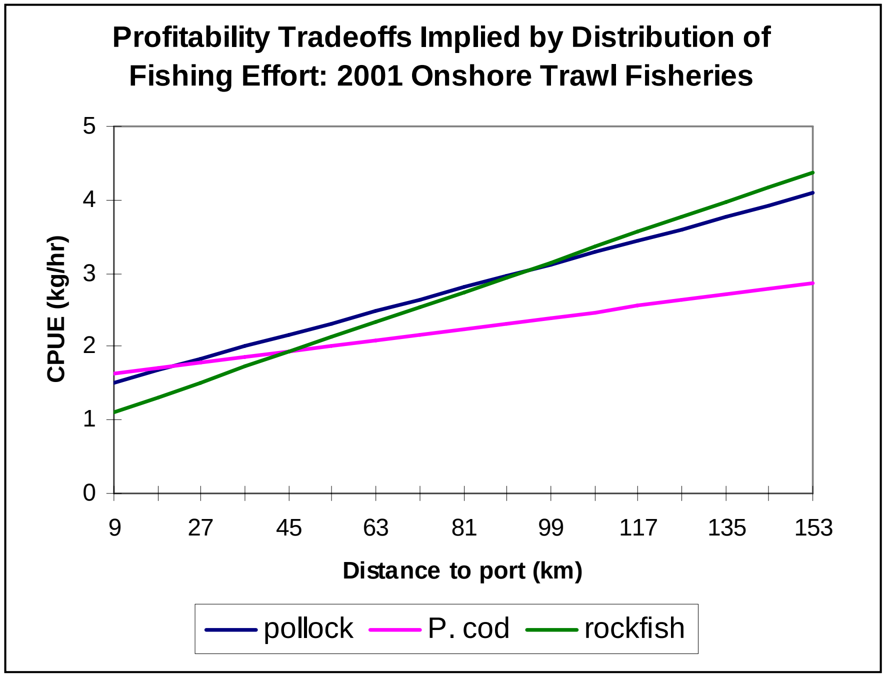
Spatial scale (3km resolution) fine enough to be relevant to decisions about marine protected areas

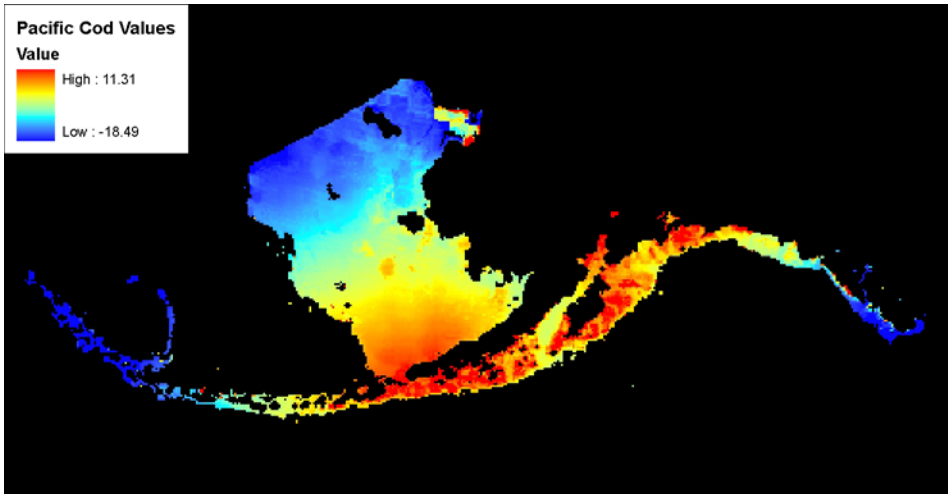
Summer/fall Pacific cod and pollock predicted spatial fishery values and expanded Steller sea lion rookery closure

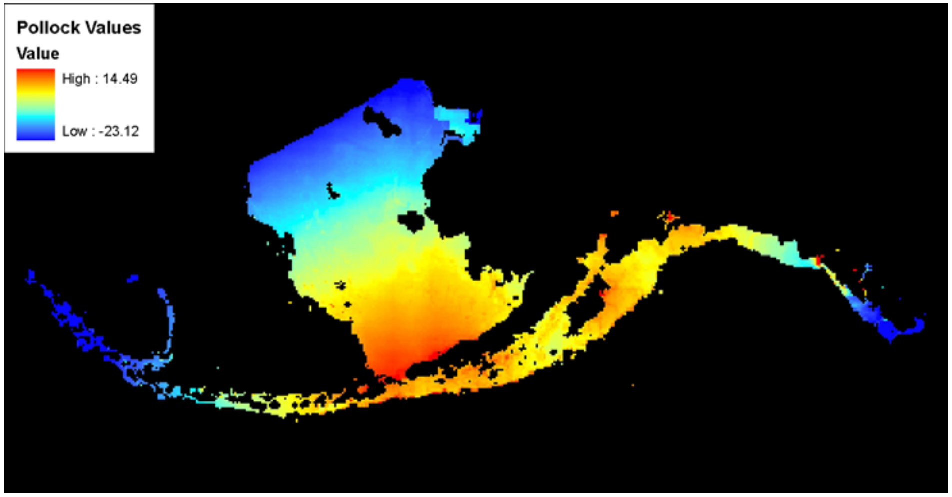


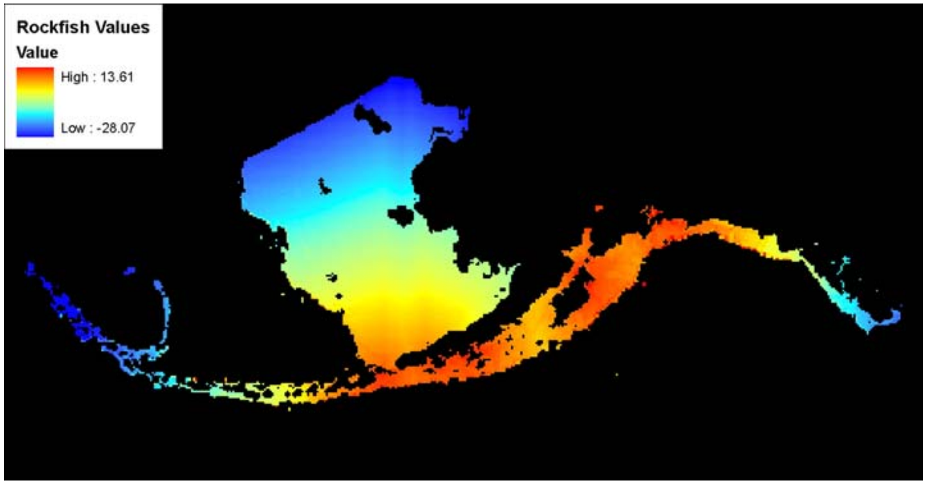
Results for shore-based trawl fleet

Bering Sea and Gulf of Alaska, 2001



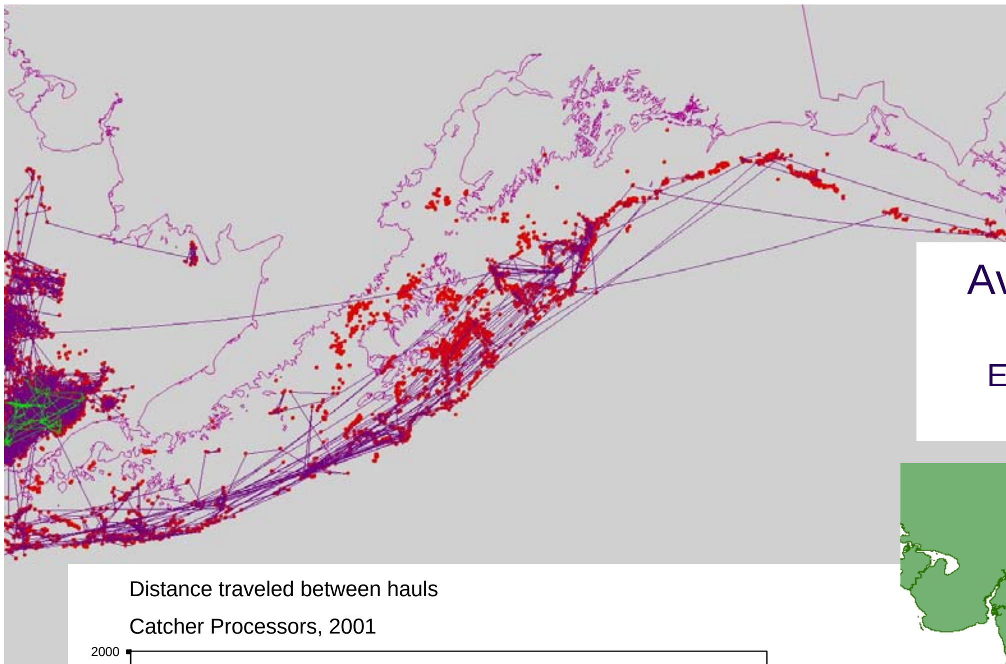


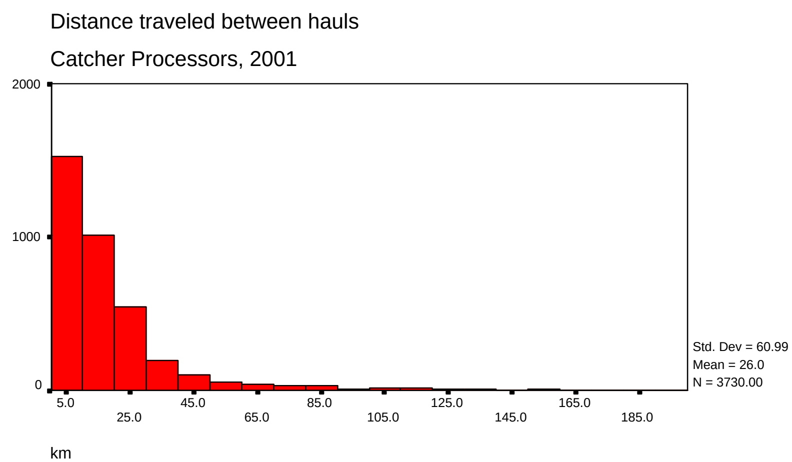




Measuring Effects of Travel Costs for Offshore Fleet:

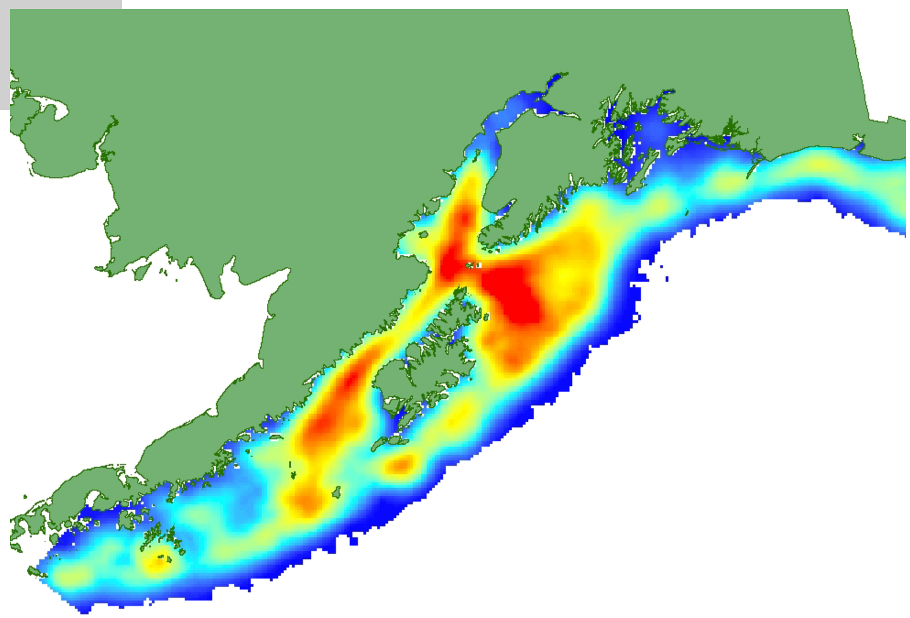
Distance traveled between observed hauls related to spatial density of good fishing sites.





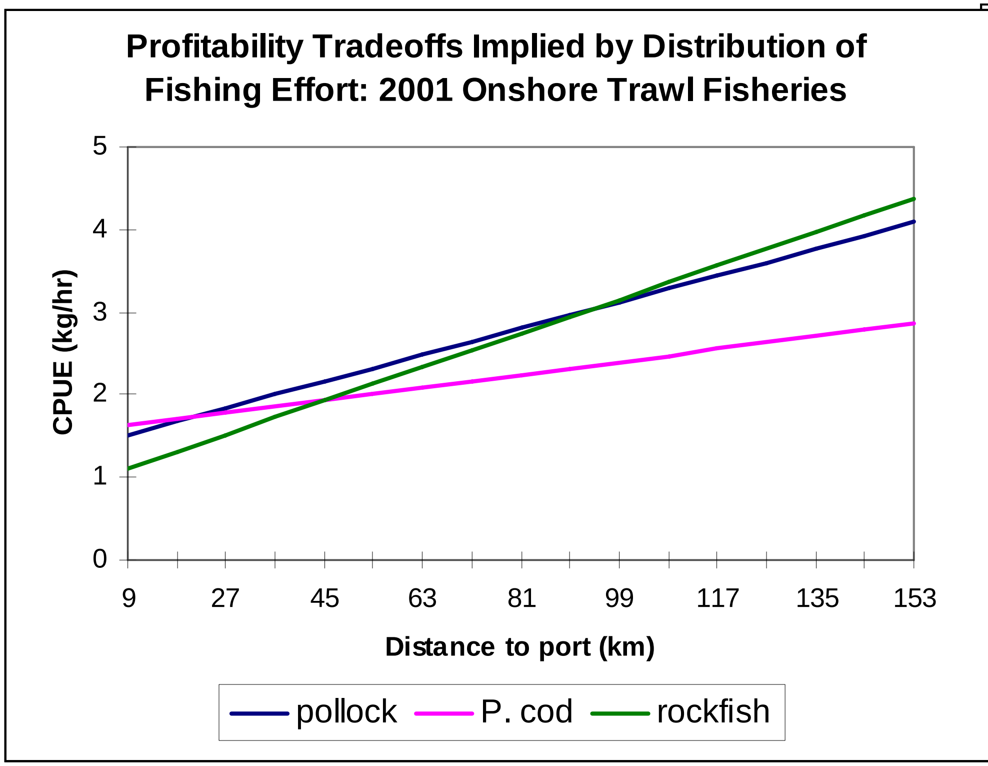
Average predicted CPUE of Pacific cod > 0.5 kg within 30km of the fishing site

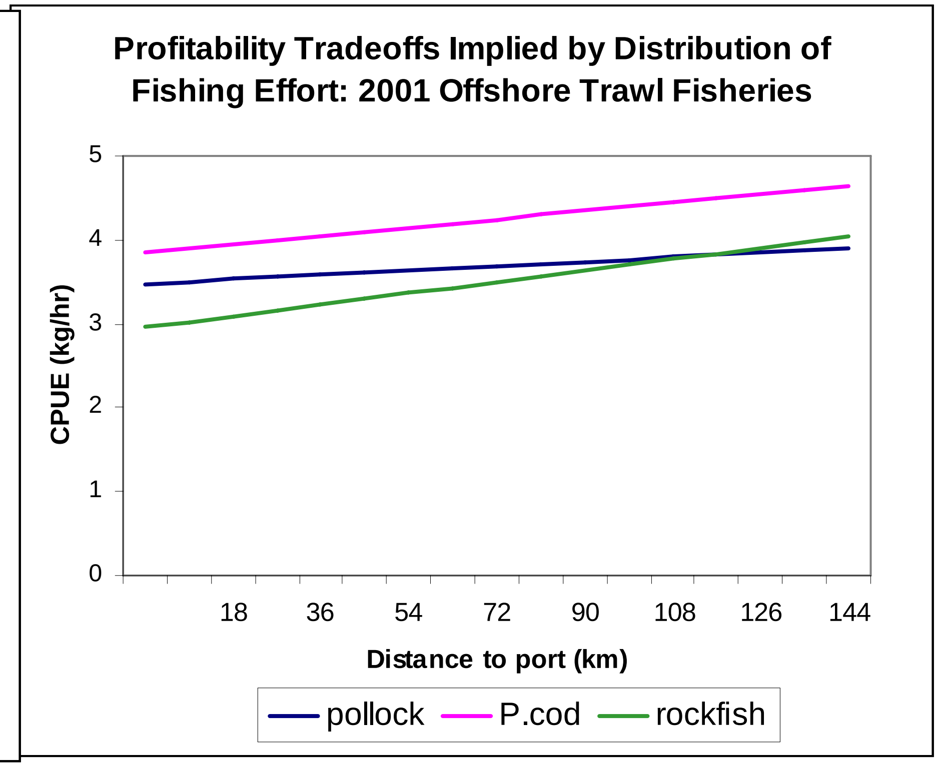
Estimated with data from 2001 NMFS Gulf of Alaska Bottom Trawl Survey



Comparison of results for shore-based and offshore trawl fleets

Pacific cod, pollock, and rockfish, 2001





Conclusions

- Support for H1: Spatial variation in environmental conditions does predict spatial variation in fish densities in the Gulf of Alaska in summer 2001.
- Support for H2: Predicted spatial variation in fish densities do predict spatial distribution of fishing effort.
- Results generate information about opportunity costs to fisheries at spatial scales (3km) fine enough to be relevant to decisions about changes in habitat protection measures.

Next steps

- Test stability of relationships across years – annual variability, regime shifts
- Extend to spatial bio-economic modeling at detailed spatial scale
  - Complete link between ecological “hot spots” and spatial harvesting “hot spots”
  - Link science of spatial ecology and economics to management needs

Acknowledgements

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