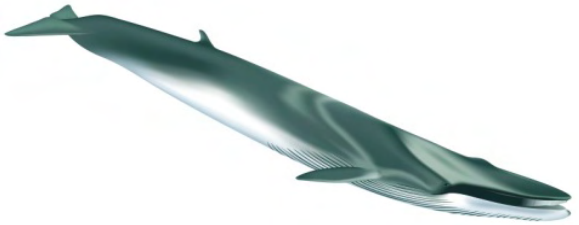
Investigating Patch Dynamics Between Foraging Whales and Krill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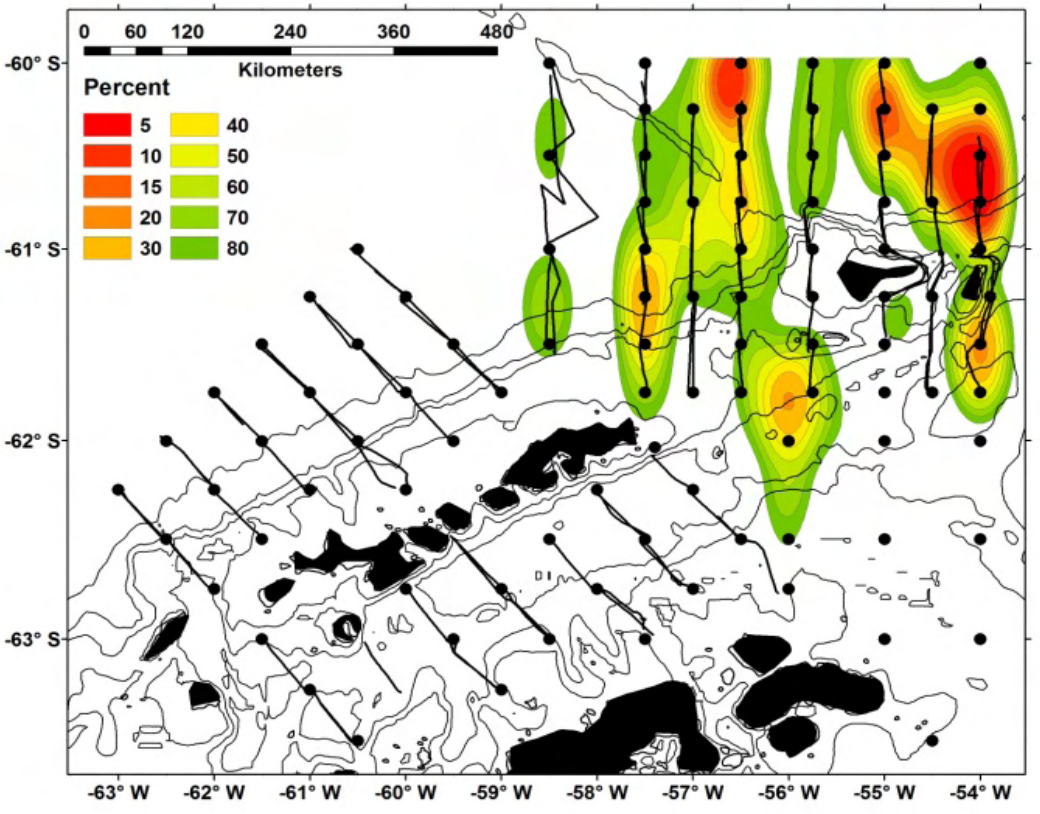
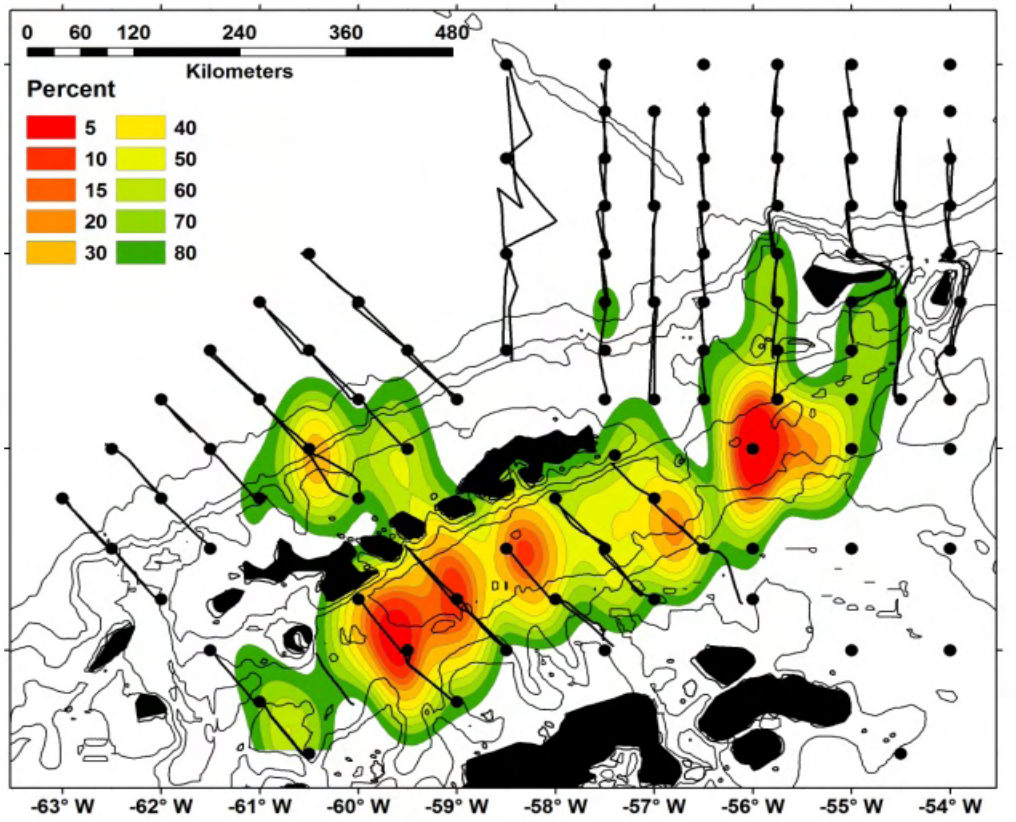
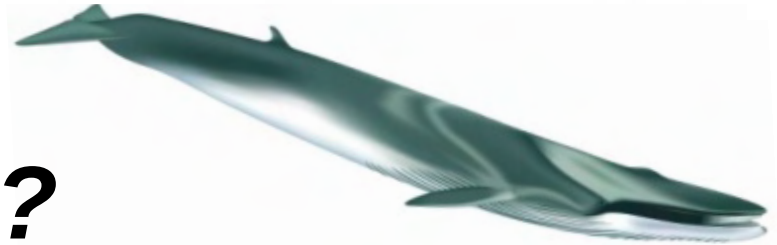
Antarctic Peninsula: Whale Hotspots (2003-2008)

Fin Whale



Humpback Whale





Why?

Background

- **Issues:**
  - Forecasting baleen whale populations
  - Consumption estimates of prey are poorly known
  - Interactions with fisheries
  - Climate Change
- **Where? Southern Ocean**
- **What? Spatial Ecology and Patch Dynamics**
  - Krill size
  - Whale foraging grounds
  - Spatial predictive modeling

Spatial Ecology and Patch Dynamics

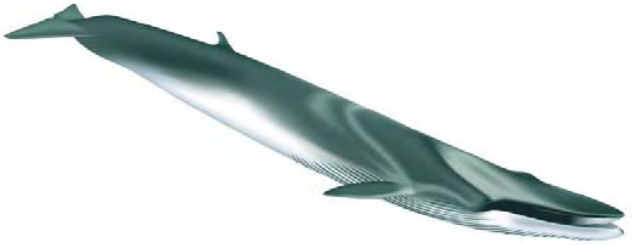
- **Long-term monitoring to investigate krill and whale distributions**
  - **Does sighting rate vary over time?**
- **Hotspot Analysis**
  - **Are there predictable locations where whales/krill occur annually? Persistent habitat use?**
- **Spatial Regression Models**
  - **Does the spatial distribution of whales vary in relation to krill demographic patterns?**

WHALES

Humpback Whale
(***Megaptera novaeangliae***)

Adult females measure 45-50 feet (13.7-15.2 m) males = 40-48 feet (12.2-14.6 m) in length.

Fin Whale
(***Balaenoptera physalus***)



Adult males measure up to 88 feet (26.8 m) in the southern hemisphere. Females are slightly larger than males.

Antarctic Minke Whale
(***Balaenoptera bonaerensis***)

Adult males average about 8 m (26 feet) Adult females average 8.2 m (27 feet)

KRILL DEMOGRAPHY: The South Shetland Islands contain distinct length/maturity classes comprising a reproducing population.

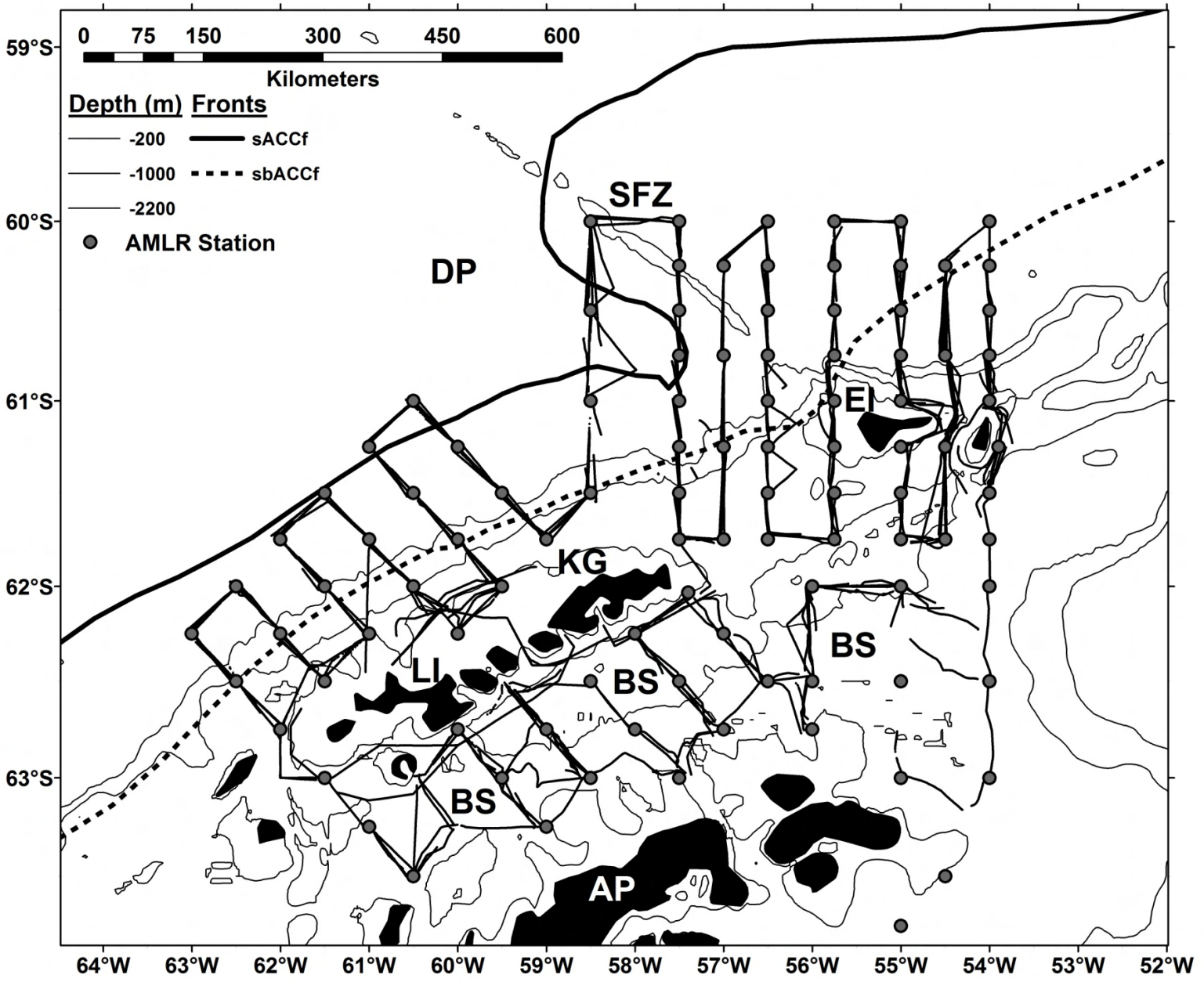
Krill length/maturity stages:

- **13-34mm Small Juveniles**
- **35-45mm Immature**
- **45-65mm Mature**

Antarctic Krill (*Euphausia superba*)
Image: Mike Goebel

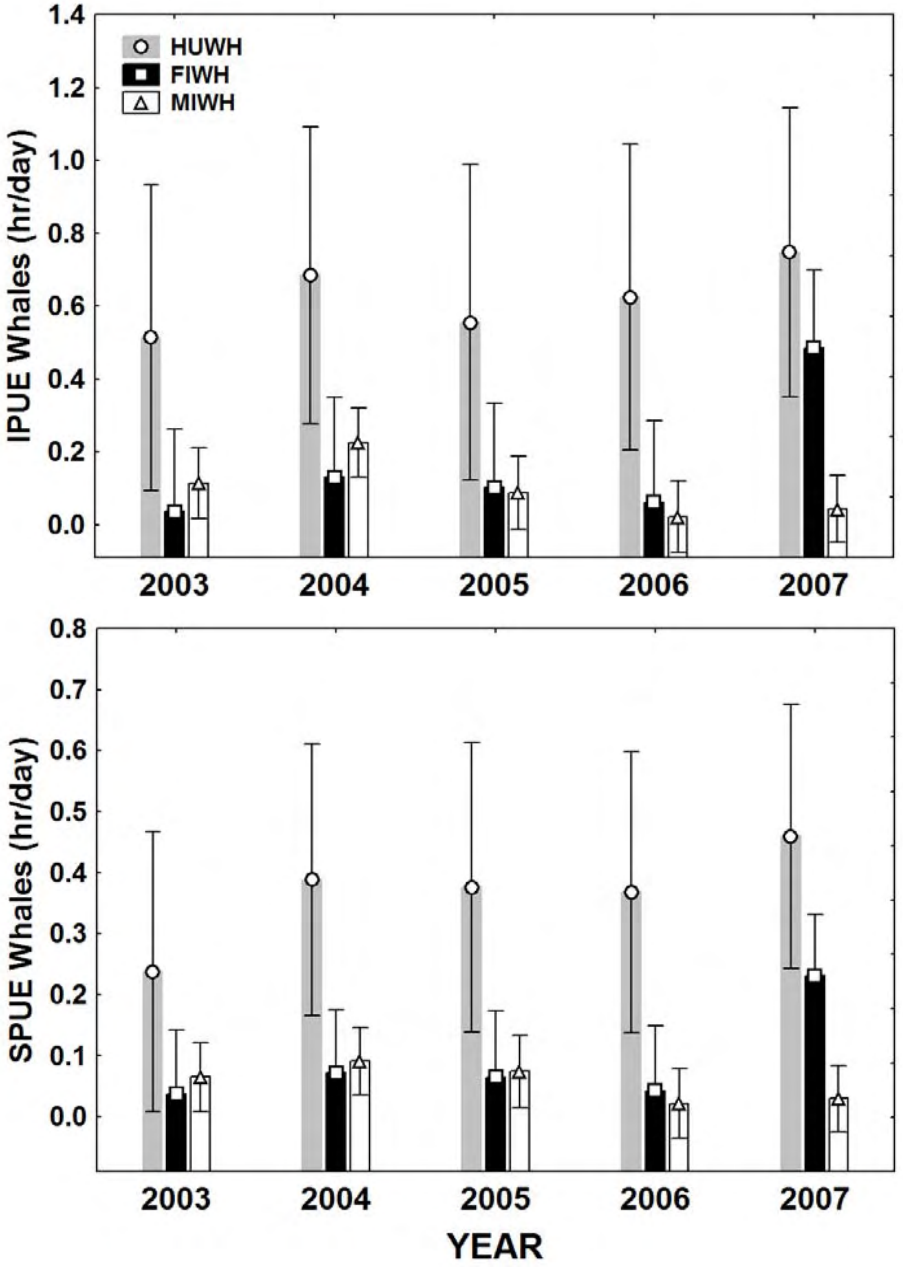
METHODS: Krill and Whale Distribution

Survey Effort: 2003-2007 ~25,000km

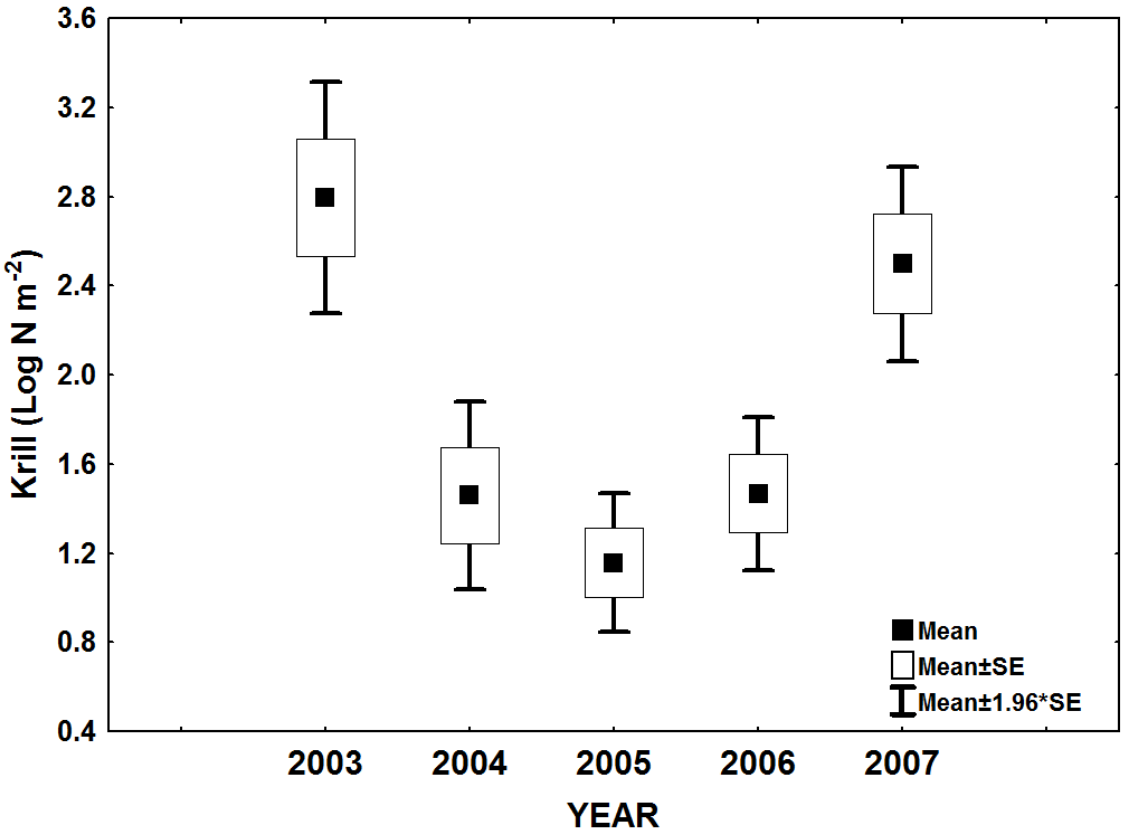


SURVEY RESULTS

Whale Individuals/Sightings Per Unit Effort (hr/day)



Krill Abundance – Net Samples



Spatial Association of Whales and Krill Length Classes

- ***OBJECTIVE***: Use Spatial Regression Models to determine if whales exhibit species specific foraging patterns that depend on krill length classes.

$$Spatial\ \ Lag\ : Y = \rho Wy + X\beta + \varepsilon$$

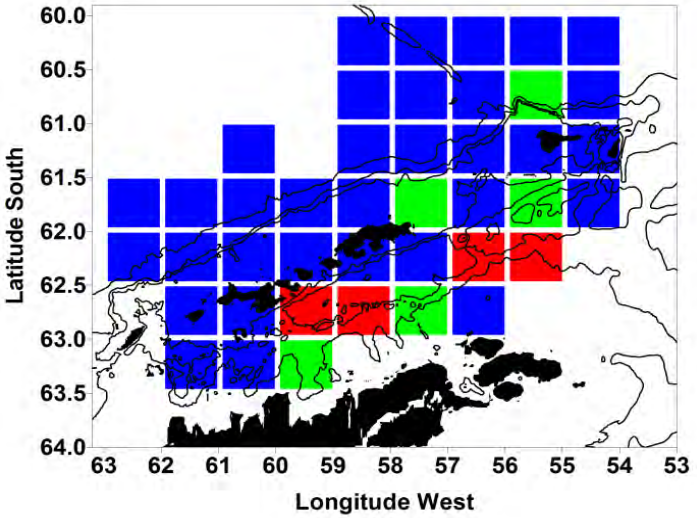
$$Spatial\ \ Error\ : Y = X\beta + \varepsilon, \ where\ \ \varepsilon = \lambda W\varepsilon + \xi$$

Y = Frequency of whales sighted in Cell (*i, j*)
X = Krill Abundance
Wy =Spatially varying lag term drawn from the spatial weight variable
We =Spatially varying error term

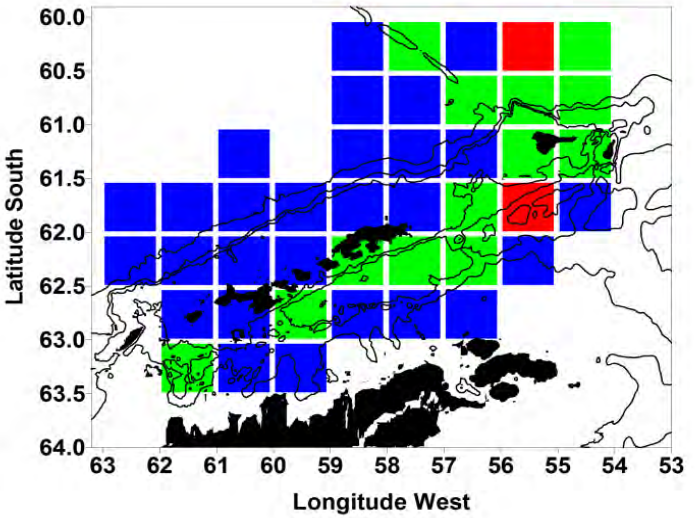
λ =Autoregressive coefficient
ρ = Spatial autoregressive coefficient
β = Regression coefficient
ε = Random error term
ξ = Vector of identically, and independent error term

Krill Length Hotspots (2003-2007)

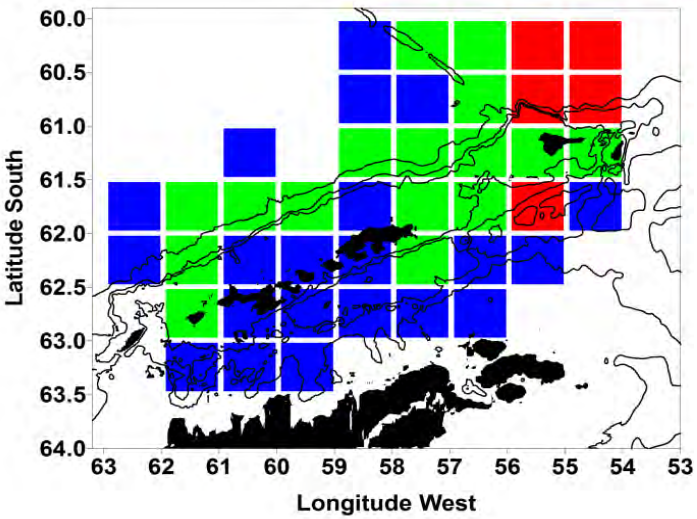
13-34mm



35-44mm



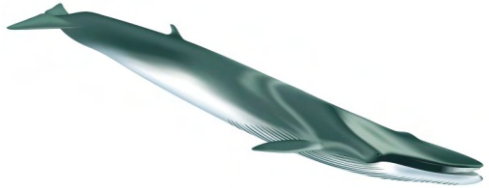
45-65mm



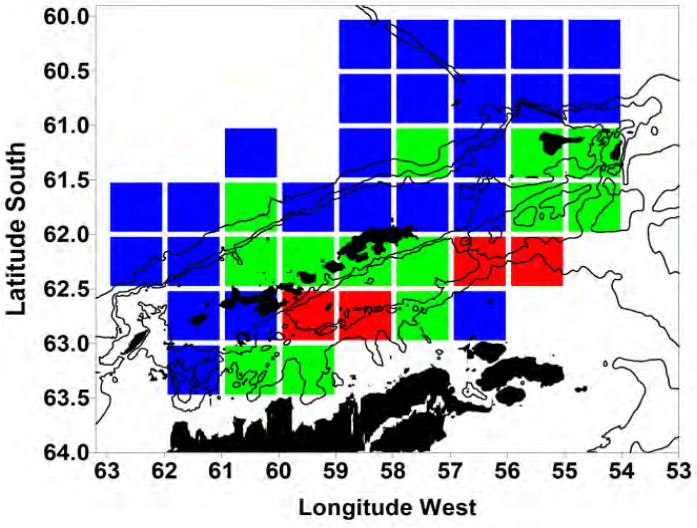
42 cells (0.5º S x 1.0º W), ~ 2860 km²

High	(4) 72.88±11.66	(2) 30.33±12.88	(5) 16.51±5.46
Medium	(5) 21.98±2.73	(13) 7.31±2.07	(16) 6.32±2.05
Low	(34) 2.32±2.85	(27) 0.97±0.98	(20) 1.72±1.21

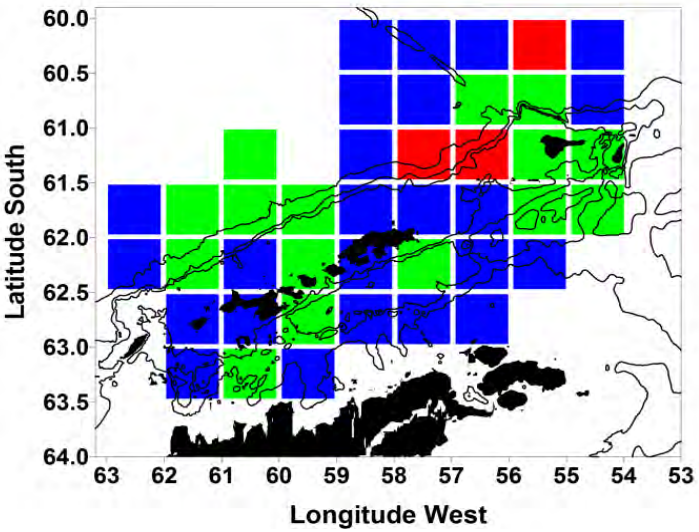
Baleen Whale Hotspots (2003-2007)



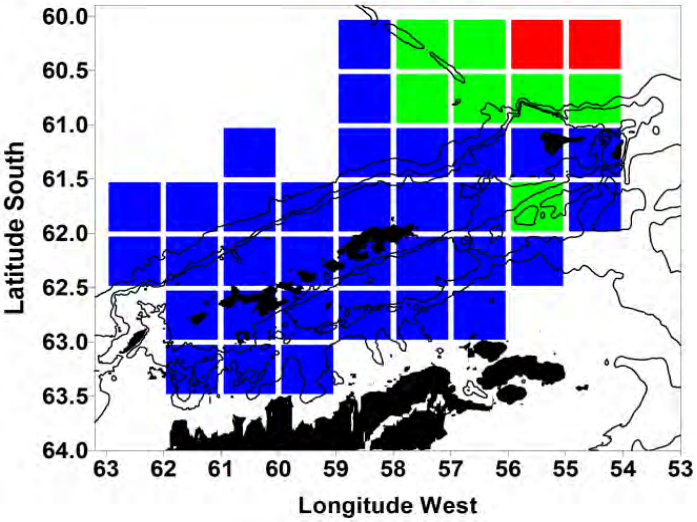
Humpback



Minke



Fin

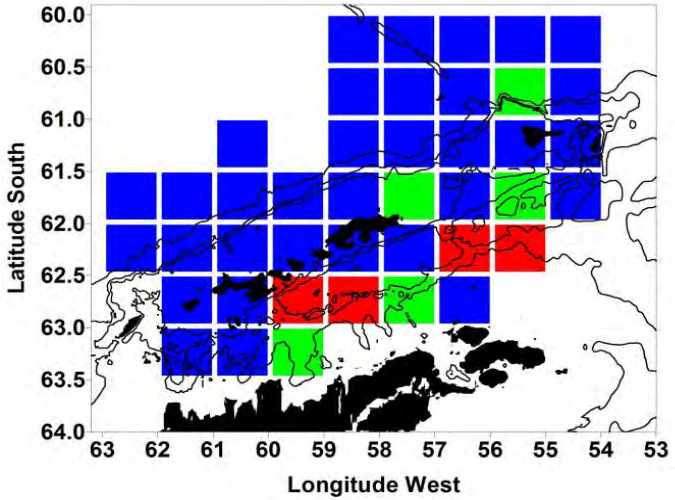


	Humpback	Minke	Fin
High	(4) 48.75±12.45	(3) 11.00±1.73	(2) 29.00±1.41
Medium	(13) 22.00±5.70	(15) 3.13±1.30	(7) 11.71±4.42
Low	(25) 2.68±3.19	(24) 0.17±0.38	(33) 0.93±1.32

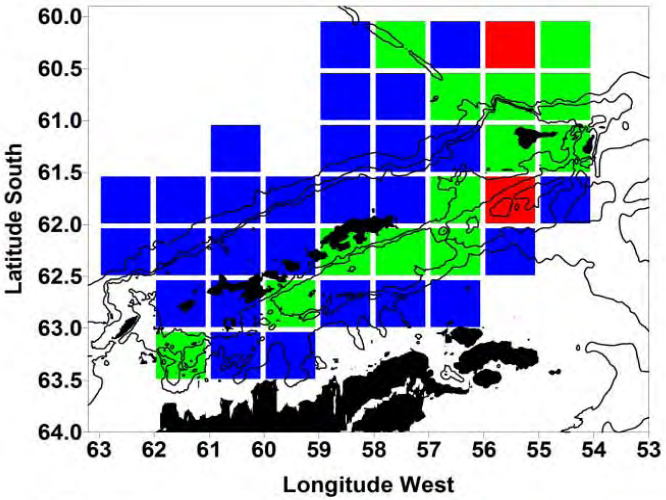
42 cells (0.5º S x 1.0º W), ~ 2860 km²

Hotspots (2003-2007)

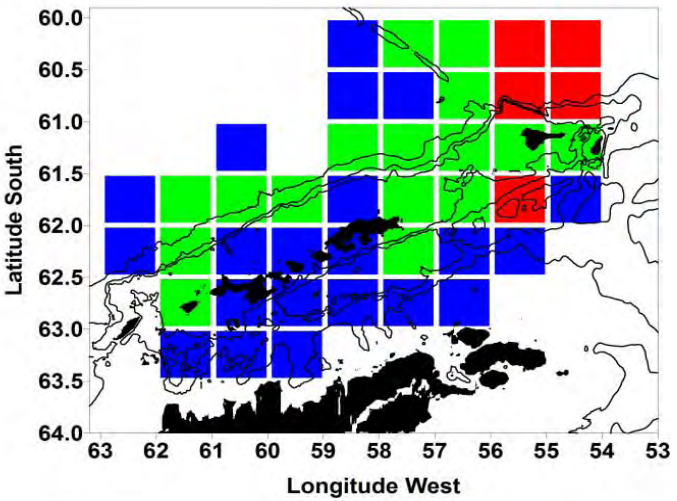
Krill 13-34mm

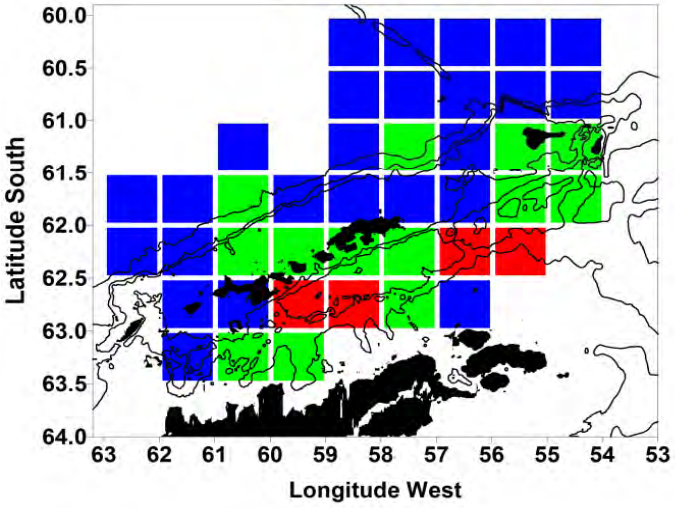


Krill 35-44mm

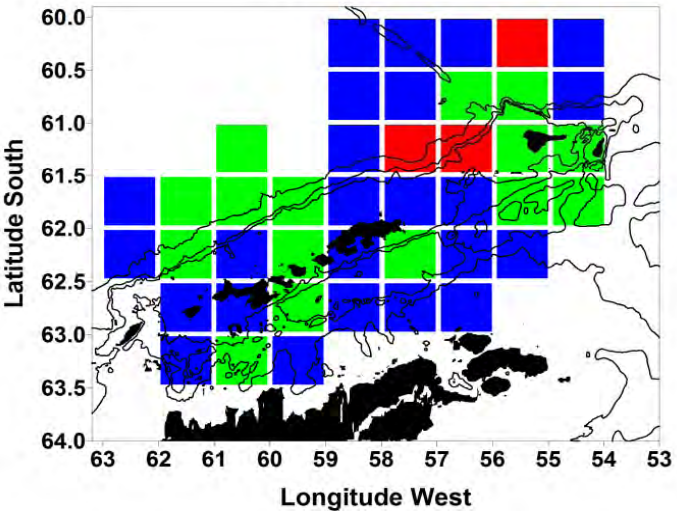


Krill 45-65mm

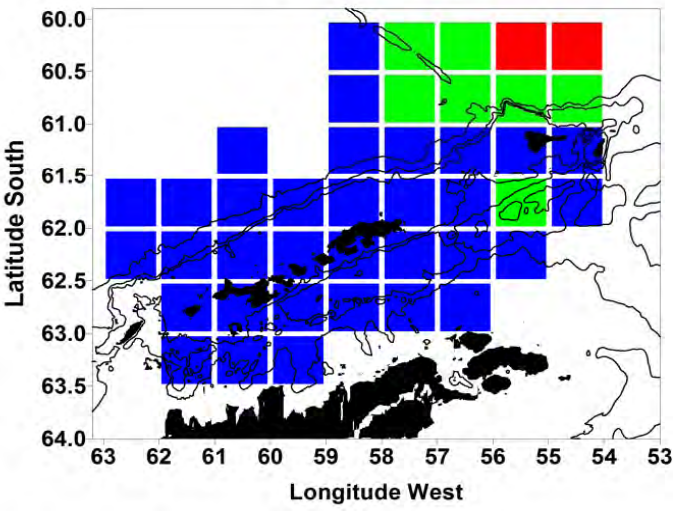




Humpback



Minke



Fin

Foraging Grounds of Humpback Whales Overlap with Small Krill

- Results of Spatial Lag Model for Association of Humpback Whales and Krill Length Classes

- $r^2 = 0.362$, AIC = 346.078

Variable	Coeff	S.E.	Z	P
Wy	0.213	0.124	1.710	0.087
Constant	8.163	3.343	2.442	**0.015**
13-34mm	0.427	0.108	3.927	**0.0008**
35-44mm	0.258	0.356	0.725	0.468
45-65mm	-0.339	0.445	-0.763	0.446

Foraging Grounds of Fin Whales Overlap with Medium-Large Krill

- Results of Spatial Lag Model for Association of Fin Whales and Krill Size Classes

- $r^2 = 0.69$, AIC = 245.078

Variable	Coeff	S.E.	Z	P
Wy	0.24	0.09	2.44	**0.014**
Constant	-1.78	0.91	-1.95	**0.051**
13-34mm	-0.04	0.04	1.07	0.284
35-44mm	0.26	0.10	2.44	**0.015**
45-65mm	0.73	0.15	4.98	**<0.0001**

Foraging Grounds of Minke Whales Overlap with Medium Krill

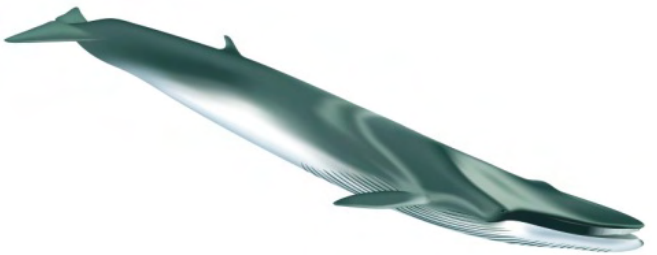
- Results of Spatial Lag Model for Association of Minke Whales and Krill Size Classes

- $r^2 = 0.22$, AIC = 101.758

Variable	Coeff	S.E.	Z	P
Wy	0.19	0.13	1.54	0.124
Constant	0.34	0.25	1.33	0.184
13-34mm	-0.18	0.09	1.83	0.067
35-44mm	0.32	0.16	2.03	**0.042**
45-65mm	0.04	0.16	0.25	0.798

Krill size is important for understanding whale distribution

- Habitat Selection?
  - Spatial segregation of whales is likely related to krill demography
    - Humpbacks are spatially associated with *small krill*
    - Fin are spatially associated with *large krill*
    - Minke Whales?
  - *Is their an interaction between krill size and patch structure?*



Relevance

- Why do we want to measure spatial association of whales and krill?
  - Marine Spatial Planning – Tracking future changes…
  - Parameterization of consumption models for whales
  - Assessing:
    - Top-down control on food webs
    - Interactions between krill fishery and whales
      - **Threshold/Precautionary catch limit**
      - **Change in fishing locations**
    - Climate change? Favorable or negative?

Thank You!